LOAD SHEDDING SCHEME BASED ON REACTIVE POWER DEMAND AND PRIORITY

Oscar Andrew Zongo

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การปลดโหลดโดยอาศัยปริมาณความต้องการกำลังไฟฟ้ารีแอกทีฟ และลำดับความสำคัญ

ออสการ์ แอนดรู ซอนโก

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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วิทยานิพนธ์นี้เสนออัลกอริธึมแบบใหม่ของการปลดโหลดสำหรับระบบไฟฟ้า อัลกอริธึมแบบใหม่นี้ถูกพัฒนา เพื่อประยุกต์กับระบบไฟฟ้าขนาดเล็ก ขนาดกลาง และขนาดใหญ่ อัลกอริธึมแบบใหม่ที่ใช้ปลดโหลดนี้อาศัยปริมาณความต้องการกำลังไฟฟ้ารีแอกทีฟ และลำดับความสำคัญ นั่นคือ โหลดที่มีปริมาณความต้องการกำลังไฟฟ้ารีแอกทีฟมาก และมีลำดับความสำคัญน้อยจะถูกปลดออกเป็นอันดับแรก ในขณะเดียวกันโหลดที่ถูกปลดนี้ได้มีการฟื้นฟูความถี่ของระบบที่ลดลง เพื่อรักษาระดับแรงดันไฟฟ้าอีกด้วย นอกจากนี้ยังใช้เทคนิคการคำนวณแบบปัญญาประดิษฐ์ (computational intelligence technique) โดยอาศัยอัลกอริธึมการค้นหาแบบฮาร์โมนี (harmony search algorithm) ในการหาค่าน้อยที่สุดของโหลดที่บัสไฟฟ้าต่างๆ เพื่อฟื้นฟูความถี่ภายในช่วงของการปลดโหลด เมื่อโหลดถูกปลดออกบางส่วนจากระบบ ภาระของโหลดที่ปลดออกนี้ถูกใช้ร่วมกันท่ามกลางผู้ใช้ในระบบไฟฟ้าหลายผู้ใช้ ดังนั้น อาจกล่าวได้ว่า ไม่มีผู้ใช้ใดๆ ที่ได้รับผลกระทบอย่างรุนแรง

การประเมินและการพัฒนาของงานวิจัยวิทยานิพนธ์นี้ได้บรรลุเป้าหมายปริมาณความต้องการของระบบไฟฟ้า เพื่อจัดการความถี่ตลอดจนแรงดันไฟฟ้าในการปลดโหลดอย่างเหมาะสมที่สภาวะการปฏิบัติงานที่ไม่แน่นอน สภาวะการปฏิบัติงานที่ไม่แน่นอนนี้อาจเป็นช่วงเวลาความต้องการปริมาณไฟฟ้าสูงสุด หรือชั่วโมงการปฏิบัติงานปกติ

ในงานวิทยานิพนธ์นี้ ความรู้ที่จำเป็นเกี่ยวกับการปลดโหลดสำหรับระบบไฟฟ้ากำลังได้ถูกศึกษาอย่างละเอียด เช่น สาเหตุความไม่สมดุลของกำลังไฟฟ้า ภายใต้ความถี่ ผลกระทบภายใต้ความถี่ บทบาทของการปลดโหลดในเชิงเศรษฐกิจ ตลอดจนสังคมและการดำรงชีวิตในเชิงพาณิชย์

สำหรับปริทัศน์วรรณกรรมในเรื่องการปฏิบัติงานของระบบไฟฟ้ากำลังและความรู้อื่นๆ ที่เกี่ยวข้องได้นำเสนอไว้ในงานวิทยานิพนธ์นี้ด้วย วัตถุประสงค์ของงานวิจัยนี้ เพื่อปลดโหลดที่ไม่มีลำดับความสำคัญ มีความต้องการกำลังไฟฟ้ารีแอกทีฟสูง ซึ่งมุ่งเน้นให้มีประสิทธิภาพใกล้เคียงกับการปฏิบัติงานที่ดีที่สุดในโลก นอกจากนี้ยังมีวัตถุประสงค์

เพื่อใช้เทคนิคการคำนวณทางปัญญาประดิษฐ์ในการปลดโหลด ซึ่งอาศัยอัลกอริธึมการค้นหาแบบฮาร์โมนีใช้ค้นหาค่าน้อยที่สุดของโหลดในระบบไฟฟ้า เพื่อฟื้นฟูความถี่ของระบบที่ลดลงภายในระยะเวลาอันสั้น

ผลของงานวิจัยนี้คือ เพื่อผลิตเครื่องมือซอฟต์แวร์การปลดโหลดที่ใช้งานง่ายและมีประสิทธิภาพ ซึ่งอำนวยความสะดวกสำหรับการวิเคราะห์ และขั้นตอนการใช้งานได้ถูกอธิบายไว้อย่างละเอียด สำหรับพารามิเตอร์ที่เกี่ยวข้อง เช่น แหล่งกำเนิดไฟฟ้าทั้งหมด รายละเอียดความต้องการโหลด และลำดับความสำคัญของโหลดได้นำมาวิเคราะห์ในการคำนวณเงื่อนไขการปลดโหลด ตลอดจนกลยุทธ์การปลดโหลดด้วย

การจำลองสถานการณ์ได้พิจารณาทั้งพฤติกรรมของความถี่และแรงดันไฟฟ้าของระบบทดสอบ ภายใต้เงื่อนไขปกติ เงื่อนไขไม่ปกติ และหลังจากปลดโหลดแล้ว

การทดสอบนี้ได้ประยุกต์กับระบบ IEEE 9-bus IEEE 14-bus IEEE 30-bus IEEE 57-bus 80-bus และ IEEE 118-bus สำหรับการทดสอบที่อาศัยการค้นหาแบบฮาร์โมนีได้ทดสอบกับระบบ IEEE 14-bus และ IEEE 30-bus ในขั้นตอนการดำเนินการปลดโหลดได้พิจารณาหลายกรณีที่แตกต่างกัน ซึ่งได้พิจารณาสิ่งรบกวนสองกรณี คือ กำลังไฟฟ้าสูญเสียของเครื่องกำเนิด และกำลังไฟฟ้าสูญเสียในสายส่ง สำหรับการวิเคราะห์ประสิทธิภาพของอัลกอริธึมการปลดโหลดแบบใหม่นี้แสดงให้เห็นว่า ผลการทดสอบที่ได้อยู่ในระดับที่ยอมรับได้ของการปฏิบัติงานที่ดีที่สุดในโลก หมายเหตุ ข้อสรุปที่ได้ทำบนพื้นฐานของผลการทดสอบที่ได้รับ

สาขาวิชา วิศวกรรมไฟฟ้า ลายมือชื่อนักศึกษา____________________

ปีการศึกษา 2557 ลายมือชื่ออาจารย์ที่ปรึกษา________________

OSCAR ANDREW ZONGO : LOAD SHEDDING SCHEME BASED ON REACTIVE POWER DEMAND AND PRIORITY. THESIS ADVISOR : ASST. PROF. ANANT OONSIVILAI, PhD., 259 PP.

POWER SYSTEM / LOAD SHEDDING / REACTIVE POWER DEMAND

This thesis presents a new algorithm of load shedding for power systems. The new algorithm is developed to meet the requirement of a small, medium and large systems. The algorithm shed loads based on the reactive power demand of the loads, that is, loads with high reactive power demands are shed first. Since loads shed have high reactive power demand, shedding them restores declining system frequency as well as improves voltages. This technique is divided into two schemes. A scheme that works on priority basis and the other one that sheds loads without taking care of the priority of those loads. In addition to these, a computational intelligence technique load shedding based on Harmony Search algorithm is also developed. The scheme minimizes loading at the buses until total load demand is exactly equal to the remaining generation so as to restore frequency within single step of load shedding, hence fast system restoration. In this scheme loads are partially shed, therefore, the burden of load shedding is shared among customers in a power system, thus, no customer is severely affected.

Literature review into power system operation and its components have been conducted. The methodology used is well analysed. The objectives set out is to shed non-priority loads having high reactive power demand, with an efficiency as close to

world's best practice. Another objective is to use computational intelligence technique in load shedding which is well met by developing a scheme based on Harmony Search Algorithm that minimizes the loading in the system to restore declining system frequency within a single step.

Simulations focused on showing frequency and voltage behavior of test systems used under normal condition, abnormal condition and after load shedding.

Conventional load shedding scheme and Load shedding scheme based on reactive power demand and priority are tested on IEEE 9-bus, IEEE 14-bus, IEEE 30-bus, IEEE 57-bus, 80-bus and IEEE 118-bus, Load shedding scheme based on reactive power demand is tested on IEEE 14-bus, IEEE 30-bus, IEEE 57-bus, 80-bus and IEEE 118-bus, and Load shedding scheme based on Harmony Search and priority is tested on IEEE 14-bus, IEEE 30-bus. The load shedding procedure is observed for several diverse instances. Two disturbance cases are considered. These are the loss of generator(s) and the loss of transmission lines. Conventional scheme is compared to Load shedding scheme based on reactive power demand and priority and Load shedding scheme based on reactive power demand is compared with Load shedding scheme based on reactive power demand and priority using tables and all schemes are compared using simulations' frequency and voltage plots. Performance analysis of the new algorithms load shedding strategies indicated that results obtained were within acceptable levels of world's best practice. Concluding remarks have been made on the basis of the results obtained.

School of Electrical Engineering Student Signature________________

Academic Year 2014 Advisor's Signature ________________

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Oscar Andrew Zongo

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CHAPTER 1

INTRODUCTION

1.1 Background

Technological development in industries and usage of more delicate appliances which are prone to damage if power supply is poor have stressed utilities to supply sufficient power to their consumers [48]. The quality of power supply to consumers is reassured if there is balance in the system between generation and demand. In recent years demand for power has increased significantly in many parts of the world causing operation of the transmission lines close to their limits. Additionally, generation reserves are insufficient to satisfy load demand. All these have caused more disturbances and power outages.

Power systems are mainly affected by faults, loss of a generator or generators and sudden switching of loads. These disturbances are the main causes of power system's voltage and frequency instability. If they are allowed to persist for a long time they may lead to total collapse of the power system. For safe operation of the power system there should be up to date means of monitoring voltage and frequency to make sure that they are at their rated values throughout the operation of the system.

Frequency and voltage are affected by the power imbalance in the system. While power system frequency is affected by the active power the voltage is mainly affected by reactive power. When there is imbalance between active power generated and active power demand in the system frequency is affected. On the other hand, when there is imbalance in system's reactive power, voltage is mainly affected. Therefore it is the task of the power system operators to make sure that these two parameters are stable.

In the event that all means possible to restore balance in the system have been applied and no improvement, the system has to resort to load shedding, because if this imbalance is allowed to last for several minutes there might occur total system failure. Load shedding is an emergency control operation in which part of the load is shed to restore balance between load and generation in the system.

Once the system is in good shape load restoration should be done to bring back the system to its normal operation. Due to the importance of load shedding in the control operation of the power system, it has attracted interests of many researchers.

1.2 Problem statement

Recent blackouts such as North-east USA, Boston on 9th February 2013 due to snow storm, New York, USA, November 3, 2012 due to Sandy, Cuba, 10th September 2012. In India July 31, 2012 half of the country was left without power. USA July 4, 2012 [6]. In September 2011 there was massive blackout in US and Mexico, On 21 May, 2013 southern Thailand blackout resulted when a power failure affected fourteen provinces (out of 76) for four hours, starting at 19:00 local time. On 22 May, 2013 Southern Vietnam and Cambodia blackout. Tanzania suffered drought-related power crises in 2006, 2007, 2009 and 2011. During that time load shedding was very important because the power system was overloaded several times forcing the utilities to disconnect some customers to restore balance in the system.

Some of these outages were caused by failure of load shedding schemes whether undervoltage or underfrequency. Therefore there is still a need to do more research on this control operation.

Conventional load shedding schemes have done a great job in protecting our power systems but their drawbacks show that there is a need to do more research so as to come up with much better schemes to meet today's needs of the power utility industry. Some of the disadvantages of the conventional load shedding schemes are excessive or insufficient load shedding as they don't take care of the magnitude of the disturbance created by the imbalance, to calculate optimal load to be shed. The schemes take care of only one parameter that is the voltage or frequency and they are too slow as they rely on conventional underfrequency relays.

In this thesis a load shedding scheme based on reactive power demands of loads is presented. The scheme is devided into two schemes. The one which takes care of the priority of the loads and the the other does not take care of the priority of the loads. But both are based on the reactive power demands of the loads. When there is frequency decline below rated value, average rate of change of frequency is calculated and used to decide optimal load to be shed. Then a table of loads with high reactive power consumption is created. Obviously, these loads with high reactive power demand have also active power demand. Loads are shed based on active power mismatch between generation and demand so as to restore system frequency as it is known that frequency decay is mainly caused by active power deficiency. But, since these loads shed have high reactive power demand, this shedding would also improve voltage profile at the buses and the system would not be on verge of voltage collapse after solving frequency decline problem. This can be very helpful because in some cases where schemes take care of only one parameter i.e. frequency it happens that as the scheme solves frequency decline problem it emerges voltage drop problem at the buses. This shows that there is a need to have a scheme that can solve both problems simultaneously. The load shedding strategy is based on frequency information, rate of change of frequency and loads' reactive power demand.

In addition to these adaptive schemes, another scheme which uses the knowledge of computational intelligent technique is also presented. This is Load shedding scheme based on Harmony Search and priority. Due to its accuracy to find the optimal load to shed, it restores system frequency within a single step of load shedding hence fast system restoration. Another advantage of this scheme is that in the condition that the load shedding problem is complex and highly nonlinear it is capable of dealing with such problems efficiently.

1.3 Thesis objectives

- To justify a load shedding scheme for the power system.
- To develop a Conventional load shedding scheme.
- To develop an Adaptive load shedding scheme.
- To develop A computational intelligence technique load shedding.
- To compare the effectiveness of an Adaptive underfrequency load shedding scheme with a Conventional load shedding scheme.
- To compare the effectiveness of an Adaptive underfrequency load shedding scheme based on reactive power and with Adaptive underfrequency load shedding scheme based on reactive power and priority.

- To compare the effectiveness of the Computational intelligence technique load shedding with Conventional load shedding scheme based on reactive power.
- To compare the effectiveness of the Computational intelligence technique load shedding with an Adaptive underfrequency load shedding scheme based on reactive power.

1.4 Chapter summary

This chapter has presented background of power system operation, challenges facing todays' power utilities. Causes of disturbances and how system frequency and voltage are affected by these faults have been explained in detail. The importance of load shedding as an emergency control measure has been shown. Load shedding problem solved by Conventional scheme and proposed schemes is also explained. Recent blackouts around the world are mentioned in this chapter. Conventional scheme and its drawbacks has been discussed and introduction to the proposed schemes given. Finally, the objectives of the thesis are mentioned.

CHAPTER 2

LITERATURE REVIEW ON LOAD SHEDDING

2.1 Underfrequency

The primary responsibility of electric grids (both large interconnected systems and microgrids) is to match demand and generation with the help of primary, secondary and tertiary controllers. After a sudden loss of generation units (or tie lines) power systems faces frequency decline [53].

2.2 Effects of underfrequency in a power system

Underfrequency degrades all components of a power system, particularly generators and turbines. In addition to equipment damage, under frequency reduces the performance of power plant auxiliaries (motor driven) and therefore generation output. Thus the loss of generation (or excess demand) may lead to a cascading loss of generating units due to excess frequency drop.

When the system splits into islands due to excess demand, load shedding becomes “the only possible protection” against cascading outages.

2.3 Load shedding schemes

This section reviews various load shedding schemes that have been used for many years in the utility industry their advantages and disadvantages [63].

2.3.1 Load shedding by circuit breaker

This is the simplest way to accomplish load shedding. For this scheme are ensured interconnected, hardware provided, protection signals from generator and feeder circuit breakers. This usually applies when speed is essential. Although the reaction time of these schemes is short, they have the following disadvantages:

- Scheme of load shedding, counted on the script of the worst case;
- It can develop only one degree of load shedding ;
- In most cases the load shedding is more than necessary;
- Modification of such systems is difficult.

2.3.2 Under-Frequency Relay Load Shedding

Guidelines for setting up a frequency load shedding are common to both large and small systems. The design methodology considers fixed load reduction at fixed system frequency levels. The rules for setting the frequency relays are common to large and small systems. Design methodology is based on exclusion of fixed loads at fixed frequencies of the system. Upon reaching the set rate and after some time, frequency relay exclude one or more loads. This cycle is repeated until the recovery has been achieved in the frequency system i.e 10% load shedding on a 0.5% reduction frequency. Since this method is completely independent from the systemic dynamics, total system failure is considered possible.

Upon reaching the frequency set point and expiration of pre-specified time delay, the frequency relay trips one or more load breakers. This cycle is repeated until the system frequency is recovered, e.g., 10% load reduction for every 0.5% frequency reduction. Since this method of load shedding can be totally independent of the system dynamics, total loss of the system is an assumed possibility. Additional drawbacks of this scheme are described below.

- Slow Response Time:

In addition to the time it takes for the frequency to reach the pre-defined settings, there is an intentional time delay setting to prevent nuisance tripping during frequency spikes. Time delay may be further prolonged due to the over-frequency condition that can occur during fault. Upon detection of frequency decay and expiration of set time delay, the frequency relay initiates the first stage of load shedding. If the amount of load shed was insufficient, the frequency continues to decay, activating the next stage of load shedding. Each additional stage introduces further delays in the load shedding process.

- Incorrect / Excessive Load Shedding:

The setting of each frequency relay is usually determined based on the most severe disturbance conditions, and most conservative generation and loading levels. This means excessive load shedding for the majority of conditions that are not as severe. In response to a dip or rate-of-change in frequency, frequency relays operate a set of fixed circuit breakers, independent of their actual operating load. Some breakers might have a load that may be quite different than the value considered in the studies. Additionally, the sequence of operation of the breakers may not be correct and/or optimal.

- Analysis Knowledge Is Always Lost:

To determine the frequency relay settings requires simulation of hundreds of transient stability studies. The objective of this analysis is to find the minimum fault clearing time and determine the minimum required load shedding by trial and error methods. The engineer performing the study learns the behavior of the system and can intuitively predict the response of the system under various operating conditions.

However, the only study result utilized by the load shedding system is a set of frequency relay settings. All other pertinent analysis results, along with the engineer's knowledge of the system, are lost.

2.3.3 Programmable Logic Controller Load Shedding

With a Programmable Logic Controller (PLC) scheme, load shedding is initiated based on the total load versus the number of generators online and/or detection of under-frequency conditions. Each substation PLC is programmed to initiate a trip signal to the appropriate feeder breakers to shed a preset sequence of loads. This static sequence is continued until the frequency returns to a normal, stable level.

A PLC-based load shedding scheme offers many advantages such as the use of a distributed network via the power management system, as well as an automated means of load relief. However, in such applications monitoring of the power system is limited to a portion of the network with the acquisition of scattered data. This drawback is further compounded by the implementation of pre-defined load priority tables at the PLC level that are executed sequentially to curtail blocks of load regardless of the dynamic changes in the system loading, generation, or operating configuration. The system-wide operating condition is often missing from the decision-making process resulting in insufficient or excessive load shedding. In addition, response time (time between the detection of the need for load shedding and action by the circuit breakers) during transient disturbances is often too long requiring even more load to be dropped.

2.3.4 Intelligent Load Shedding

An effective load shedding approach requires a comprehensive understanding of power system dynamics and process constraints, combined with knowledge of system disturbances. This required information is summarized below:

A. Pre-disturbance operating conditions:

- Total system load demand
- Total system power exchange to the grid
- Generation of each on-site unit
- Spinning reserve for each on-site unit
- Control settings for each running unit
- Settings and loading conditions for all major rotating machines
- System configurations (tie-line numbers, tie-line status and power transferring, bus-tie status and flows, transformers and feeder status and loading, loading of each load, especially loading for the sheddable loads, etc.)

B. Post-disturbance operating conditions:

- New system load demand
- Remaining generation from on-site generation
- Spinning reserve for each remaining unit
- Time duration to bring up the spinning reserve
- New system configurations
- Status, settings and loading conditions of the remaining major rotating machines
- Status of each sheddable load

C. Nature and duration of the disturbance:

- Electrical and/or Mechanical faults
- Complete or partial loss of power grid connection
- Complete or partial loss of on-site generation
- Load addition (impact)
- Location of disturbance
- Duration of disturbance and its termination (self-clearance, fault isolation, protection device tripping, etc.)
- Subsequent system disturbances

D. System transient response to a disturbance:

- System frequency response (decay, rate-of-change, final frequency)
- System voltage response
- Rotor angle stability of each remaining unit
- Operation of protective devices

2.4. Applications of Adaptive Load shedding schemes to different power systems

Vladimir V. Terzija (2006) presented a new approach to adaptive underfrequency load shedding [67]. A procedure for protecting electric power systems from dynamic instability and frequency collapse is presented. It consists of two main stages. In the first stage, the frequency and the rate of frequency change of frequency were estimated by the nonrecursive Newton-type algorithm. By using the simplest expression of the generator swing equation, in the second algorithm stage, the magnitude of the disturbance was determined. The UFLS plan is adapted to the magnitude estimated, obtaining in this way a more efficient system operation during emergency conditions. Results of procedure testing were demonstrated through the dynamic simulations by using: 1) a simple three-machine test system and 2) a ten-machine New England system. This technique estimates the magnitude of the disturbance and utilizes frequency information to find rate of change of frequency which was used to decide when to shed load and by how much. In this paper, a new concept for the magnitude of disturbance estimation used in an Adaptive Underfrequency Load shedding Scheme (AUFLS) plan was presented. Through the dynamic simulations of multimachine power systems, the sensitivity of power system frequency response to the disturbance location was investigated and discussed. It was shown that the disturbance location must be included in the plan in order to design more efficient system operation during emergency conditions. The estimation of frequency and the rate of frequency change was successfully provided by applying the Newton Type Algorithm (NTA), a nonlinear nonrecursive estimator. The presented procedure for estimation of the disturbance magnitude was tested and successfully incorporated into an AUFLS plan, tuning the settings to the magnitude estimated. All results were presented in the time domain, as well as in a clearly presented plane of the loci of and, respectively, versus frequency.

Farrokh Shokooh et al. (2005) demonstrated the need for a modern load shedding scheme and introduced the new technology of intelligent load shedding [64]. Comparisons of intelligent load shedding with conventional load shedding methods were made from perspectives of system design, system engineering, project implementation, and system operation. A case study of the application of an intelligent load shedding scheme in a large industrial facility was provided. Load shedding in industrial power systems serves as the ultimate guard that protects the system from an overload induced collapse. This critical load preservation is normally done with the use of circuit breaker interlocks, under frequency relaying, and PLC-based schemes. Common drawbacks of these schemes include lack of detailed pre- and post-disturbance data, real-time system configuration, type and duration of the disturbances, as well as other important information. This paper introduced an intelligent optimal and fast load shedding technology referred to as ILS. ILS combines system online data, equipment ratings, user-defined control parameters, a knowledge base obtained from offline system simulations, system dependencies, and continually updated dynamic load shed tables. This system can perform load shedding in less than 100 milliseconds from the initial occurrence of a disturbance. ILS technology was successfully installed and operational at industrial facilities.

Hamid Bentarzi et al. (2009) developed a new approach applied to an adaptive load shedding scheme using recent development technology such as wide area synchro-phasor measurement [7]. All generator frequencies that may be measured by Phasor Measurement Units (PMUs) are sent to central unit where a magnitude of disturbance will be calculated. These measured frequencies also will be used to determine the amount of load to be shed as well as the number of shedding steps. This technique also works on frequency information to calculate magnitude of the disturbance to make decision when and how much load should be shed. In this work, one application of PMU in power system was described which is the implementation of an adaptive load shedding scheme. Because in this type of load shedding the amount of load to be shed was determined adaptively according to the size of the disturbance and hence avoids excess load to be shed. The obtained simulation results were satisfactory. The first frequency setting of the proposed adaptive centralized load shedding scheme was set to 49.5 Hz in order to allow the frequency decline to be arrested far before reaching the critical frequency. The other frequency settings were determined automatically according to the last value of shedding frequency. The advantage of this method is that the amount of load to be shed is not large for all the disturbances unlike the conventional one. Therefore, unnecessary shedding is avoided which allows both a better service to different consumers and the system collapse prevention.

Swaroop Kumar et al. (2010) covered the modeling and the transient stability analysis of the IEEE 9 bus test system using ETAP [30]. In this paper, for various faults on the test system fast fault clearing and load shed were analyzed to bring back the system to the stability. Frequency was a reliable indicator if deficiency condition in the power system exists or not. Change in power demand or in production causes a fluctuation of the speed of the turbine-generator, a condition exists in the power system, resulting in fluctuation of the frequency in the system. Rate of change of frequency was used as indicator of the transient stability of the system and to calculate the amount of load to be shed by adaptive load shedding and measures were taken to maintain stability and frequency of the system. In this paper the stability of the IEEE 9-bus system was studied. Two contingencies were simulated on the test system. Rate of change of frequency is used as the operating principle. The subsequent changes of loss of generation in test system, its transient stability problems and its controlling methodologies through fast fault clearing and adaptive load shedding methods were discussed. By the implementation of the adaptive load shedding methods they could decrease the amount of load to be shed than the amount shed in conventional load shedding methods.

Farrokh Shokooh et al. (2005) [63]. This paper introduced an intelligent optimal and fast load shedding technology referred to as ILS. ILS combined system online data, equipment ratings, user-defined control parameters, a knowledge base obtained from offline system simulations, system dependencies, and continually updated dynamic load shed tables. This system could perform load shedding in less than 100 milliseconds from the initial occurrence of a disturbance. ILS technology was successfully installed and operational at industrial facilities.

H.A.Rakhshani et al. (2011) discussed a condition when a power distribution system experiences a serious disturbance or heavy load trip, the system frequency may drop and even collapse and also total generating power is not able to supply load demand [49]. Since some power distribution systems possess a lower inertia and come with limited reserves, the load shedding becomes an important strategy to restore system frequency. A proper design of the load shedding scheme should minimize consumer disruption in the case of the load excess and help balance the load to the remaining generation in a system. The initial rate of change of frequency is useful to detect an overload when the disturbance happens. A modified adaptive strategy, which can reduce total amount of load for shedding close to theoretical minimum, was proposed. A modified adaptive strategy was proposed for determining the amount of load to be shed by under frequency relays. The modification method considering the maximum frequency change at last step is proven very useful to improve the possible defects due to system dynamic characteristics and avoid over or under-shedding without predicting system overload capacity. From the observation of the frequency response to system disturbance, the size of the step change in load could be estimated, and the first step of load shedding could be set adaptively. The following steps were set equal and shed at increments of 0.1 Hz until the total amount of load shed was reached. This load-shedding scheme can save critical loads, and it can be successfully applied to protect industrial power systems with private generation.

Alireza Raghami et al. (2012) optimized the frequency load shedding conventional method [50]. This optimized method intelligently decided to shed appropriate system load proportional to the severity of power system disturbance. It was meant to prevent redundant load cut off by making a variety of choices in each load shedding step that has been used in the conventional scheme up to now. The main idea behind using this intelligent load shedding scheme could be evaluated for applicability in Smart Grids. To prove the results, a few disturbances were simulated for the IEEE standard 9-bus system, and the grid defensive counteractions were analyzed within two situ ations. In the first situation, when the disturbances happen in the grid utilized with a conventional load shedding program, and the second situation uses the same disturbances with the intelligent load shedding scheme. As mentioned in this paper, some steps were attempted to move forward in order to fulfill fundamental power system principles and to increase the quality of serving energy. Reducing the load shedding extensiveness in situations when there is no other solution to restore stability of a damaged power network, justifies more studies to correct the probable difficulties of the new intelligent algorithm. These corrective actions may differ due to understudy grids, but attenuating the numerical ranges for the comparison of integrating df/dt through increasing the number of choices in each UFLS triggering step could be an effective method. The main idea behind using this modern load shedding scheme can be evaluated for applicability in Smart Grids. As this paper demonstrates, the optimized method avoids shedding a portion of loads in a way that allows the other power system principles to be met again. Therefore, the new intelligent method increased reliability and reduced operational cost concurrent with energy economy. All these consequential effects are the main objectives of Smart Grids.

Dimas Fajar et al. (2012) presented a method for solving underfrequency load shedding (UFLS) problem by using fuzzy logic controller [18]. Gradient frequency method was used for gaining the active power deficit, then fuzzy decision making will breakdown the amount of the active power energy in every bus needed for load shedding. This method was implemented at 500 kV Java-Bali electrical power system. The results showed during the disturbance for a trip of 1510 MW Paiton generation, the system voltage decreased, the load decreased 205 MW, df/dt is 0.5967 Hz/s and the total load to shed is 1003 MW. Comparing with load shedding from scheme of PLN Java-Bali, the above disturbance gave df/dt 0.6 Hz/s and total load to shed 1181 MW. In this paper, the proposed method (Intelligent UFLS) was used to determine the amount load that must be shed in each bus. Test results by using the 500 kV Java-Bali EPS showed that the Intelligent UFLS method gave better result to minimize the total load to be shed than the standard given by PLN Java-Bali. The simulation showed that for the disturbance of 1510 MW and the spinning reserve is 300 MW the total load to be shed is 1003.1274 MW.

2.4.1 Discussion 1

Most of modern load shedding schemes are adaptive. They use frequency as well as rate of change of frequency for underfrequency load shedding schemes and voltage and rate of change of voltage for undervoltage load shedding schemes to decide when and by how much to shed load. The scheme should shed minimum amount of load to restore balance within a very short possible time and take few steps. Since frequency is a system wide and a first parameter to show imbalance in the system, using it to decide when to shed load would avoid imbalance reaching critical stage. For the past twenty years voltage has become a major cause of many power system blackouts, therefore there is a need to consider both parameters i.e. frequency and voltage in designing load shedding schemes. As there are many transients in the system, todays' schemes require time delay before starting load shedding procedure as frequency or voltage decline might be due to transients in the system. A best scheme is the one that can prevent a power system collapse in worst case disturbances.

The best way to improve voltage profile fast is by reducing reactive power demand. It is better to utilize the possibility that shedding loads with high reactive power would not only improve voltage but also restore system frequency. Shed loads with high reactive power demand to improve voltages at the buses. Since those loads have also active power consumption, shedding them would restore system frequency. My aim is to develop a scheme which is fast and accurate in restoration of frequency and voltage at the same time. In addition to this, my scheme will work on priority basis, shedding low priority loads while high priority loads will be left on service due to economic reasons. The scheme developed is applied to IEEE 9-bus, IEEE 14-bus, IEEE 30-bus, IEEE 57-bus and IEEE 118-bus power systems.

2.5 Applications of computational intelligence techniques (CIT) for load shedding in power systems [33]

For the past three decades there have been an increase in researches in the use of computational intelligence techniques (CIT) in power systems. CIT have been widely applied in power system applications. Below are some of the applications of CIT for load shedding in power systems, along with their advantages and disadvantages:

Fuzzy logic control (FLC) is a mathematical tool suitable for modeling a system which is too complex and not well defined by mathematical formulation. FLC has been widely applied in almost every part of a power system. Various researchers have applied fuzzy logic control for load shedding application. A fuzzy controller has been used for intelligent load shedding to provide vulnerability control in a grid-connected power system [20]. The performance of FLC on the IEEE 300-bus test system shows that it enables accurate load shedding during contingencies. The fuzzy logic application for avoiding voltage collapse by shedding weak load buses is presented in [55]. The technique was tested on the Ward-Hale 6-bus system and the IEEE 14, 30, and 57-bus systems. The simulation results show that the proposed technique can be implemented successfully on a system of any size. Sallam and Khafaga [56] applied fuzzy logic control for load shedding to obtain voltage stability in an IEEE 14-bus system. Simulation results show that load shedding with the fuzzy logic controller successfully stabilized the system and restored the voltage to a nominal value. Another application of FLC for load shedding is specifically to arrest dynamic voltage instability as presented in [69]. In an islanded distribution system, the power system frequency is very sensitive to load variation and may cause generator outages or overloading if not restored quickly and properly. To solve this problem, a new fuzzy logic based UFLS technique for islanded mode was developed and is presented in [42]. The proposed technique was formulated on frequency (f), rate of change of frequency (df/dt), and load prioritization. The technique was tested on several generator tripping and overload events. The simulation results show that a fuzzy-based technique provides optimum load shedding and successfully restores the frequency to a nominal value [42].

Genetic algorithm (GA) application in load shedding Genetic algorithms (GA) are the global optimization technique for solving non-linear, multi-objective problems introduced by John Henry Holland at the University of Michigan in 1975 [21]. 136 J.A. Laghari et al. / Energy Conversion and Management 75 (2013) 130–140 GA application in power system includes optimal reactive power [13] and over-current relay coordination [14].

GA also has some application in load shedding problems. Sanaye- Pasand and Davarpanah [57] applied a genetic algorithm for load shedding applications in power systems. The database for load shedding problems was obtained from a power flow study and was successfully implemented on the IEEE 30-bus system. Another GA based load shedding technique that considers the load shedding from each bus is proposed in [51]. The GA and PSO techniques were used to solve generator outage and line outage cases, and were validated on the IEEE 30-bus system. The responses of GA and PSO in all the case studies were compared. The results show that in terms of computation time, PSO is faster than GA; the minimum amount of load is shed by GA [51]. The genetic algorithms application for minimization of the load shed amount is proposed in [12] for a single-machine infinite bus. The technique was tested by simulating the 12-month load demand for an optimal UFLS setting and the results compared with a conventional technique. The results indicate that the GA-based technique is feasible and effective in providing optimal load shedding [12]. Luan et al. [37] discussed a GA-based method to determine the supply restoration and optimal load shedding strategy for distribution networks. An effort to determine the UFLS relay setting for an isolated power system and a micro grid by genetic algorithm is performed in [22] and [75], respectively. GA was employed to determine the minimum load shed at each stage for the under-frequency relay. The proposed method was validated on an isolated power system that includes wind and diesel power generators [75], and on a micro grid test system having a gas turbine, a wind turbine, and a solar power system [75]. Lopes et al. [34] proposed a GA-based method to determine the optimal load shedding technique for contingencies. The proposed technique has proved to be feasible and efficient. Another application of GA for the security assessment of a power system when subjected to a loss of K components is presented in [5]. GA treated this problem as a bi-level program in which upper-level optimization identified a set of out-of-service components in the power system, while lower-level optimization modeled the reaction of the system operator during these outages. The results show the effective performance of GA in terms of solution quality.

The main drawback of genetic algorithms which restricts its implementation in real-time application is its slow response. It has been observed that the computation time of GAs to determine the amount of load shed is very large. This relative slowness limits their usage for online application [4].

Kennedy and Eberhart introduced the PSO technique in 1995, inspired by the social behavior of organisms such as birds flocking and fish schooling [29]. PSO has been proved as a robust and fast technique in solving non-linear, multi-objective problems. The PSO technique has been widely adopted in power engineering applications.

PSO application in an optimal load shedding algorithm to determine the maximum loading point or collapse point is discussed in [2]. The technique was validated on the IEEE 14-bus system and was also compared with the GA technique. It was found that PSO finds the global optimum solution more quickly as compared to genetic algorithms [2]. A hybrid approach called a particle swarm-based-simulated annealing optimization technique has also been applied in an under-voltage load shedding problem [54]. The technique provides optimal undervoltage load shedding to assist long-term voltage stability; it was applied on the IEEE14 and IEEE118-bus test systems. The proposed technique identifies the global optimum solution within a smaller number of iterations. This PSO ability of taking only minimal time may encourage its implementation for real-time optimal load shedding in power systems [54]. A comprehensive learning particle swarm optimization (CLPSO) has been applied to optimally partition the distribution system in case of main upstream loss. In each island, the power balance is achieved through load shedding. The proposed technique was verified on a two-test system, a 33-radial bus system, and an Egyptian 66 kV, 45-bus meshed network [17].

2.5.1 Discussion 2

This thesis has discussed the ability of computational intelligence techniques to obtain accurate load shedding within a short time in emergency conditions. The review shows that computational intelligence techniques are the better option for modern power systems compared with conventional load shedding techniques. Computational intelligence techniques have the ability to provide fast and optimum load shedding during contingencies to prevent power blackouts. However, each computational intelligence technique has certain drawbacks that restrict their implementation in real-time applications. The load shedding in a power system is a very complex and quick process. Faults during contingencies are unpredictable and the time required to perform load shedding is also very short. Extensive research into improving these computational intelligence techniques is still required to ensure effective implementation in real-time applications.

2.6 Chapter summary

This chapter has explained about underfrequency and its effects in power system. It has explained how underfrequency occurs and how some power system components are affected by underfrequency. Different types of load shedding schemes operations have been discussed and application to defferent power systems of adaptive and computational intelligency techniques load shedding schemes developed by other researchers have been given and discussed.

CHAPTER 3

LOAD SHEDDING SCHEMES

3.1 Conventional load shedding scheme

In conventional load shedding scheme the input is the system frequency. This is measured throughout the operation of the power system. When there is imbalance in the power system causing severe frequency decline below 49.7 Hz, time delay of few minutes is allowed. If frequency continues to decline load shedding is triggered. A first block of loads is shed.

Drawbacks of these schemes are:

- shed loads without taking care of the magnitude of the disturbance
- They sometimes shed more loads or not enough thereby causing overfrequency or failure to restore frequency
- They are slow in response and require many steps of load shedding.

3.1.1 Algorithm of Conventional load shedding scheme

I. Set minimum frequency $f_{\min}$.

II. Measure system frequency f_s.

III. If f_s is less than $f_{\min}$, start load shedding procedure.

IV. Select loads rondomly to shed.

V. Shed loads selected.

VI. Measure system frequency f_s.

VII. If $f_s > f_{\min}$, stop the algorithm otherwise go to step number (IV)

3.1.2 Flowchart of Conventional load shedding scheme

Flowchart below is the representation of the algorithm of the Conventional load shedding scheme. Minimum frequency is set. System requency is always measured. If it happens that the frequency is less than the nominal frequency a time delay is allowed. After a time delay if system frequency is still less than nominal frequency load shedding is triggered. The scheme shed loads while checking system. Shedding of loads continues until frequency is restored.

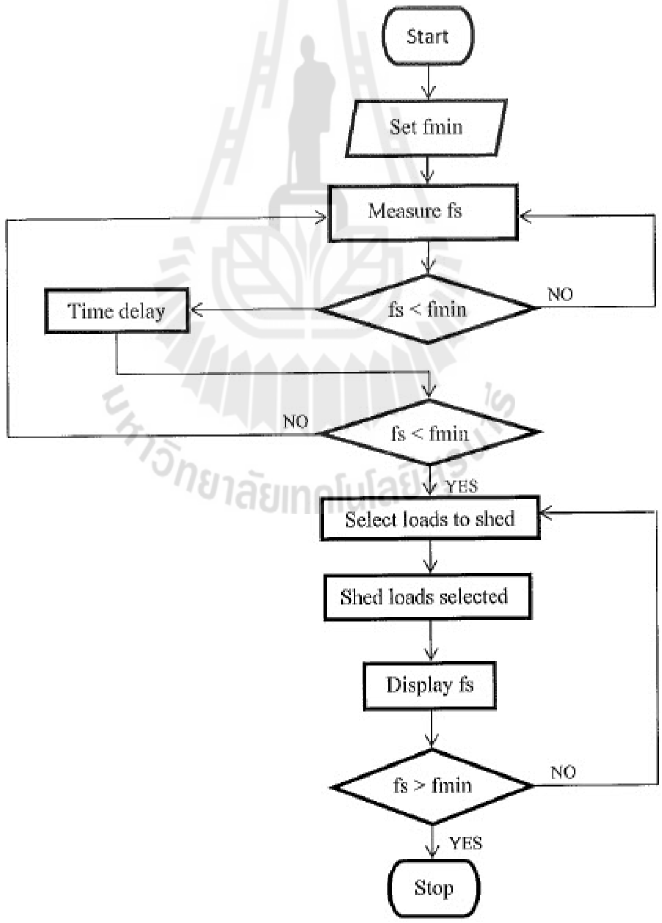


Figure 3.1. Flowchart for the conventional load shedding scheme

3.2 Load shedding scheme based on reactive power demand.

In the proposed load shedding scheme the input is also system frequency. This is always measured. At the same time rate of change of frequency is calculated during the operation of the power system. When there is imbalance in the power system causing severe frequency decline below 49.7 Hz average rate of change of frequency is found at that point. The value of average rate of change of frequency is used to calculate magnitude of the disturbance hence optimal load to be shed. Then loads are ranked based on their reactive power demand and priority starting with load having high reactive power demand and low priority in descending order. These loads are shed first.

3.2.1 Computation of rate of change of frequency

Power system frequency drops when the power supply in the system becomes insufficient due to loss of generation or tie line support. Overloading of the generators is followed by considerable change in system voltages, causing a fluctuation in load power P_{elec}. In addition, the generator's governing system utilizes the spinning reserve (if available), changing P_{mech}. Thus P_{mech} and change in time, altering frequency 'f ' and its rate of change (df/dt). While the low frequency f of P_{elec} is the final result of the power deficiency, its rate of change (df/dt) is an instantaneous indicator of power deficiency and can enable recognition of the MW imbalance. However, the change in machine speed is oscillatory in nature. These oscillations depend on the response of the generators and are seen differently at different locations. If the amount of frequency drop is large, protection systems for the low frequency may be activated in the power plants and the consequent shutdown of plant may lead to the separation of the interconnected system or black-out of the power system. The time taken by the system to settle to a low frequency would depend upon the inertia of the system. Higher the inertia of the system larger would be the time and vice versa. However, before frequency settles to lower level, there are oscillations and these could lead to the higher line loading and consequently tripping of the generators/tie lines. Therefore it is important to grasp the characteristics of the frequency response of the power system to loss of generation in order to stabilize the system faster and avoid catastrophe.

Therefore the system can measure frequency and find rate of change of frequency all the time as follows:

Let,

$$f_s = [f_1, f_2, f_3, \ldots, f_n] \tag{1}$$

Where f_s = system frequencies measured

And

$$t = [t_1, t_2, t_3, \ldots, t_n] \tag{2}$$

Where t = time at which frequencies were measured

Rate of change of frequency is given by:

$$\frac{df}{dt} = \frac{f_{n+1} - f_n}{t_{n+1} - t_n} \tag{3}$$

3.2.2 Estimation of average rate of change of frequency

The rate of change of frequency used in (3) is the average rate of change of frequency from the start of operation to the time load shedding is initiated as given below.

$$\left.\frac{df}{dt}\right|_{average} = \frac{\left.\frac{df}{dt}\right|_1 + \left.\frac{df}{dt}\right|_2 + \left.\frac{df}{dt}\right|_3 + \ldots + \left.\frac{df}{dt}\right|_n}{n} \tag{4}$$

3.2.3 Calculation of the load amount to be shed

Let us consider a three-phase synchronous alternator that is driven by a prime mover. The equation of motion of the machine rotor is given by[44].

$$J\frac{d^2\theta}{dt^2} = T_m - T_e = T_a \tag{5}$$

Where

J	is the total moment of inertia of the rotor mass in kgm^2
T_m	is the mechanical torque supplied by the prime mover in N-m
T_e	is the electrical torque output of the alternator in N-m
θ	is the angular position of the rotor in rad

Neglecting the losses, the difference between the mechanical and electrical torque gives the net accelerating torque T_a. In the steady state, the electrical torque is equal to the mechanical torque, and hence the accelerating power will be zero. During this period the rotor will move at *synchronous speed* ω_s in rad/s.

The angular position θ is measured with a stationary reference frame. To represent it with respect to the synchronously rotating frame, we define

$$\theta = \omega_s t + \delta \tag{6}$$

where δ is the angular position in rad with respect to the synchronously rotating reference frame. Taking the time derivative of the above equation we get

$$\frac{d\theta}{dt} = \omega_s + \frac{d\delta}{dt} \tag{7}$$

Defining the angular speed of the rotor as

$$\omega_r = \frac{d\theta}{dt} \tag{8}$$

we can write (8) as

$$\omega_r - \omega_s = \frac{d\delta}{dt} \tag{9}$$

We can therefore conclude that the rotor angular speed is equal to the synchronous speed only when $d\delta/dt$ is equal to zero. We can therefore term $d\delta/dt$ as the error in speed. Taking derivative of (8), we can then rewrite (9) as

$$J\frac{d^2\delta}{dt^2} = T_m - T_e = T_a \tag{10}$$

Multiplying both side of (10) by ω_m we get

$$J\omega_r \frac{d^2\delta}{dt^2} = P_m - P_e = P_a \tag{11}$$

where P_m, P_e and P_a respectively are the mechanical, electrical and accelerating power in MW.

We now define a normalized inertia constant as

$$H = \frac{\text{Stored kinetic energy at synchronous speed in mega - joules}}{\text{Generator MVA rating}} = \frac{J\omega_s^2}{2S_{rated}} \tag{12}$$

Substituting (12) in (10) we get

$$2H\frac{S_{rated}}{\omega_s^2}\omega_r \frac{d^2\delta}{dt^2} = P_m - P_e = P_a \tag{13}$$

In steady state, the machine angular speed is equal to the synchronous speed and hence we can replace ω_r in the above equation by ω_s. Note that in (13) P_m, P_e and P_a are given in MW. Therefore dividing them by the generator MVA rating S_{rated} we can get these quantities in per unit. Hence dividing both sides of (13) by S_{rated} we get

$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e = P_a \text{ per unit} \tag{14}$$

Equation (14) describes the behaviour of the rotor dynamics and hence is known as the swing equation. The angle δ is the angle of the internal emf of the generator and it dictates the amount of power that can be transferred. This angle is therefore called the “load angle”.

For a power system with N_G generators, the swing equation of the i^{th} generator can be formulated as follows[59]:

$$\frac{2H_i}{f_0}\cdot\frac{df_i}{dt} = P_{m_i} - P_{e_i} (i = 1,2,..., N_G \tag{15}$$

Where:

H is the inertia time constant of the *i*th generator

P_{m_i} is the mechanical power of the *i*th generator

P_{e_i} is the electromagnetic power of the *i*th generator

f_0 is the rated frequency of the system

Thus, the total active power deficiency can be obtained as

$$\sum\left(\frac{2H_i}{f_0}\cdot\frac{df_i}{dt}\right) = \sum_{i=1}^{N_G}\left(P_{m_i} - P_{e_i}\right) \tag{16}$$

Rearranging (5) yields,

$$\frac{2\sum_{i=1}^{N_G}\left(H_i \frac{df_i}{dt}\right)}{f_0} = \sum_{i=1}^{N_G} P_{m_i} - \sum_{i=1}^{N_G} P_{e_i} = P_M - P_g \tag{17}$$

Where:

$P_M = \sum_{i=1}^{N_G} P_{m_i}$ is the total mechanical power

$P_g = \sum_{i=1}^{N_G} P_{e_i}$ is the total electromagnetic power

Equation (6) can be simplified as

$$\frac{2}{f_0}\frac{d}{dt}\left[\sum_{i=1}^{N_G}\left(H_i f_i\right)\right] = P_M - P_g \tag{18}$$

Substituting $H = \sum_{i=1}^{N_G} H_i$ into (5) yields:

$$\frac{2H}{f_0}\frac{d}{dt}\left[\frac{\sum_{i=1}^{N_G}\left(H_i f_i\right)}{H}\right] = P_M - P_g \tag{19}$$

Finally, (8) can be simplified as

$$\frac{2H}{f_0}\cdot\frac{df}{dt} = P_M - P_g \tag{20}$$

Where:

$f_0 = \dfrac{\sum_{i=1}^{N_G}\left(H_i f_i\right)}{H}$ is the actual frequency of the system.

$H = \sum_{i=1}^{N_G} H_i$ is the inertia time constant of the equivalent system generator.

Hence, the swing equation of the equivalent system generator can be described as

$$\frac{df}{dt} = \frac{f_0}{2H} \Delta P_S \tag{21}$$

Where:

$\Delta P_S = P_M - P_g$ represents the total active power imbalance in the system.

3.2.4 Algorithm for the load shedding scheme based on reactive power demand.

i. Input nominal frequency.

ii. Set minimum frequency.

iii. Set initial time to start reading frequency.

iv. Measure system frequency.

v. Find rate of change of frequency after every half cycle.

vi. If system frequency is less than minimum frequency, start load shedding procedure.

vii. Find average rate of change of frequency.

viii. Find optimal load to be shed.

ix. Rank loads (descending order) based on their reactive power demands.

x. Shed loads ranked in step (ix).

xi. Check: If system frequency is above minimum frequency limit, stop the algorithm otherwise go to step number (vii).

3.2.5 Flowchart of the load shedding scheme based on reactive power demand.

The scheme starts by setting minimum frequency. Then system frequency and voltages at the buses are measured. Computation of rate of change of frequency is done after every half cycle. If system frequency is becomes below set value the rate of change of frequency is averaged. This is used to estimate magnitude of the disturbance thereby obtaining optimal load to be shed. Then a table of loads with high reactive power demand is created. Summation of loads to be shed is done starting with highly ranked load in descending order until this sum is equal or greater than amount of load to be shed already computed. Loads to be shed are identified and shed. Finally check of system frequency against rated frequency and time delay is done. If system frequency is less than rated frequency program go to step number 4. If satisfactory, program ends.

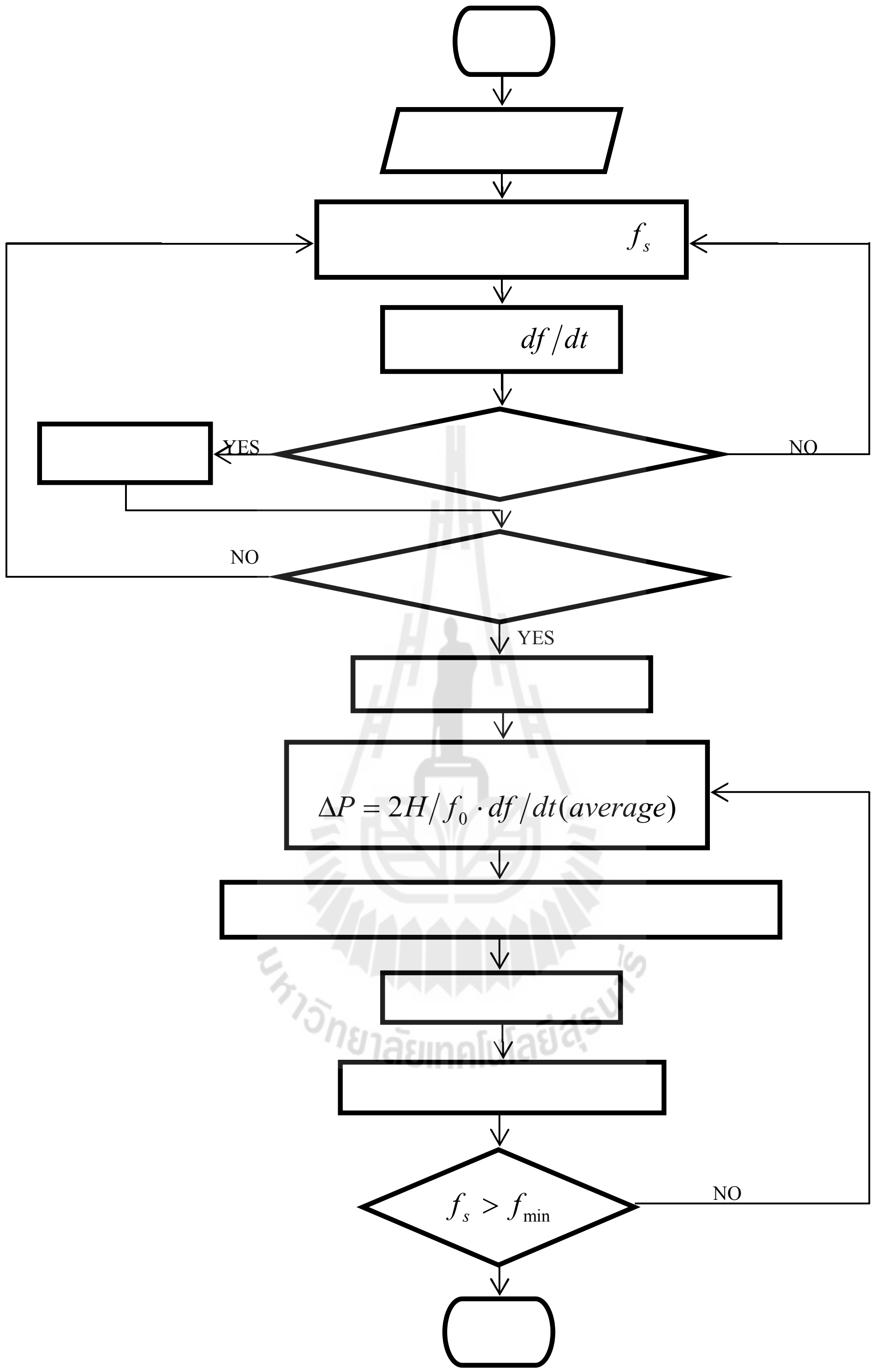


Figure 3.2 Flowchart for Load shedding scheme based on reactive power demand.

3.2.6 Pseudo code for selection of loads to be shed for load shedding scheme based on reactive power demand.

WHILE system frequency < 49.7 Hz

sort loads in descending order based on their reactive power demands.

select loads sorted from top to bottom until $\Delta P_{new} \leq \Delta P_S$

identify loads selected

shed loads selected

ENDWHILE

3.3 Load shedding scheme based on reactive power demand and priority

The only difference between this load shedding and the previous scheme is in the selection of load to be shed. In this scheme loads are shed based on their reactive power demands and priorities.

3.3.1 Algorithm for the load shedding scheme based on reactive power demand and priority

xii. Input nominal frequency.

xiii. Set minimum frequency.

xiv. Set initial time to start reading frequency.

xv. Measure system frequency.

xvi. Find rate of change of frequency after every half cycle.

xvii. If system frequency is less than minimum frequency, start load shedding procedure.

xviii. Find average rate of change of frequency.

xix. Find optimal load to be shed.

xx. Rank loads based on their reactive power demands and priorities by keeping loads with high priority at the bottom of the list.

xxi. Shed loads ranked in step (ix).

xxii. Check: If system frequency is above minimum frequency limit, stop the algorithm otherwise go to step number (vii).

3.3.2 Flowchart of the load shedding scheme based on reactive power demand and priority

Minimum frequency is set. System frequency and voltages at the buses are measured. Computation of rate of change of frequency is done after every half cycle. If system frequency is becomes below set value the rate of change of frequency is averaged. This is used to estimate magnitude of the disturbance thereby obtaining optimal load to be shed. A table of loads with high reactive power demand is created on priority basis, i.e. loads with low priority are ranked high first and loads with high priority are ranked least last. Summation of loads to be shed is done starting with highly ranked load in descending order until sum is equal or greater than amount of load to be shed. Loads to be shed are identified and shed. Check of system frequency against rated frequency and time delay is done. If system frequency is less than rated frequency program go to step number (iv). If satisfactory, program ends.

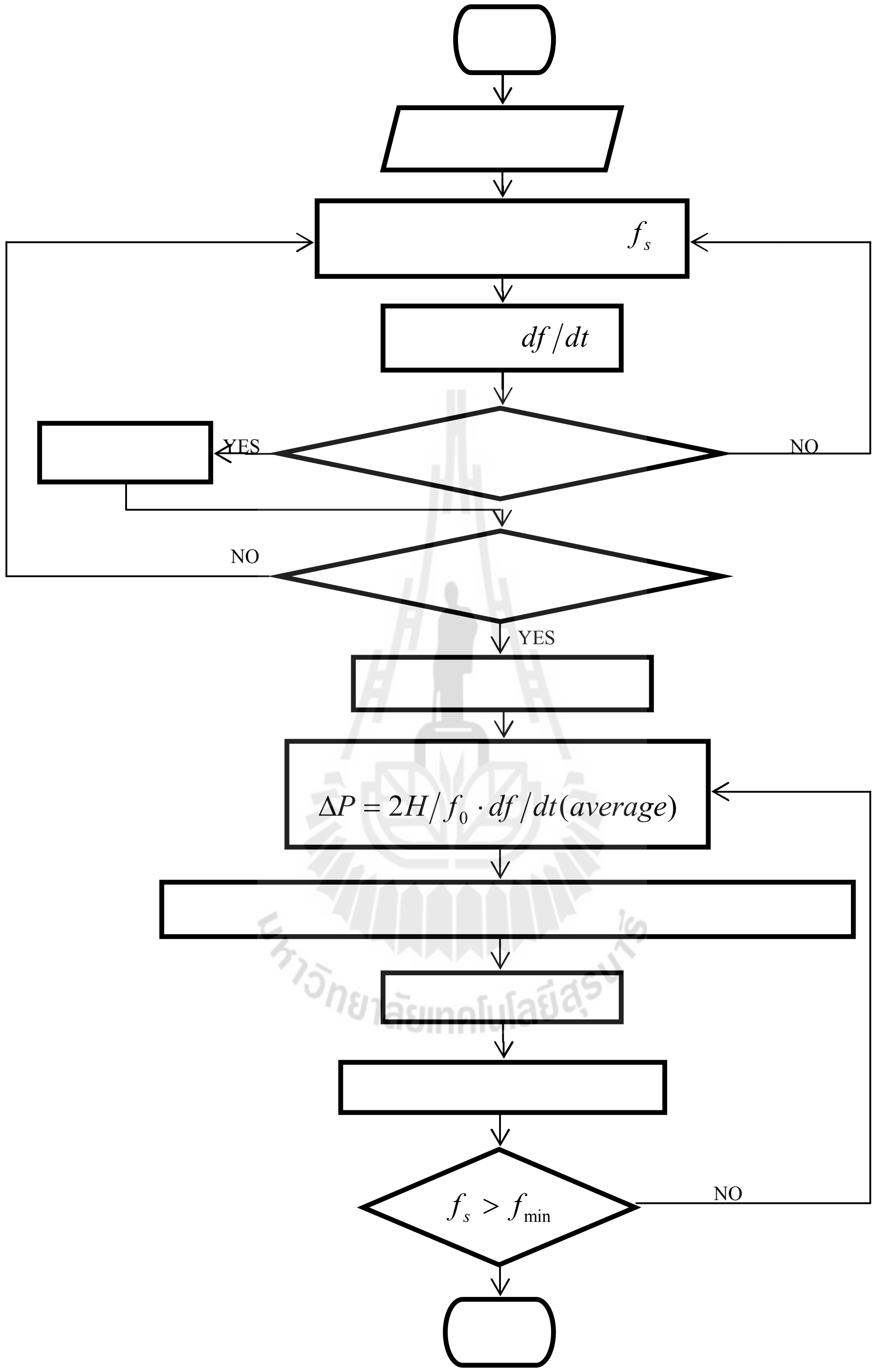


Figure 3.3 Flowchart for Load shedding scheme based on reactive power demand and priority

3.3.3 Pseudo code for selection of loads to be shed for load shedding scheme based on reactive power demand and priority.

WHILE system frequency < 49.7 Hz

sort loads in descending order based on their reactive power demand and priority.

select loads sorted from top to bottom until $\Delta P_{new} \leq \Delta P_S$

identify loads selected

shed loads selected

ENDWHILE

3.4 Load shedding scheme using Harmony Search to compute optimal load shed

Recent blackouts around the world question the reliability of conventional and adaptive load shedding techniques in avoiding such power outages[33]. To address this issue, reliable techniques are required to provide fast and accurate load shedding to prevent collapse in the power system. Computational intelligence techniques, due to their robustness and flexibility in dealing with complex non-linear systems, could be an option in addressing this problem. Computational intelligence includes techniques like artificial neural networks, genetic algorithms, harmony search algorithm, fuzzy logic control, particle swarm optimization etc. Research in these techniques is being undertaken in order to discover means for more efficient and reliable load shedding. This thesis provides an overview of harmony search algorithm and uses it to solve the load shedding problem solved by conventional scheme and load shedding scheme based on reactive power and priority(adaptive scheme).

3.4.1 Harmony search

Harmony search method mimics a jazz improvisation process by musicians in order to seek a fantastic state of harmony [52,81,82].

3.4.2 Harmony search steps

i. Initialize the problem and algorithm parameters.

ii. Initialize the harmony memory.

iii. Improvise a new harmony.

iv. Update the harmony memory.

v. Check the stopping criterion.

3.4.3 Optimization procedure of the harmony search algorithm

- Initialize the problem and algorithm parameters

The optimization problem is specified as follows:

$$\min\left\{f(x)\middle| x \in X\right\} \tag{22}$$

Subject to $g(x) \geq 0$

$h(x) = 0$

Where:

$f(x)$ is the objective function.

$g(x)$ is the inequality constraint function.

$h(x)$ is the equality constraint function.

$\boldsymbol{x}$ is the set of each decision variable.

x_i and $\mathbf{X}$ is the set of the possible range of values for each decision variable, that is $x_{\min} \leq X \leq x_{\max}$.

The HS algorithm parameters are also specified in this step. These are as follows:

- The Harmony Memory Size (HMS), or the number of solution vectors in the harmony memory;
- Harmony Memory Considering Rate (HMCR);
- Pitch Adjusting Rate (PAR);
- Number of decision variables (*N*)
- The Number of Improvisations (NI), or stopping criterion.

The harmony memory (HM) is a memory location where all the solution vectors (sets of decision variables) are stored. This HM is similar to the genetic pool in the GA. Here, HMCR and PAR are parameters that are used to improve the solution vector. Both are defined in Step 3.

- Initialize the harmony memory

In Step 2, the HM matrix is filled with as many randomly generated solution vectors as the HMS

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \tag{23}$$

- Improvise a new harmony

A new harmony vector, $x^j = \left(x_1^j, x_2^j, ..., x_N^j\right)$, is generated based on three rules:

- Memory consideration
- Pitch adjustment
- Random selection.

Thereby generating a new harmony called 'improvisation'. In the memory consideration, the value of the first decision variable x_1^i for the new vector is chosen from any value in the specified HM range $\left(x_1^1 - x_1^{HMS}\right)$. Values of the other decision variables $\left(x_2^j, x_3^j, ..., x_N^j\right)$ are chosen in the same manner. The HMCR, which varies between 0 and 1, is the rate of choosing one value from the historical values stored in the HM, while (1 − HMCR) is the rate of randomly selecting one value from the possible range of values.

$$x_i^j \leftarrow \begin{cases} x_i^1 \in \left\{x_i^1, x_i^2, \cdots, x_i^{HMS}\right\}, probability = HMCR \\ x_i^j \in X_i, probability = (1 - HMCR) \end{cases} \tag{24}$$

For example, a HMCR of 0.85 indicates that the HS algorithm will choose the decision variable value from historically stored values in the HM with the 85% probability or from the entire possible range with the 100–85% probability. Every component obtained by the memory consideration is examined to determine whether it should be pitch-adjusted. This operation uses the PAR parameter, which is the rate of pitch adjustment as follows:

Pitch adjusting rate for

$$x_i^j \leftarrow \begin{cases} yes\ with\ probability\ PAR \\ No\ with\ probablity\ (1 - PAR) \end{cases} \tag{25}$$

The value of (1 − PAR) sets the rate of doing nothing. If the pitch adjustment decision for x_i^j is Yes, x_i^j is replaced as follows:

$$x_i^j \leftarrow x_i^j \pm r\,and(\ )*bw \tag{26}$$

Where bw is an arbitrary distance bandwidth, *r* and ( ) is a random number between 0 and 1.

In Step 3, HM consideration, pitch adjustment or random selection is applied to each variable of the new harmony vector in turn.

- Update harmony memory

If the new harmony vector, $x^j = \left(x_1^j, x_2^j, ..., x_N^j\right)$ is better than the worst harmony in the HM‘, judged in terms of the objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

- Check stopping criterion

If the stopping criterion (maximum number of improvisations) is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated.

3.4.4 Flowchart of Harmony Search algorithm

The algorithm starts by initializing the optimization problem. In this step the objective function and constraints are specified. Algorithm parameters are also specified. In the second step harmony memory is initialized. Then, a new harmony is improvised by generating a new harmony vector based on memory consideration, pitch adjustment and random selection. The fourth step is the update of the harmony memory and finally if the stopping criterion is reached the algorithm stops. The flowchart is shown below.

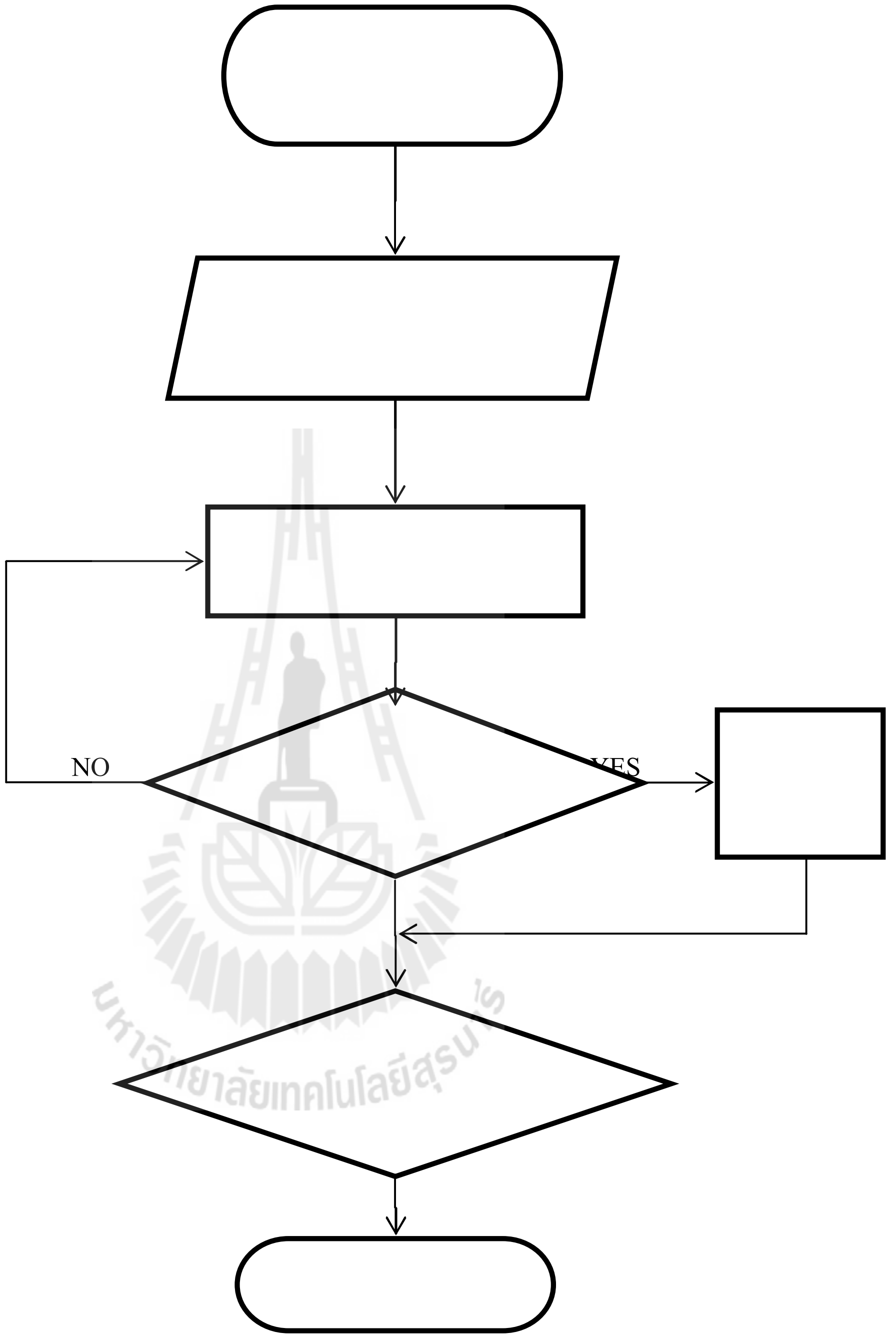


Figure 3.4 Flowchart of Harmony Search algorithm.

3.4.5 Pseudo code of the harmony search algorithm

Begin

Objective $f(x), x = (x_1, x_2, ..., x_d)^T$

Generate initial harmonics (real number arrays)

Define pitch adjusting rate (r_{pa})

Define harmony memory accepting rate (r_{accept})

while (t < Maximum number of iterations)

Generate new harmonics by accepting best harmonics

Adjust pitch to get new harmonics (solutions)

if $(rand > r_{accept})$, choose an existing harmonic randomly

elseif $(rand > r_{pa})$, adjust the pitch randomly within limits

else generate new harmonics via randomization

endif

Accept the new harmonics (solutions) if better

endwhile

Find the current best solutions

end"

3.4.6 Advantages of Harmony Search algorithm

i. Does not require differential gradients, thus it can consider discontinuous functions as well as continuous functions.

ii. Can handle discrete variables as well as continuous variables.

iii. Does not require initial value setting for the variables.

iv. It is free from divergence.

v. May escape local optima.

vi. May overcome the drawbacks of GA's building block theory which works well only if the relationship among variables in a chromosome is carefully considered. If neighbor variables in a chromosome have weaker relationship than remote variables, building block theory may not work well because of crossover operation. However, HS explicitly considers the relationship using ensemble operation.

vii. Has a novel stochastic derivative applied to discrete variables, which uses musician's experiences as a searching direction.

viii. Certain HS variants do not require algorithm parameters such as HMCR and PAR, thus novice users can easily use the algorithm.

3.4.7 Creation of the load shedding optimization problem

Equation (21) can be written as:

$$f_0 = \frac{2H \cdot df/dt}{\Delta P} \tag{27}$$

From (19) we have,

$$f_1 = \frac{2H_1 \cdot df/dt|_1}{\Delta P_1} \tag{28}$$

Where:

f_1 is the rated frequency of the system under normal operating condition.

ΔP_1 is the power imbalance under normal operating condition.

H_1 is the total system inertia under normal operating condition.

$df/dt|_1$ is the average rate of change of frequency.

And

$$f_2 = \frac{2H_2 \cdot df/dt|_2}{\Delta P_2} \tag{29}$$

Where:

f_2 is the rated frequency of the system under abnormal operating condition.

ΔP_2 is the power imbalance under abnormal operating condition.

H_2 is the total system inertia under abnormal operating condition.

$df/dt|_2$ is the average rate of change of frequency.

Subtracting (29) from (28) gives,

$$f_1 - f_2 = \frac{2H_1 \cdot df/dt|_1}{\Delta P_1} - \frac{2H_2 \cdot df/dt|_2}{\Delta P_2} \tag{30}$$

But,

$$\Delta P_1 = P_{GT1} - P_{DT1}$$

$$\Delta P_2 = P_{GT2} - P_{DT2}$$

$$f_1 - f_2 = \Delta f$$

Where: P_{GT1} is total power generation under normal condition.

P_{DT1} is the total load under normal condition.

P_{GT2} is total power generation during a disturbance.

P_{DT2} is the total load during a disturbance.

Δf is the frequency deviation.

Therefore equation (30) can be written as,

$$\Delta f = \frac{2H_1 \cdot df/dt|_1}{P_{GT1} - P_{DT1}} - \frac{2H_2 \cdot df/dt|_2}{P_{GT2} - P_{DT2}} \tag{31}$$

$$\Delta f = 2\left(\frac{H_1 \cdot df/dt|_1}{P_{GT1} - P_{DT1}} - \frac{H_2 \cdot df/dt|_2}{P_{GT2} - P_{DT2}}\right) \tag{32}$$

Equation (32) can be modelled as an optimization minimization problem as follows:

Minimize Δf

Subject to:

$$\begin{gathered} 0 \le P_{D1} \\ \vdots \\ 0 \le P_{Dn} \end{gathered}$$

Where: $P_{D1}, P_{D2}, \cdots, P_{Dn}$ are loads in each bus which sum up to P_{DT2}.

Note:
At the time of load shedding action parameters
$P_{GT1}, P_{DT1}, H_1, df/dt|_1, P_{GT2}, H_2, df/dt|_2$ will be known.

This means that the only unknown is P_{DT2} which is the summation of loads in each bus given by:

$$P_{DT2} = P_{D1} + P_{D2} + P_{D3} + \cdots + P_{Dn.} \tag{33}$$

This optimization problem was solved by Harmony search algorithm to find optimal amount of load at each bus that would reduce P_{DT2} thereby decreasing ΔP_2 hence minimize Δf and restore system frequency for IEEE 14-bus and IEEE-30 bus power systems. Simulations and results are shown on chapter 7.

3.4.8 Algorithm for the load shedding scheme using Harmony Search to compute optimal load shed

i. Input nominal frequency.

ii. Set minimum frequency.

iii. Set initial time to start reading frequency.

iv. Measure system frequency.

v. Find rate of change of frequency after every half cycle.

vi. Find average rate of change of frequency.

vii. If system frequency is less than minimum frequency.

viii. Allow a time delay of few minutes.

ix. Measure system frequency.

x. If system frequency is less than minimum frequency.

xi. Start load shedding procedure.

xii. Find average rate of change of frequency.

xiii. Find optimal load to be shed at each bus by Harmony Search algorithm while avoiding priority loads.

xiv. Shed loads ranked in step (xvii).

xv. Measure system frequency.

xvi. Check: If system frequency is above minimum frequency limit, stop the algorithm otherwise go to step number (XV).

3.4.9 Flowchart for Harmony Search scheme

The scheme starts by setting minimum frequency. System frequency is measured. Rate of change of frequency is found and average rate of change of frequency is calculated. If system frequency is below mimimum limit a time delay of few minutes is allowed. Then, frequency is checked again. If it is still below minimum set value load shedding is triggered. Avearge rate of change of frequency is calculated again. Harmony search algorithm is used to find optimal load to be shed in each bus Then a table of loads that can be shed is created while avoiding priority loads. Loads to be shed are identified and shed. Finally check of system frequency is done. If system frequency is less than rated frequency program go to step number (XV). If satisfactory, program ends.

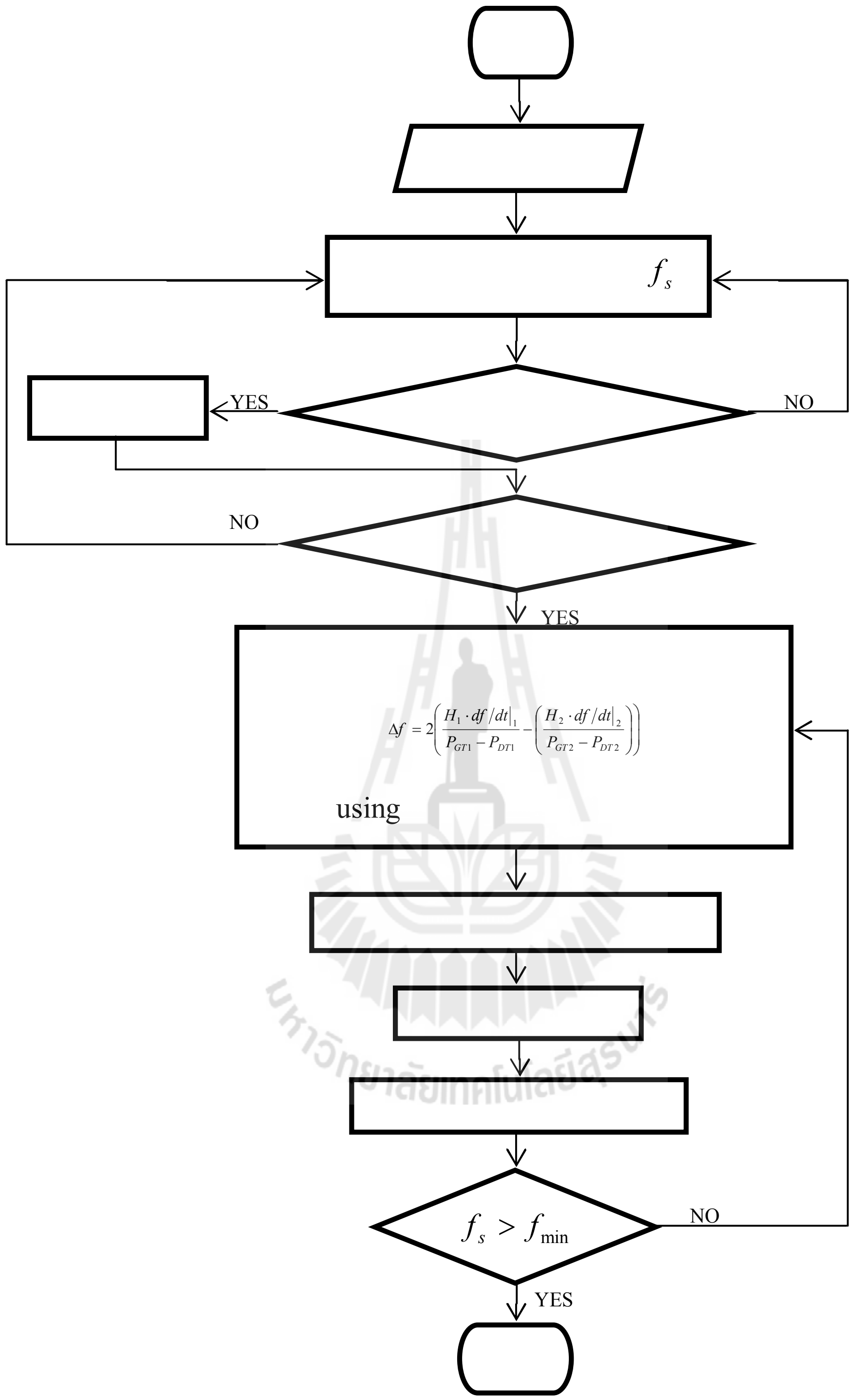


Figure 3.5 Flowchart for load shedding scheme based on Harmony Search algorithm.

3.5 Comparison features of Conventional load shedding and Computational intelligence techniques load shedding.

Table 3.1 Comparison between Conventional and Computational intelligency techniques load shedding schemes[33].

No.	**Feature**	**Conventional techniques**	**Computational intelligence techniques**
1	Optimum load Shedding.	Do not provide optimum load Shedding.	Have the ability to provide optimum load shedding.
2	Complex power System.	Cannot deal efficiently with modern and complex power systems.	Can deal efficiently with Modern and complex power systems.
3	Load shedding amount.	Full load shedding, hence few customers affected severely.	Partial load shedding, hence sharing of burden among customers.

3.6 Load Prioritization

Once the architecture and detection methods are selected to develop the load shedding algorithm, the next step is to decide which load blocks to drop first. Prioritizing load blocks is an old concept, probably as old as the load shedding technique itself[53]. Usually many utilities prefer to drop low priority loads during a load shedding process. Different departments are involved in determining the load priorities such as planning engineers, sales, management, and other groups including operators. Some utilities allowed rotating the customers for load shedding purposes. However, all of the priority and rotation schedules were predetermined, and the actual demand was assumed constant.

The factors that are generally considered in the process of determining load(s) to shed are power rating of a load and/or some predetermined priority based on the importance of a load. From the system benefits point of view, system critical natures of loads should also be considered for load shedding. Loads with higher active power rating tend to be shed first so that a least number of loads are shed to satisfy system constraints. For any given amount of load to shed, it is preferred to shed a least number of loads. Thus shedding larger loads reaches the target load shed with less equipment.

In this load shedding scheme the factors that were considered in determining the loads to be shed are:

- Reactive power demand of the load.
- Priority of the load based on its economic importance and/or social importance.

Loads are ranked in descending order based on their reactive power demand. High priority loads are placed at the bottom of the list. Loads are shed from top to bottom. Therefore the scheme will end up shedding loads with high reactive power demand and low priority.

3.7 Chapter summary

This chapter has presented Conventional load shedding scheme. Its algorithm and flowchart have been given and discussed. Also the advantages and disadvantages of this scheme are mentioned. Load shedding scheme based on reactive power demand and Load shedding scheme based on reactive power demand and priority have developed. Finally Harmony search technique has been explained in detail and the scheme based on it developed. The chapter also show creation of the load shedding optimization problem which is solved by this technique. Conventional load shedding scheme and Computational techniques load shedding schemes have also been compared.

CHAPTER 4

POWER SYSTEM AND ITS COMPONENTS

4.1 Introduction

Electric Power Systems comprises of components that transform other types of energy into electrical energy and transmit this energy to a consumer. The production and transmission of electricity is relatively efficient and inexpensive, although unlike other forms of energy, electricity is not easily stored and thus must generally be used as it is being produced.

4.2 Load frequency control

For a large scale power systems which consists of inter-connected control areas, it is important to keep the frequency and inter area tie power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude. So the control of the real and reactive power in the power system is dealt separately. The load frequency control mainly deals with the control of the system frequency and real power whereas the automatic Voltage regulator loop regulates the changes in the reactive power and voltage magnitude. Load frequency control is the basis of many advanced concepts of the large scale control of the power system.

Automatic generation control (AGC) is very important issue in power system operation and control to ensure the supply of sufficient and reliable electric power with good quality. Owing to the continuous growth of electrical power system in size and complexity with increasing interconnections, the problem of power and frequency oscillations due to unpredictable load changes, has become increasingly serious. These random load changes result in power generation-consumption mismatch, which in turn, affects the quality and reliability of electric power. These mismatches have to be corrected for generation and distribution of sufficient power.

One of the important issues in the operation of power system is Automatic Generation Control (AGC). It helps in supplying adequate and consistent electric power with good quality. It is the secondary control in LFC which re-establishes the frequency to its nominal value (50 Hz) and sustains the interchange of power between areas (in case of more than one control area). For this the load demand in the generator prime mover set is increased or decreased in the form of kinetic energy, resulting in change of frequency. The transient in primary, secondary and tertiary control is of the order of seconds and minutes respectively Automatic generation control is to provide control signals to regulate the real power output of various electric generators within a prescribed area in response to changes in system frequency and tie-line loading so as to maintain the scheduled system frequency and established interchange with other areas. In other words the design of automatic generation controller depends upon various energy source dynamics involved in the AGC of the area.

If the load on the system is increased suddenly then the turbine speed drops before the governor can adjust the input of the steam to the new load. As the change in the value of speed diminishes the error signal becomes smaller and the positions of the governor and not of the fly balls get closer to the point required to maintain the constant speed. One way to restore the speed or frequency to its nominal value is to add an integrator on the way. The integrator will unit shall monitor the the average error over a period of time and will overcome the offset. Thus as the load of the system changes continuously the generation is adjusted automatically to restore the frequency to the nominal value. This scheme is known as automatic generation control. In an interconnected system consisting of several pools, the role of the AGC is to divide the load among the system, stations and generators so as to achieve maximum economy and reasonably uniform frequency.

4.3 Droop control

Droop control is a control strategy commonly applied to generators for primary frequency control (and occasionally voltaqe control) to allow parallel generator operation (e.g. load sharing). Recall that the active and reactive power transmitted across a lossless line are:

$$P = \frac{V_1 V_2}{X} \sin \delta \tag{34}$$

$$Q = \frac{V_1}{X}\left(V_1 - V_2 \cos\delta\right) \tag{35}$$

Since the power angle δ is typically small, we can simplify this further by using the approximations $\sin\delta \approx \delta$ and $\cos\delta = 1$:

$$\delta \approx \frac{PX}{V_1 V_2} \tag{36}$$

$$\left(V_2 - V_1\right) \approx \frac{QX}{V_2} \tag{37}$$

From the above, we can see that active power has a large influence on the power angle and reactive power has a large influence on the voltage difference. Restated, by controlling active and reactive power, we can also control the power angle and voltage. We also know from the swing equation that frequency is related to the power angle, so by controlling active power, we can therefore control frequency.

This forms the basis of frequency and voltage droop control where active and reactive power are adjusted according to linear characteristics, based on the following control equations:

$$f = f_0 - k_p\left(P - P_0\right) \tag{38}$$

$$V = V_0 - k_q(Q - Q_0) \tag{39}$$

Where: f is the system frequency

f_0 is the base frequency

k_p is the frequency droop control setting

P is the active power of the unit

P_0 is the base active power of the unit

V is the voltage at the measurement location

V_0 is the base voltage

Q is the reactive power of the unit

Q_0 is the base reactive power of the unit

k_q is the voltage droop control setting

These two equations are plotted in the characteristics below:

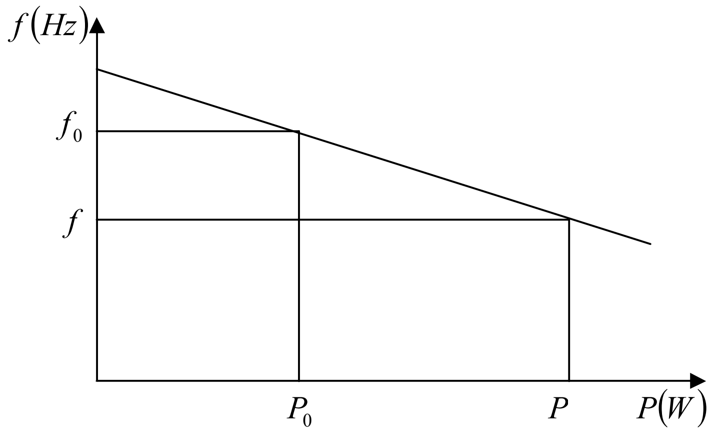


Figure 4.1 Frequency droop characteristic.

The frequency droop characteristic above can be interpreted as follows: when frequency falls from f_0 to f, the power output of the generating unit is allowed to increase from P_0 to P. A falling frequency indicates an increase in loading and a requirement for more active power. Multiple parallel units with the same droop characteristic can respond to the fall in frequency by increasing their active power outputs simultaneously. The increase in active power output will counteract the reduction in frequency and the units will settle at active power outputs and frequency at a steady-state point on the droop characteristic. The droop characteristic therefore allows multiple units to share load without the units fighting each other to control the load (called "hunting"). The same logic above can be applied to the voltage droop characteristic.

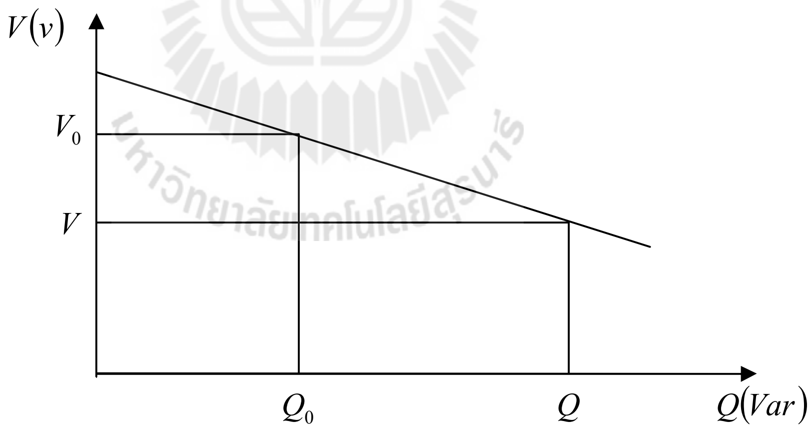


Figure 4.2 Voltage droop characteristic.

When voltage falls from V_0 to V the power output of the generating unit is allowed to increase from Q_0 to Q. A voltage drop indicates an increase in reactive power demand and a requirement for more reactive power supply.

4.3.1 Droop control setpoints

Droop settings are normally quoted in % droop. The setting indicates the percentage amount the measured quantity must change to cause a 100% change in the controlled quantity. For example, a 5% frequency droop setting means that for a 5% change in frequency, the unit's power output changes by 100%. This means that if the frequency falls by 1%, the unit with a 5% droop setting will increase its power output by 20%.

4.4 The inertia constant H

Traditionally, power system operation is based on the assumption that electricity generation, in the form of thermal power plants, reliably supplied with fossil or nuclear fuels, or hydro plants, is fully dispatchable, i.e. controllable, and involves rotating synchronous generators [ulbig]. Via their stored kinetic energy they add rotational inertia, an important property of frequency dynamics and stability. The contribution of inertia is an inherent and crucial feature of rotating synchronous generators. Due to electro-mechanical coupling, a generator's rotating mass provides kinetic energy to the grid (or absorbs it from the grid) in case of a frequency deviation Δf. The kinetic energy provided is proportional to the rate of change of frequency Δf. The grid frequency f is directly coupled to the rotational speed of a synchronous generator and thus to the active power balance. Rotational inertia, i.e. the inertia constant H, minimizes Δf in case of frequency deviations. This renders frequency dynamics more benign, i.e slower, and thus increases the available response time to react to fault events such as line losses, power plant outages or large-scale set-point changes of either generation or load units.

Maintaining the grid frequency within an acceptable range is a necessary requirement for the stable operation of power systems. Frequency stability, and in turn stable operation, depend on the active power balance, meaning that the total power in-feed minus the total consumption (including systems losses) is kept close to zero. In normal operation small variations of this balance occur spontaneously. Deviations from its nominal value f_0 (50 Hz or 60 Hz depending on region) should be kept small, as damaging vibrations in synchronous machines and load shedding occur for larger deviations. This can influence the whole power system, in the worst case ending in fault cascades and black-outs. Low levels of rotational inertia in a power system, caused in particular by inverter-connected Renewable Energy Sourcs (RES), i.e. wind turbine and Photovoltaic (PV) units that as such do not provide any inertia, have implications on frequency dynamics. Frequency dynamics are becoming faster in power systems with low rotational inertia. This can lead to situations in which traditional frequency control schemes become, relatively spoken, too slow for preventing large frequency deviations and the impeding consequences of this. The loss of rotational inertia as such and the time-variance of inertia lead to new frequency instability phenomena in power systems. Frequency and power system stability may be at risk.

Mathematically,

$$H = \frac{KE}{MVA} = \frac{\frac{1}{2}J\omega_m^2}{S_{base}}(Ws/VA = s) \tag{40}$$

Where:

$K.E.$ is the kinetic energy of rotating masses.

MVA is the generator MVA rating.

4.4.1 Inertia constant H on different MVA bases

- Machine base
  - Steam turbines = 4-9 s
  - Gas turbines = 3-4 s
  - Hydro turbines = 2-4 s
  - Synchronous compensator = 1-1.5s
- Common base
  - $H \sim$ generator size (Kw-GW)
  - Infinite bus has infinite H

4.5 Power through a transmmision line

For power systems based on rotating generators, frequency and active power are closely interconnected. A load increase implies that the load torque increases without a corresponding increase in the prime mover torque, which means that the rotational speed, and directly the frequency, decreases. The slowing of frequency with increased load is what a droop control is trying to achieve in a controlled and stable manner[8].

Consider the problem of complex power transferred by a transmission line. The transmission line is modeled in Figure 7 as an RL circuit with the voltages at the terminals of the line being held constant.

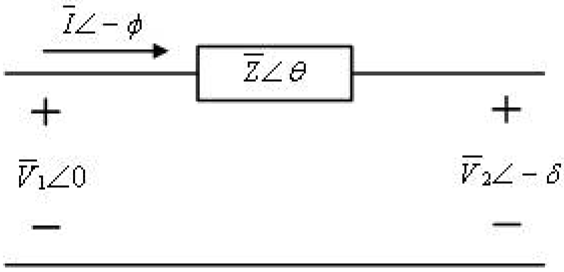


Figure 4.3 Transmission line model

The power flowing into a power line at the terminal is described by the equation

$$\overline{S} = P + JQ = \overline{V}\,\overline{I}^{*} = \overline{V_1}\left(\frac{\overline{V_1} - \overline{V_2}}{\overline{Z}}\right)$$

$$= V_1\left(\frac{V_1 - V_2 e^{j\delta}}{Ze^{-j\theta}}\right)$$

$$= \frac{V_1}{Z}e^{j\theta} - \frac{V_1V_2}{Z}e^{j\theta+\delta} \quad (41)$$

Using Euler's formula to break the total power into real and imaginary components gives the real and reactive power flowing through the line to be

$$P = \frac{V_1^2}{Z}\cos\theta - \frac{V_1V_2}{Z}\cos\theta + \delta \quad (42)$$

$$Q = \frac{V_1^2}{Z}\sin\theta - \frac{V_1 V_2}{Z}\sin\theta + \delta \tag{43}$$

Further defining the line impedance to be $Ze^{j\theta} = R + jX$, the equations can be written as

$$P = \frac{V_1}{X^2 + R^2}\left[RV_1 - V_2\cos\delta + V_2 X\sin\delta\right] \tag{44}$$

$$Q = \frac{V_1}{X^2 + R^2}\left[XV_1 - V_2\cos\delta - RV_2\sin\delta\right] \tag{45}$$

Typical transmission lines are modeled with the inductance being much greater than the resistance so the resistance is commonly neglected. The equations can then be written as the well known equations (34) and (35).

If the power angle δ is small, then the small angle formula can be used so that sin δ = δ and cos δ = 1. Simplifying and rewriting the equations gives (36) and (37).

Equations (36) – (37) show that the power angle depends heavily on the real power and the voltage difference depends on the reactive power. Stated differently, if the real power can be controlled, then so can the power angle, and if the reactive power can be regulated, then the voltage V_1 will be controllable as well. In the power system, each unit uses the frequency, instead of the power angle or phase angle, to control the active power flows since the units do not know the initial phase values of the other units in the stand-alone system. By regulating the real and reactive power flows through a power system, the voltage and frequency can be determined. This observation leads to the common droop control equations (17) and (18), where f_0 and V_0 are the base frequency and voltage respectively, and P_0 and Q_0 are the temporary set points for the real and reactive power of the machine.

4.6 Components of an Electric Power System

A modern electric power system consists of six main components:

i. The power station.

ii. A set of transformers to raise the generated power to the high voltages used on the transmission lines.

iii. The transmission lines.

iv. The substations at which the power is stepped down to the voltage on the distribution lines.

v. The distribution lines.

vi. The transformers that lower the distribution voltage to the level used by the consumer's equipment.

4.6.1 Power Station

The power station of a power system consists of a prime mover, such as a turbine driven by water, steam, or combustion gases that operate a system of electric motors and generators. Most of the world's electric power is generated in steam plants driven by coal, oil, nuclear energy, or gas. A smaller percentage of the world's electric power is generated by hydroelectric (waterpower), diesel, and internal-combustion plants.

4.6.2 Transformers

Modern electric power systems use transformers to convert electricity into different voltages. With transformers, each stage of the system can be operated at an appropriate voltage. In a typical system, the generators at the power station deliver a voltage of from 1,000 to 26,000 volts (V). Transformers step this voltage up to values ranging from 138,000 to 765,000 V for the long-distance primary transmission line because higher voltages can be transmitted more efficiently over long distances. At the substation the voltage may be transformed down to levels of 69,000 to 138,000 V for further transfer on the distribution system. Another set of transformers step the voltage down again to a distribution level such as 2,400 or 4,160 V or 15, 27, or 33 kilovolts (kV). Finally the voltage is transformed once again at the distribution transformer near the point of use to 240 or 120 V.

4.6.3 TransmissionLines

The lines of high-voltage transmission systems are usually composed of wires of copper, aluminum, or copper-clad or aluminum-clad steel, which are suspended from tall latticework towers of steel by strings of porcelain insulators. By the use of clad steel wires and high towers, the distance between towers can be increased, and the cost of the transmission line thus reduced. In modern installations with essentially straight paths, high-voltage lines may be built with as few as six towers to the kilometer. In some areas high-voltage lines are suspended from tall wooden poles spaced more closely together. For lower voltage distribution lines, wooden poles are generally used rather than steel towers. In cities and other areas where open lines create a safety hazard or are considered unattractive, insulated underground cables are used for distribution. Some of these cables have a hollow core through which oil circulates under low pressure. The oil provides temporary protection from water damage to the enclosed wires should the cable develop a leak. Pipe-type cables in which three cables are enclosed in a pipe filled with oil under high pressure (14 kg per sq cm/200 psi) are frequently used. These cables are used for transmission of current at voltages as high as 345,000 V (or 345 kV).

4.6.4 SupplementaryEquipment

Any electric-distribution system involves a large amount of supplementary equipment to protect the generators, transformers, and the transmission lines themselves. The system often includes devices designed to regulate the voltage or other characteristics of power delivered to consumers.
To protect all elements of a power system from short circuits and overloads, and for normal switching operations, circuit breakers are employed. These breakers are large switches that are activated automatically in the event of a short circuit or other condition that produces a sudden rise of current. Because a current forms across the terminals of the circuit breaker at the moment when the current is interrupted, some large breakers (such as those used to protect a generator or a section of primary transmission line) are immersed in a liquid that is a poor conductor of electricity, such as oil, to quench the current. In large air-type circuit breakers, as well as in oil breakers, magnetic fields are used to break up the current. Small air-circuit breakers are used for protection in shops, factories, and in modern home installations. In residential electric wiring, fuses were once commonly employed for the same purpose. A fuse consists of a piece of alloy with a low melting point, inserted in the

circuit, which melts, breaking the circuit if the current rises above a certain value. Most residences now use air-circuit breakers.

4.6.5 Synchronous machines

In a synchronous generator, a DC current is applied to the rotor winding producing a rotor magnetic field. The rotor is then turned by external means producing a rotating magnetic field, which induces a 3-phase voltage within the stator winding.

- Field windings are the windings producing the main magnetic field (rotor windings.
- armature windings are the windings where the main voltage is induced (stator windings).

Synchronous generators produce electricity whose frequency is synchronized with the mechanical rotational speed.

$$f_e = \frac{p}{120} n_m \tag{46}$$

Where f_e is the electrical frequency, Hz

n_m is the rotor speed of the machine.

p is the number of poles.

- Steam turbines are most efficient when rotating at high speed; therefore, to generate 60 Hz, they are usually rotating at 3600 rpm (2-pole).

- Water turbines are most efficient when rotating at low speeds (200-300 rpm); therefore, they usually turn generators with many poles.

In three coils, each of N_C turns, placed around the rotor magnetic field, the induced voltage in each coil will have the same magnitude and phases differing by 120^0.

$$e_{aa'}(t) = N_C \phi \omega_m \cos \omega_m t \tag{47}$$

$$e_{bb'} 9t) = N_C \phi \omega_m \cos\left(\omega_m t - 120^0\right) \tag{48}$$

$$e_{cc'}(t) = N_C \phi \omega_m \cos\left(\omega_m t - 240^0\right) \tag{49}$$

Peak voltage:

$$E_{\max} = N_C \phi \omega_m = 2\pi N_C \phi f \tag{50}$$

RMS voltage:

$$E_A = \frac{2\pi}{\sqrt{2}} N_C \varphi f = \sqrt{2}\pi N_C \phi f \tag{51}$$

The magnitude of internal generated voltage induced in agiven stator is

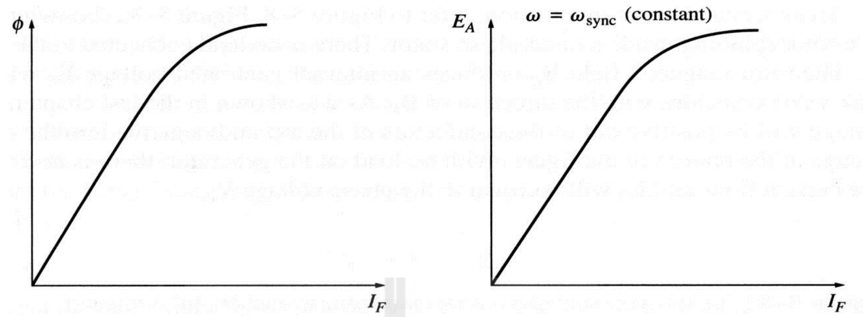
$$E_A = \sqrt{2}\pi N_C \phi f = K \phi \omega \tag{52}$$

Where K is a constant representing the construction of the machine,

ϕ is flux in the machine

ω is the rotational speed of the machine.

Since flux in the machine depends on the field current through it, the internal generated voltage is a function of the rotor field current.



9(a) **9(b)**

Figure 4.4 Magnetization curve (open-circuit characteristic) of a synchronous machine

- 9(a). Plot of magnetic flux ϕ versus field current.
- 9(b). Plot of generated emf versus field current.

DC field excitation is an important part of the overall design of a synchronous generator. The field excitation must ensure not only a stable AC terminal voltage, but must also respond to sudden load changes. Rapid field excitation response is important. There are three methods of excitation namely:

- slip rings link the rotor's field winding to an external dc source.
- dc generator exciter

  a dc generator is built on the same shaft as the ac generator's rotor.

  a commutator rectifies the current that is sent to the field winding.

- brushless exciter in which an ac generator with fixed field winding and a rotor with a three phase circuit diode/SCR rectification supplies dc current to the field windings.

4.6.6 Three-phase circuit breaker

The purpose of a circuit breaker is to interrupt current flowing in the line, transformer, bus, or other equipment when a problem occurs and the power has to be turned off. A breaker accomplishes this by mechanically moving electrical contacts apart inside an *interrupter,* causing an arc to occur that is immediately suppressed by the high-dielectric medium inside the interrupter. Circuit breakers are triggered to open or close by the protective relaying equipment using the substation battery system

These dielectric media also classify the breaker, such as oil circuit breaker (OCB), gas circuit breaker (GCB), and power circuit breaker (PCB). Compared to fuses, circuit breakers have the ability to open and close repeatedly, whereas a fuse opens the circuit one time and must be replaced. Fuses are single-phase devices, whereas breakers are normally gang operated three-phase devices. Breakers can interrupt very high magnitudes of current. They can close into a fault and trip open again. They can be controlled remotely. They need periodic maintenance.

4.6.7 Electrical loads

Devices that are connected to the power system are referred to as electrical loads. Toasters, refrigerators, bug zappers, and so on are considered as electrical loads. There are three types of electrical loads of electrical loads. They vary accoeding to to their leading or lagging time relationship between voltage and current. The three load types are resistive, inductive, and capacitive. Each type has specific characteristics that make them unique.

Understanding the differences between these load types will help explain how power systems can operate efficiently. Power system engineers, system operators, maintenance personel and others try to maximize system efficiency on a continuous basis by having a good understanding of the three types of loads. They understand how having them work together can minimize system losses, additional equipment capacity, and maximize system reliability. The three different types of load are summarized below.

- Resistive load: The resistance in a wire (conductor) causes friction and reduces the amount of current flow if the voltage remains constant. Byproducts of this electrical friction are heat and light. The units (measurement) of resistance are referred to as ohms. The units of electrical power associated with resistive load are watts. Lightbulbs, toasters, electric hot water heaters, and so on are resistive loads.
- Inductive load: Inductive loads require a magnetic field to operate. All electrical loads that have a coil of wire to produce the magnetic field are called inductive loads. Examples of inductive loads are fans, vacuume cleaners, and many other motorized devices. In essence, all motors are inductive loads. The unique difference between inductive loads and other load types is that the current in an inductive load lags the applied voltage. Inductive loads take time to develop their magnetic field when the voltage is apllied, so the current is delayed. The units (measurements) of inductance are called Henry's. Regarding electrical motors, a load placed on a spinning shaft to perform a work function draws what is referred to as real power (watts) from the electrical energy source. In addition to real

power, what is referred to as reactive power is also drawn from the electrical energy source to produce the magnetic fields in the motor. The total power consumed by the motor is therefore , the sum of both real and reactive power. The units of electrical power associated with reactive power are called positive VARs. (VAR stands for volts-amps-rective.).

- Capacitive load: A capacitor is a device made of two metal conductors separated by an insulator called dielectric (air, paper,glass, and other nonconductive materials). These dielectric materials become charged when voltage is applied to the attached conductors. Capacitors can remain charged long after the voltage source has been removed. Example of capacitor loads are TV picture tubes and components used in electronic devices. Opposite to inductors, the current the current associated with capacitors leads the voltage because of time it takes for the dielectric material to charge up to full voltage from the charging current. Therefore, it is said that the current in a capacitor leads the voltage. The units (measurement) of capacitance are called farads.

  Similar to inductors, the power associated with capacitors is also called reactive power, but has the opposite polarity. Thus, inductors have positive VARs and capacitors have negative VARs. Note, the negative VARs of inductors can be cancelled by the positive VARs of capacitors, to leading a net zero reactive power requirement (called unity power factor).

4.7 Chapter summary

Introduction to power system has been presented. This chapter also has explained how load frequency control is done. Droop conrol's primary control mechanism has been described. Generators' inertia constant is discussed. The components of an electric power system are mentioned and explained.

CHAPTER 5

TEST SYSTEMS

Components discussed in the previous chapter can be connected to form a power system. In this thesis six power systems were modellled and used to test load shedding sachemes developed.

1. IEEE 9-bus
2. IEEE 14-bus
3. IEEE 30-bus
4. IEEE 57-bus
5. 80-bus
6. IEEE 118-bus

One line diagrams of these systems are presented. The Convensional scheme, Load shedding scheme based on reactive power demand, Load shedding scheme based on reactive power demand and priority and Load shedding scheme based on Harmony Search were applied to these systems.

5.1 IEEE 9-bus power system one line diagram

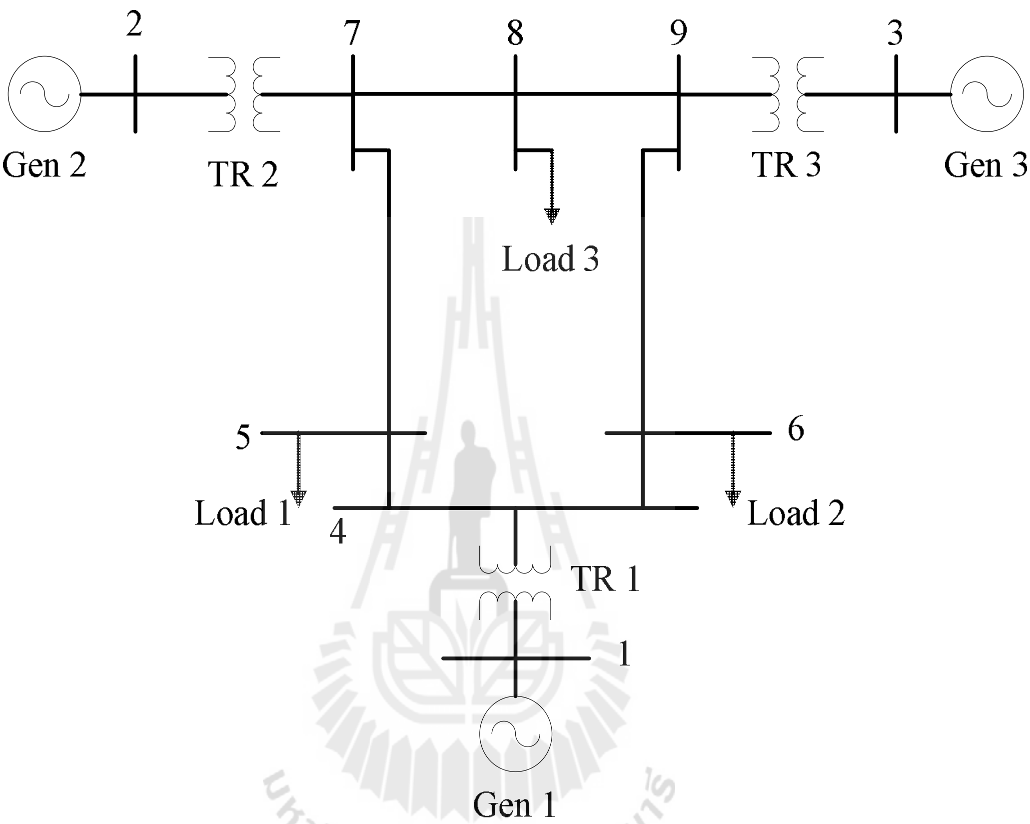


Figure 5.1 IEEE 9-bus

5.2 IEEE 14-bus power system one line diagram

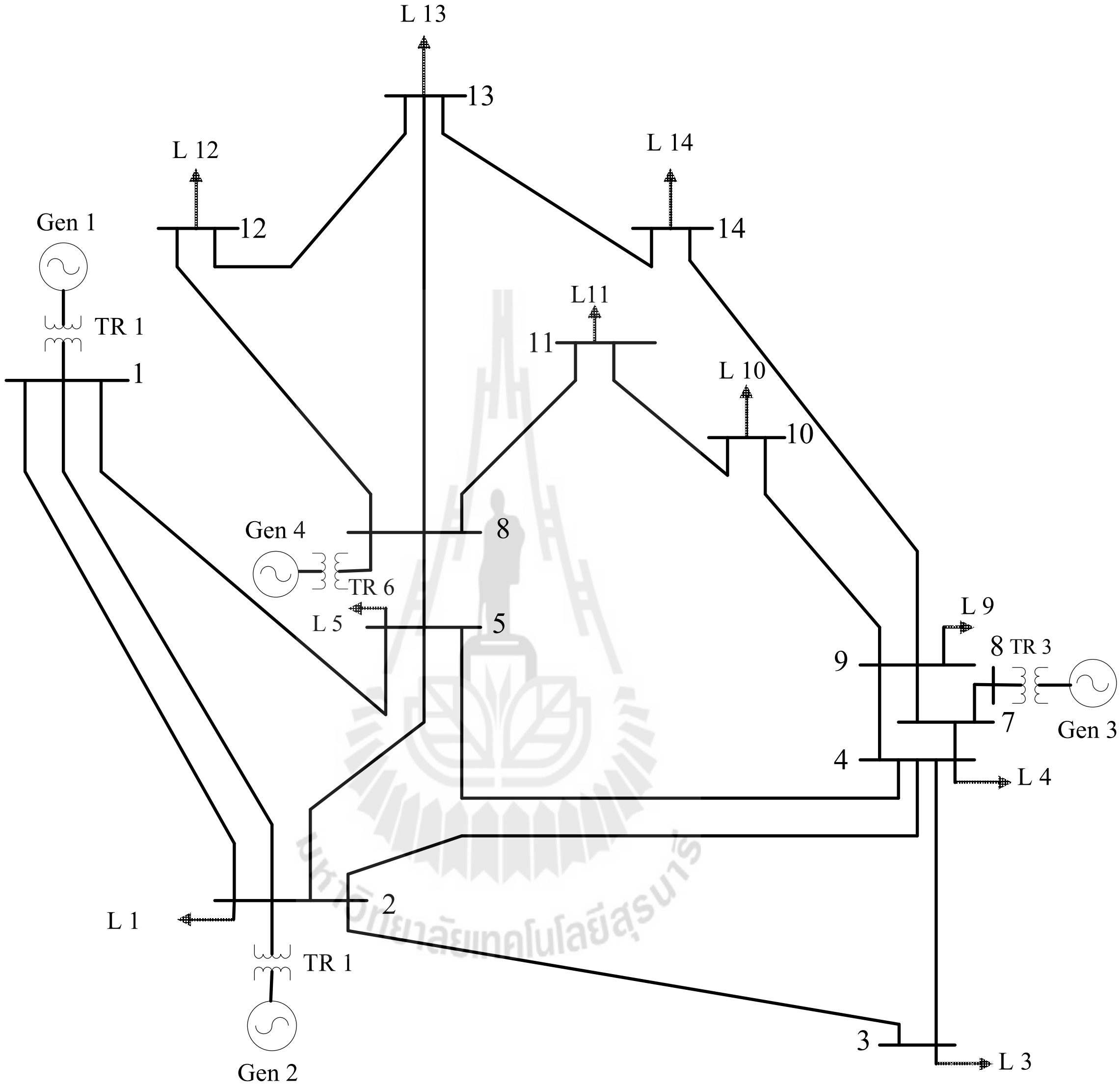


Figure 5.2 IEEE 14-bus

5.3 IEEE 30-bus power system one line diagram

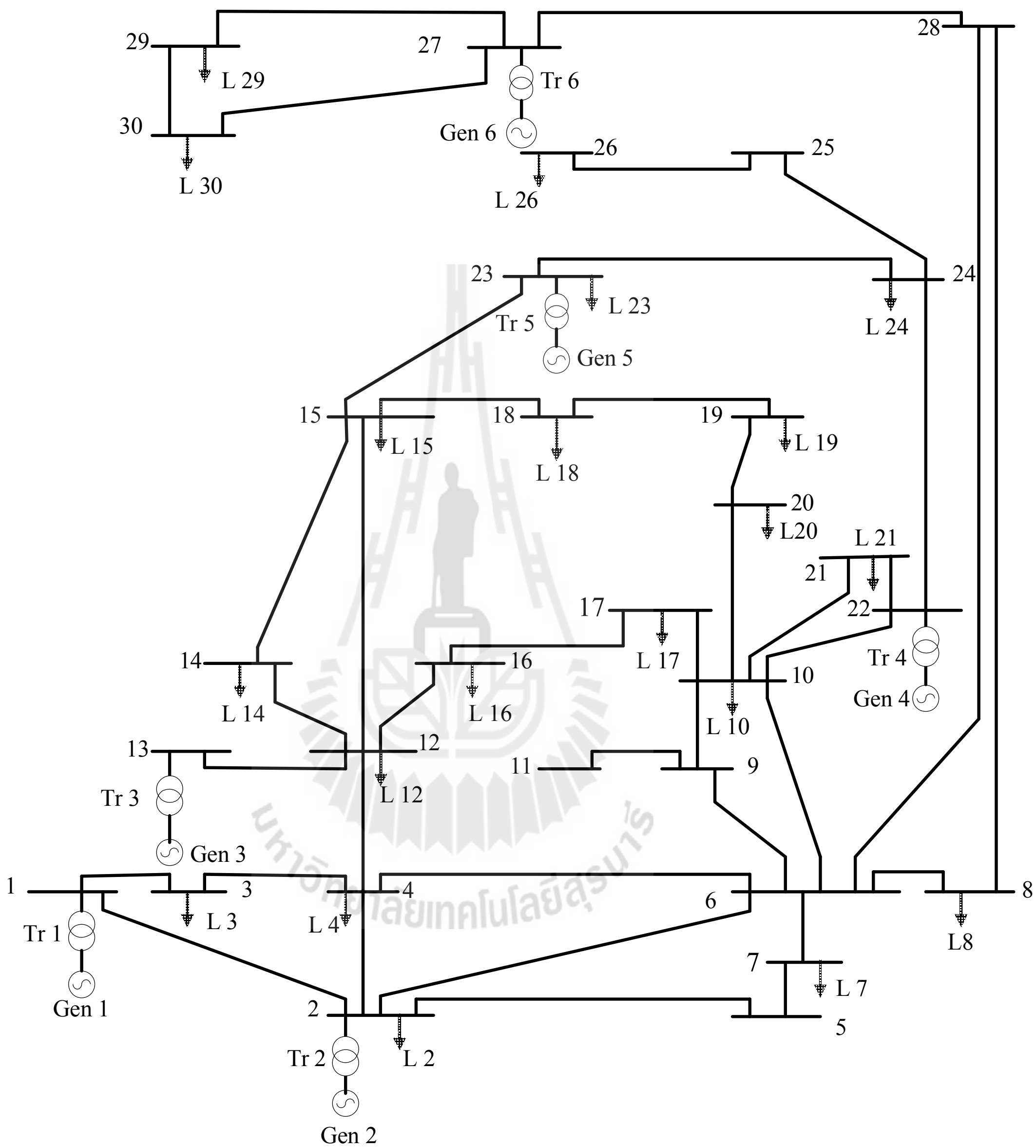


Figure 5.3 IEEE 30-bus

5.4 IEEE 57-bus power system one line diagram

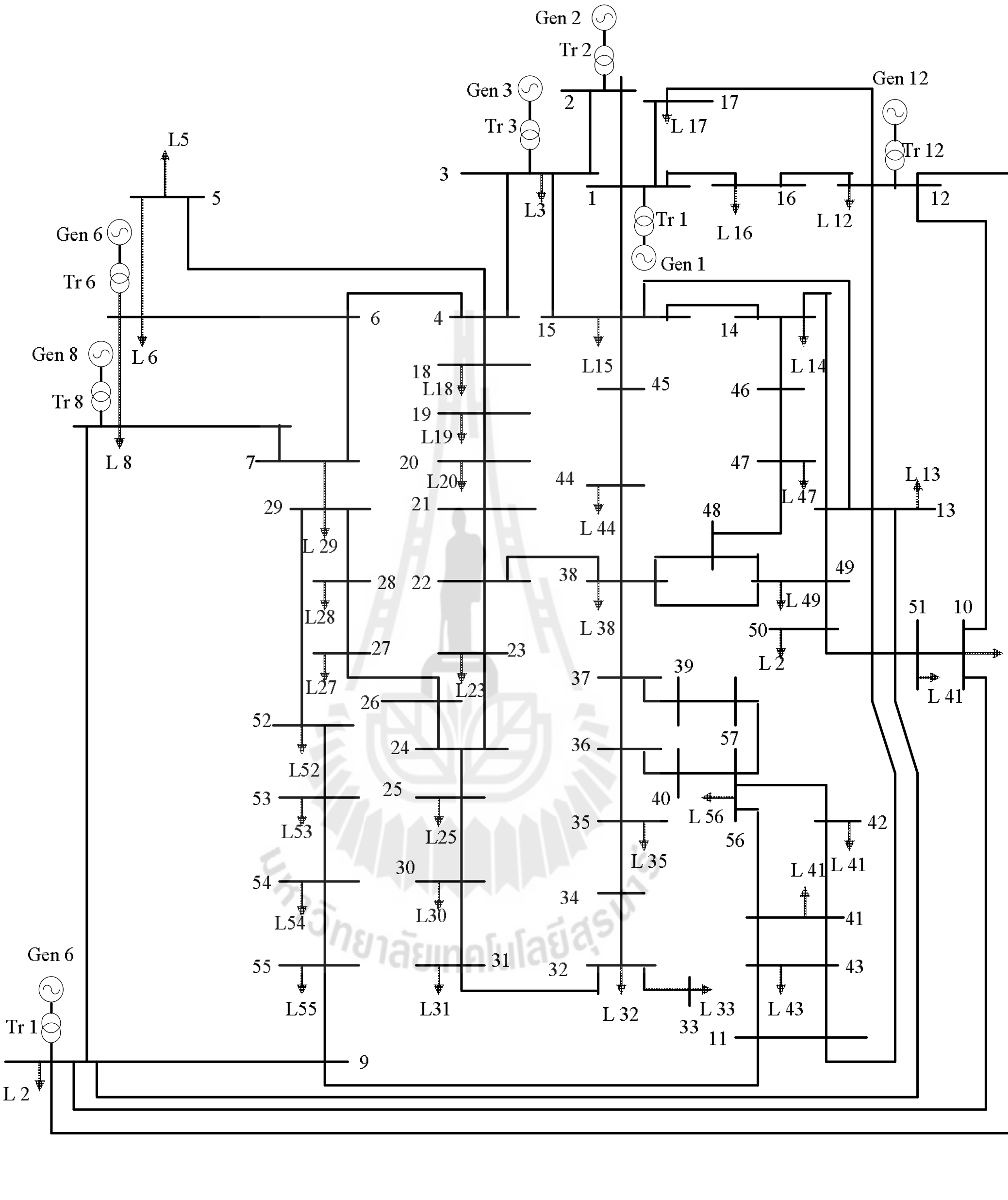


Figure 5.4 IEEE 57-bus

5.5 IEEE 118-bus power system one line diagram

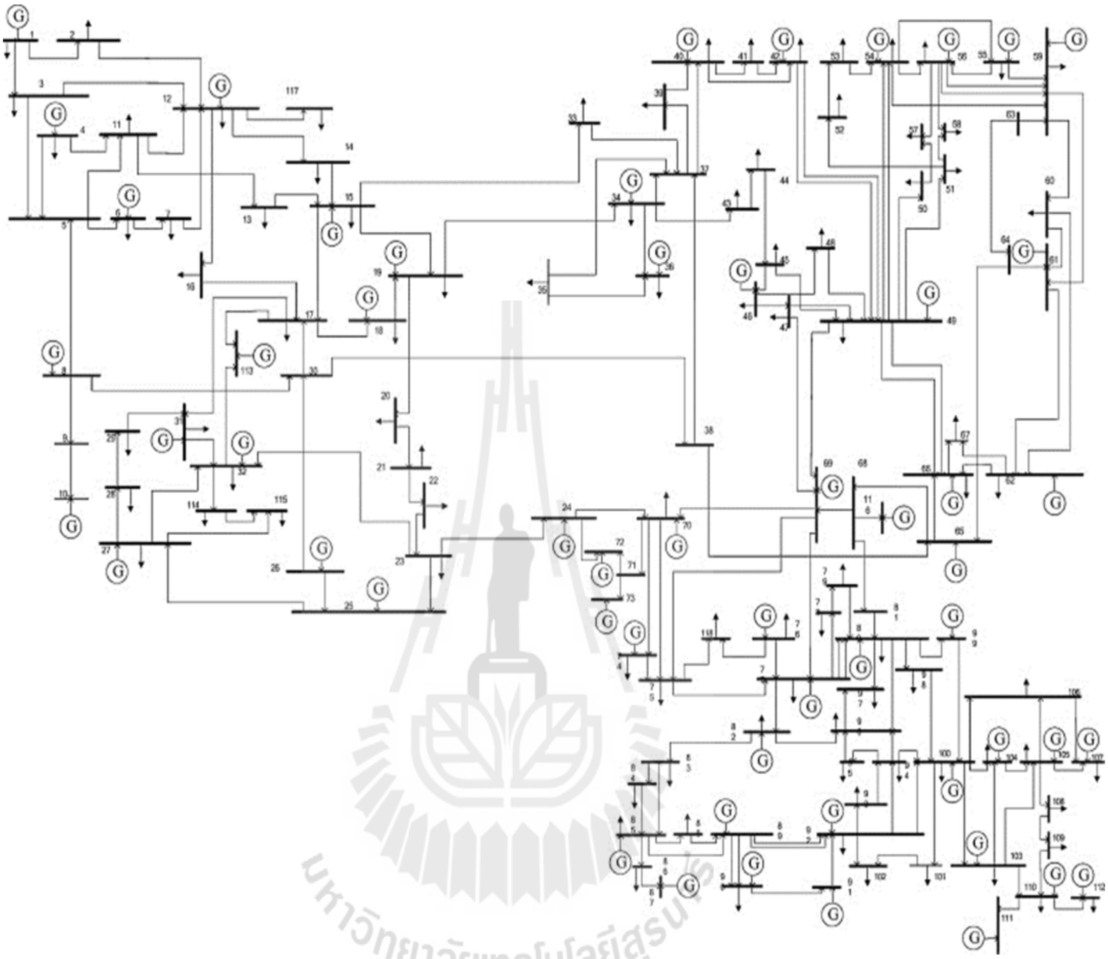


Figure 5.5 IEEE 118-bus (motor.ece.iit.edu/data/JEAS_IEEE118.doc)

CHAPTER 6

SIMULATIONS OF TEST SYSTEMS AND POWER FLOW SOLUTIONS

6.1 Simulations of test systems in SIMULINK

Conventional load shedding scheme, Load shedding scheme based on reactive power demand, Load shedding scheme based on reactive power demand and priority and Harmony Search algorithm based scheme were tested on the IEEE test systems described in the previous chapter. For each of the test system, different test cases were considered. Two types of disturbance cases were considered. The first disturbance case considered was the loss of generator (s). The second was the loss of transmission lines. This chapter contains the results and the plots obtained before and after applying load shedding. Frequency and voltage plots before and after the implementation of the load shedding shown. Loads and generator data were obtained from [16].

6.2 IEEE 9-bus system

Table 6.1 Active and reactive power demands of loads at different buses.

Bus number	Active power demand (MW)	Reactive power demand (MVar)
5	125	50
6	90	30
8	100	35
Total	**315**	**115**

Table 6.2 Generators' bus numbers and their output power.

Bus number	Power generation (MW)	Power generation (MVar)
1	0	0
2	163	0
3	85	0
Total	**248**	**0**

6.2.1 Loss of a generator

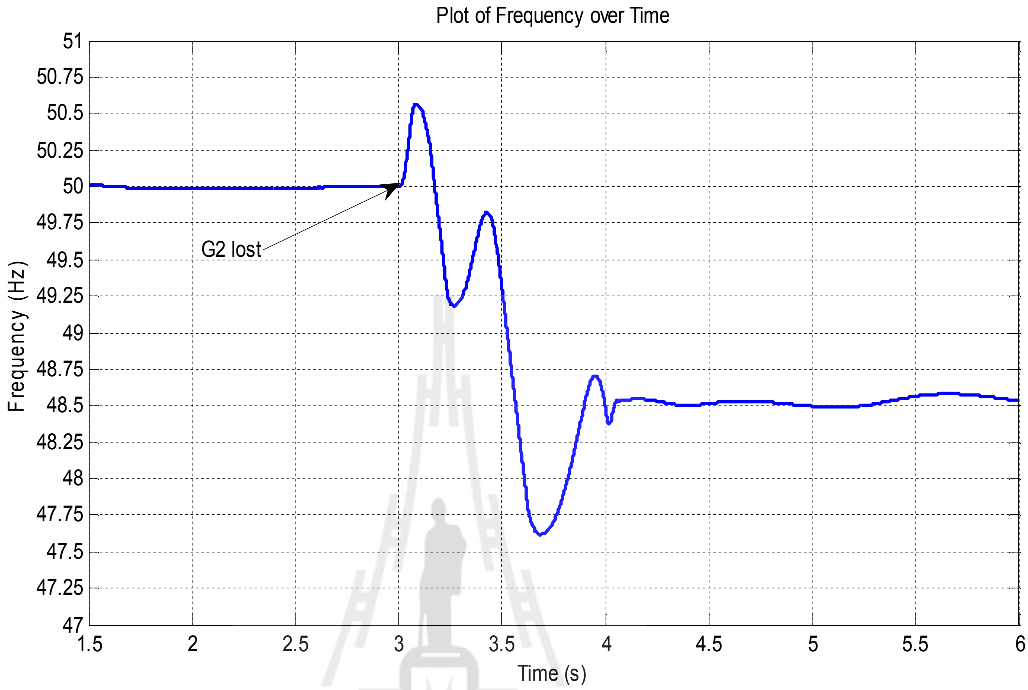


Figure 6.1 Frequency decline due to the loss of a generator.

- Generator loss at Time = 3s caused severe flactuations in system frequency and then dropped to 48.5 Hz. Thus, it became necessary to improve it.

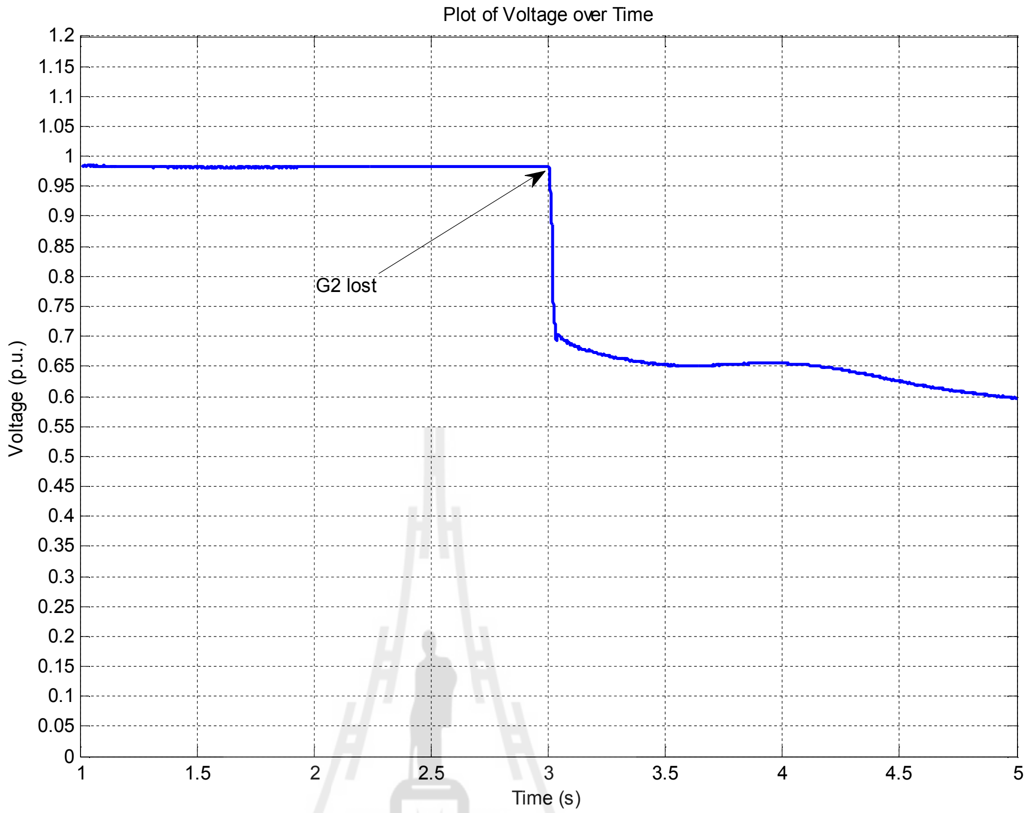


Figure 6.2 Voltage instability due to the loss of a generator.

- Besides the frequency, the voltage is also affected due to the loss of a generator at Time=3s.

Table 6.3 Load shedding test conditions data for load shedding using Conventional scheme and Scheme based on reactive power demand for IEEE 9-bus.

Disturbance	Time	MW lost	System state	Load shed by Conventional scheme (No. of loads shed)	Load shed by Proposed scheme (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G2	T=3	163	Poor	1	1	0

Table 6.4 Loads shed by Conventional scheme and Scheme based on reactive power demand and priority.

Loads shed by Conventional scheme			Loads shed by scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	Mvar shed
5	125	50	9	125	50

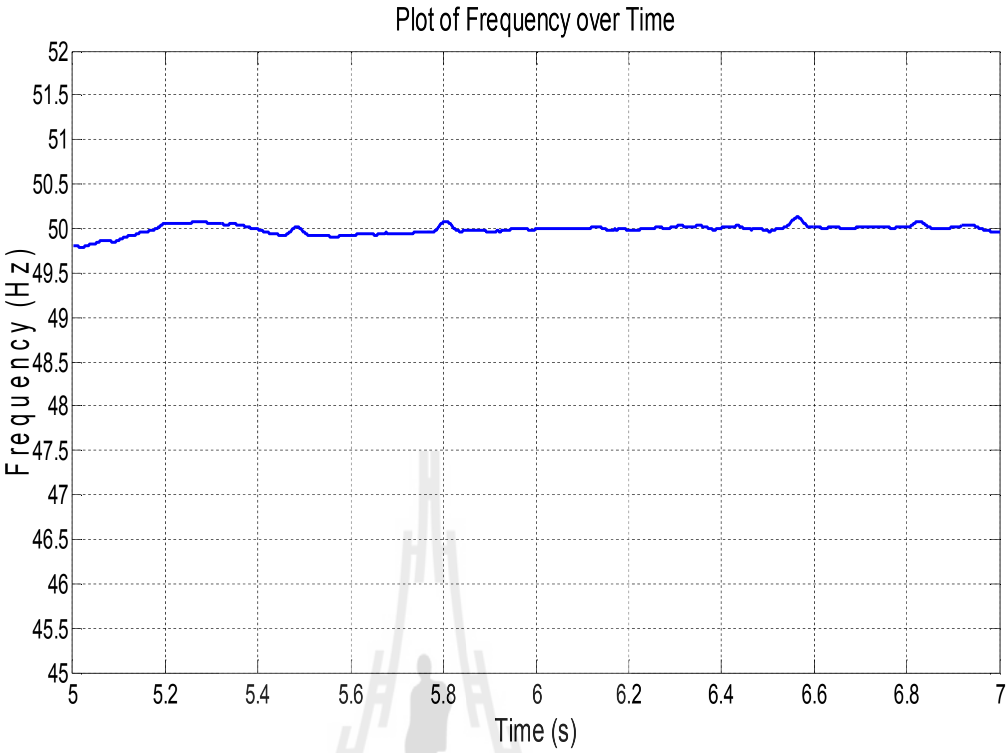


Figure 6.3 Frequency after load shedding by Conventional scheme.

- The frequency improves above the specified lower limit. It settles at a its rated value of 50 Hz at Time=5s. Scheme shed one load.

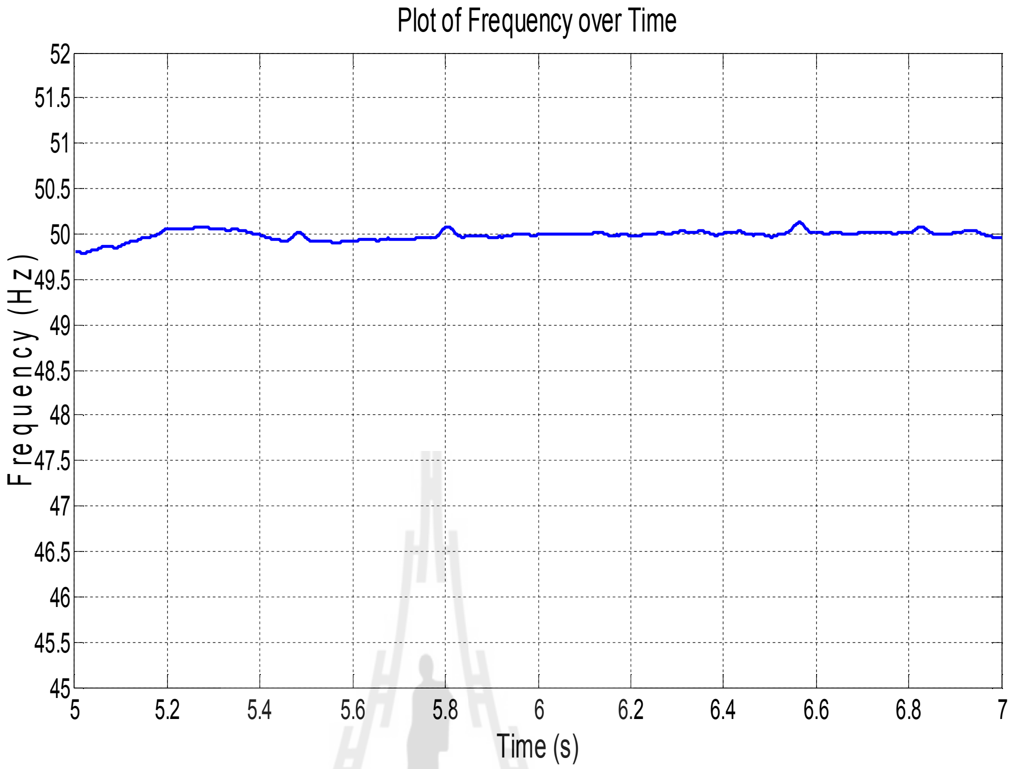


Figure 6.4 Frequency after applying Load shedding scheme based on reactive power demand and priority.

- The frequency improves above the specified lower limit. It settles at a at its rated value of 50 Hz. Scheme shed one load based on the reactive power demand of the of loads.

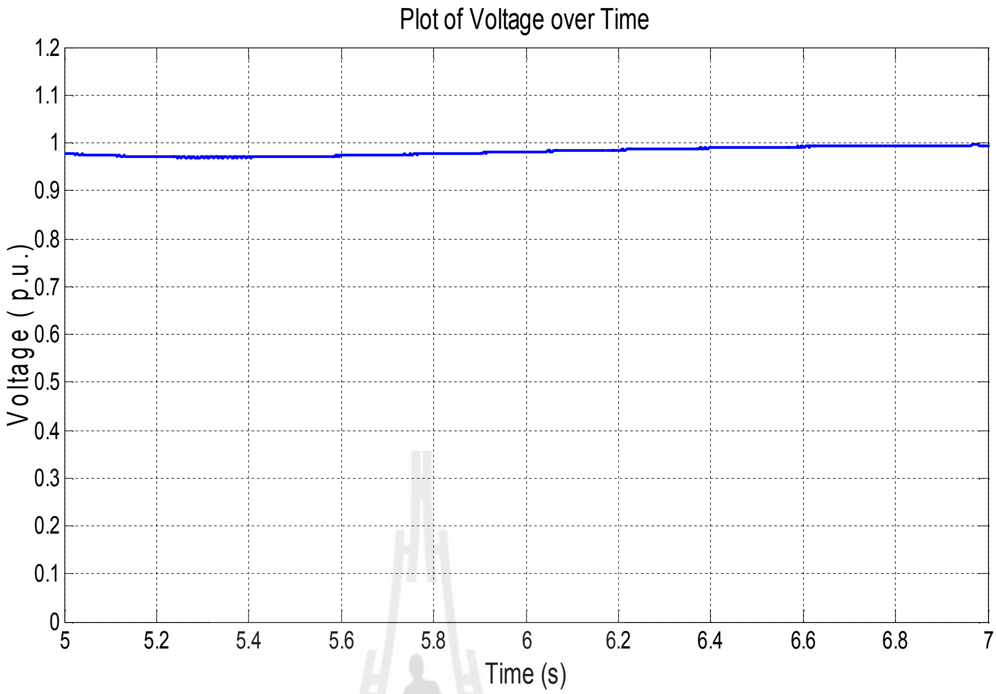


Figure 6.5 Voltage after load shedding by Conventional scheme.

- The voltage plot shows an improvement as well. In fact the final voltage value at the buses shown in figure 15 has been improved due to the appropriate amount of load shedding. Scheme shed one load.

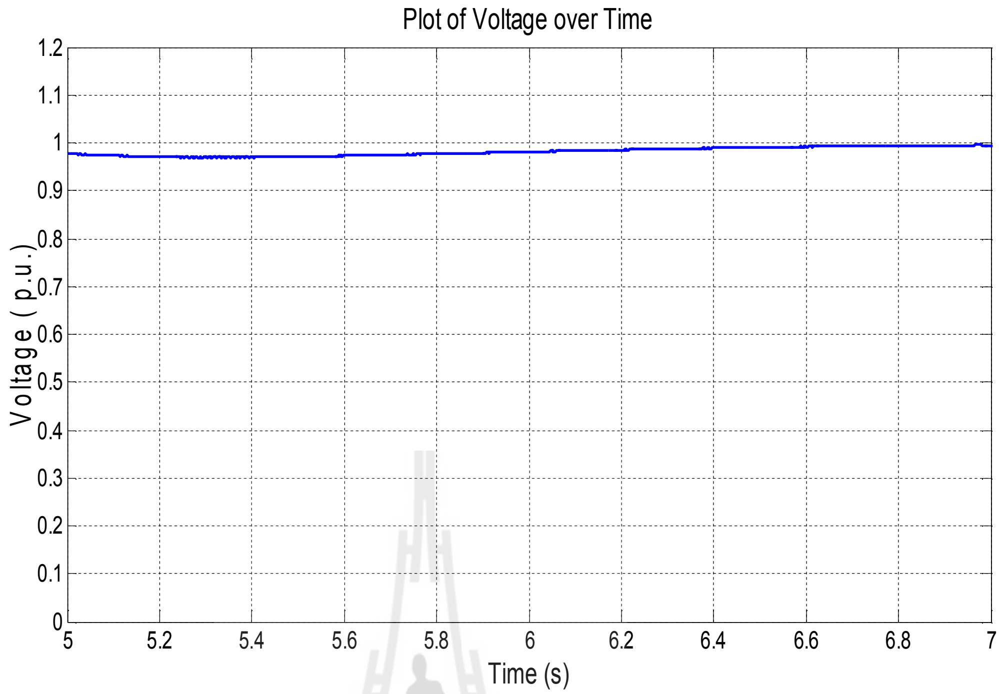


Figure 6.6 Voltage after applying Load shedding scheme based on reactive power demand and priority.

- The voltage plot shows an improvement as well. The final voltage value at the buses shown in figure 15 has been improved due to the appropriate amount of load shedding. Scheme shed one load based on the reactive power demand of the loads.

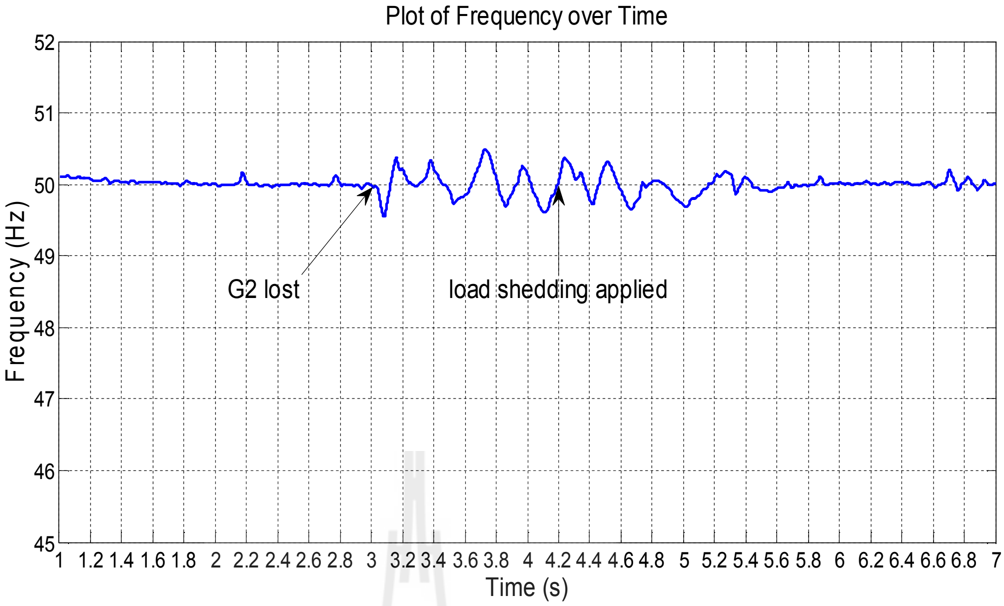


Figure 6.7 Frequency of the system before and after load shedding by Conventional scheme.

- Initially the frequency was 50 Hz. It remained at that constant value up to Time= 3s. At this time occurred the loss of a generator which caused frequency instability before the application of load shedding at Time = 4.2s which improved the frequency to a rated value of 50 Hz. One load was shed.

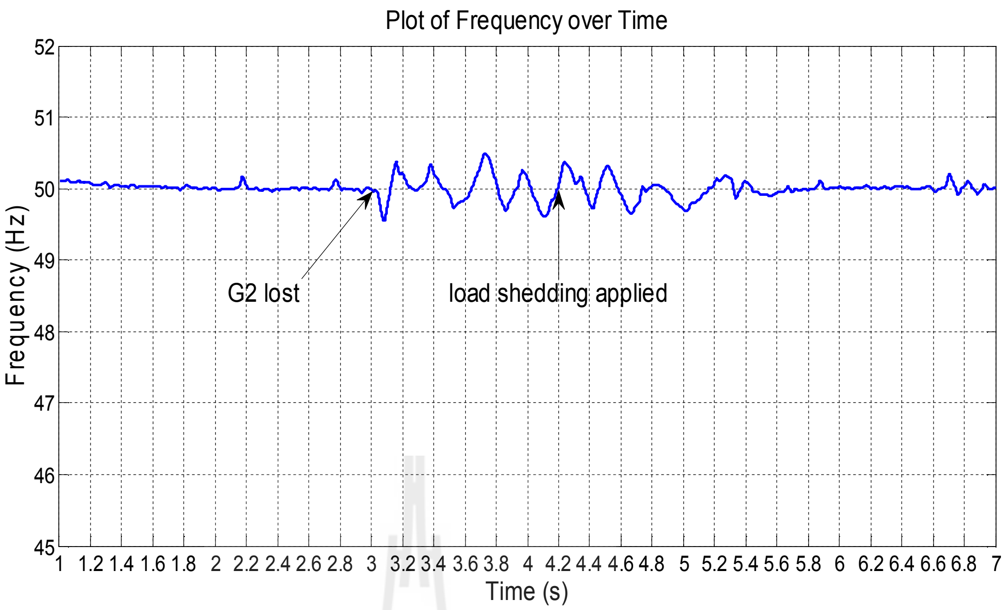


Figure 6.8 Frequency before and after applying Load shedding scheme based on reactive power demand and priority.

- Initially the frequency was 50 Hz. It remained at that constant value up to Time= 3s. At this time occurred the loss of a generator which caused frequency instability before the application of load shedding at Time = 4.2s which improved the frequency to a rated value of 50 Hz. One load was shed.

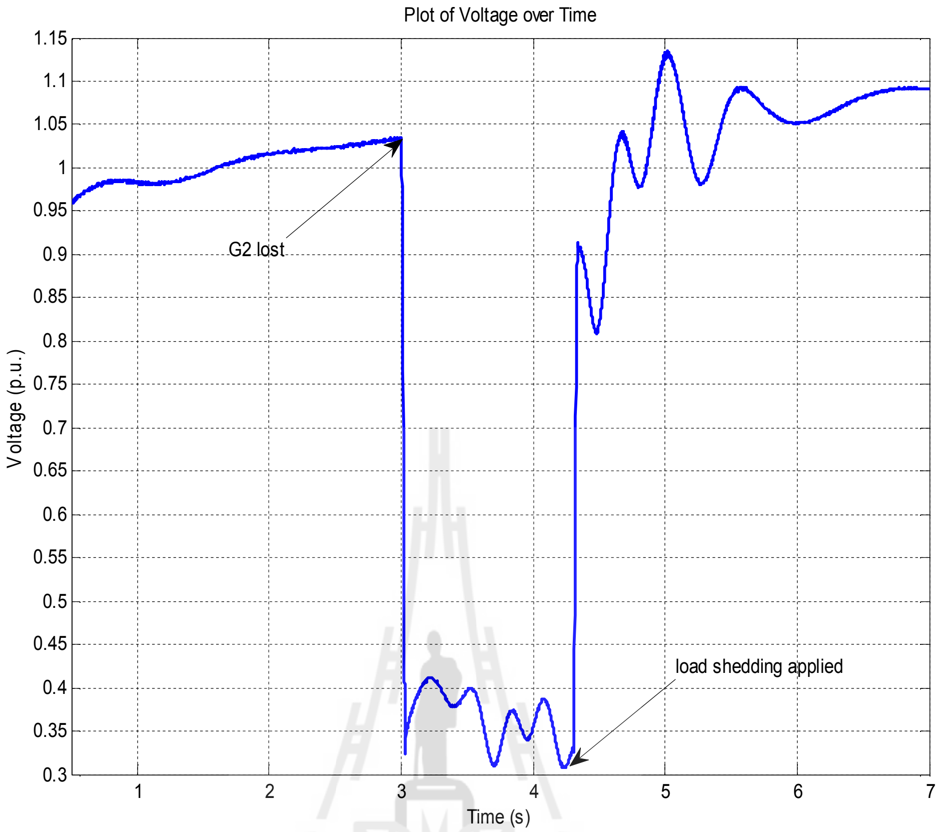


Figure 6.9 Voltage before and after load shedding by Conventional scheme.

- Initially the voltage was just above 0.95 p.u. It increased above 1 p.u. at Time= 3s. At this time occurred the loss of a generator which decreased the voltage below 0.35 p.u. Then load shedding was applied at Time=4.2s which increased the voltage to near 1.1 p.u at Time=7s. One load was shed.

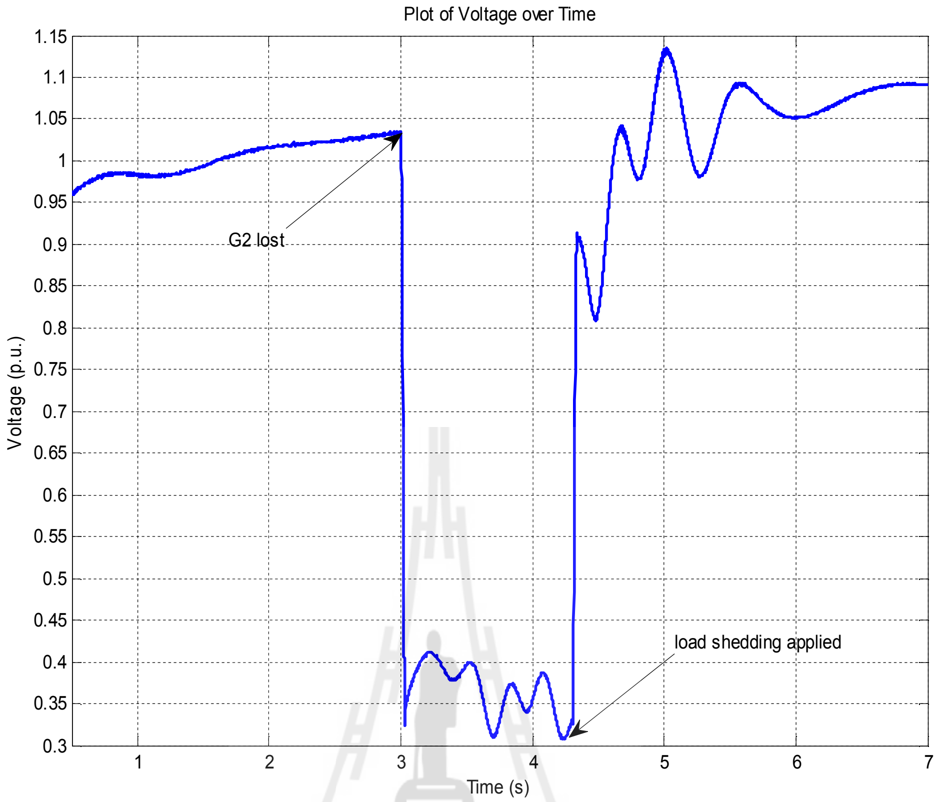


Figure 6.10 Voltage of the system before and after applying Load shedding scheme based on reactive power demand and priority.

- Initially the voltage was just above 0.95 p.u. It increased above 1 p.u. at Time= 3s. At this time occurred the loss of a generator which decreased the voltage below 0.35 p.u. Then load shedding was applied at Time=4.2s which increased the voltage to near 1.1 p.u at Time=7s. One load was shed.

6.2.2 Loss of two lines

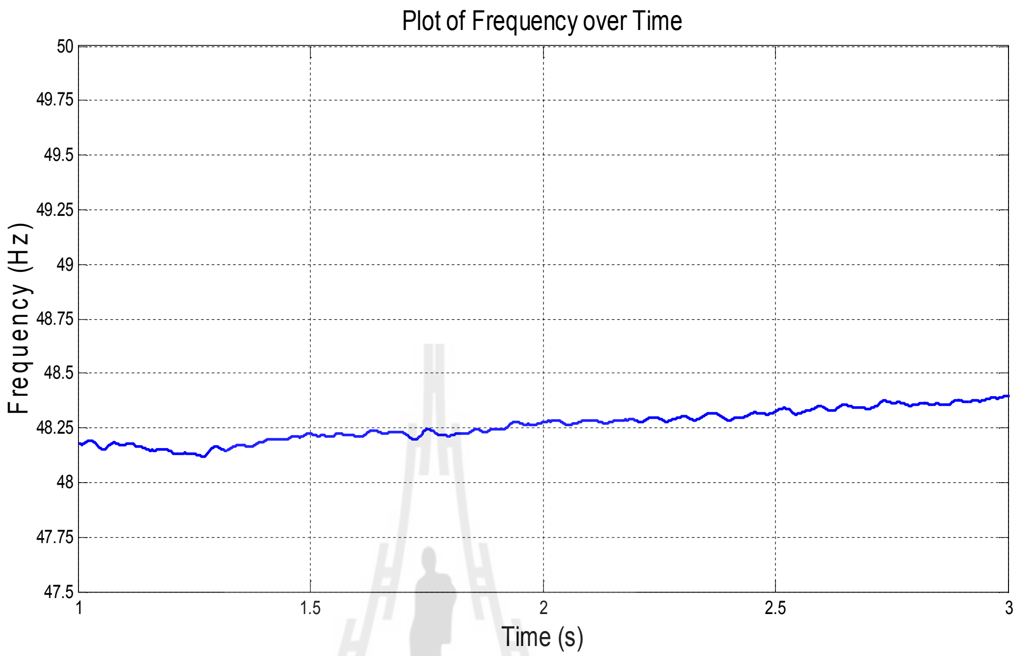


Figure 6.11 Frequency of the system due to loss of two lines.

- Loss of two lines causes the frequency to decline below 48.5 Hz as it can be seen in the plot of figure 24 without load shedding application. Thus it becomes necessary to improve the frequency of the system.

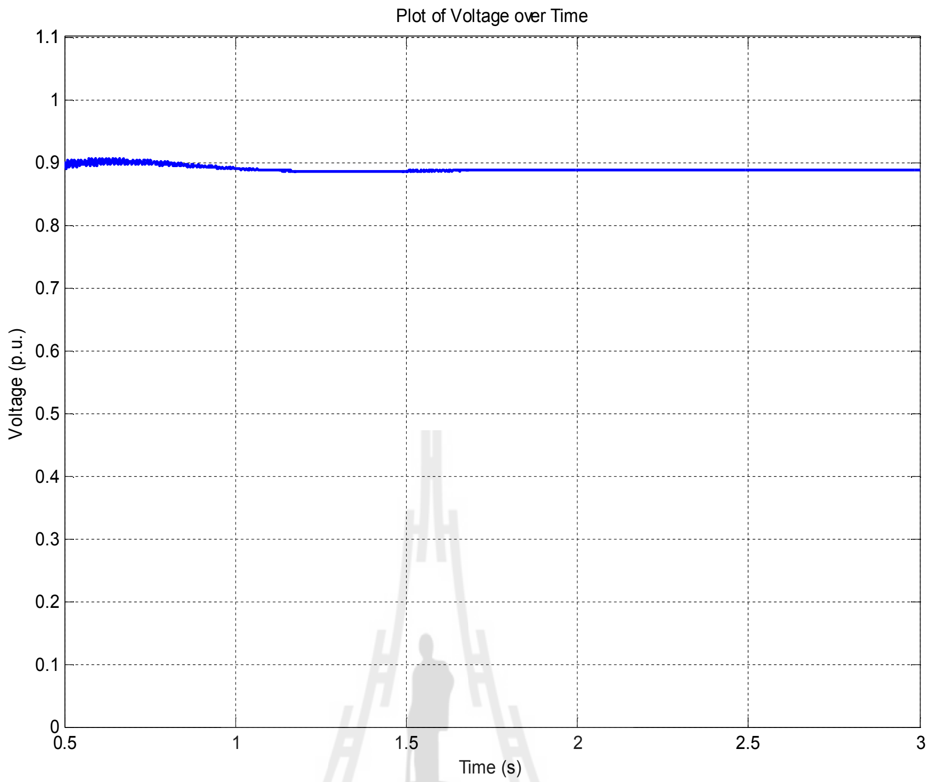


Figure 6.12 Voltage of the system due to loss of two lines.

- Loss of two lines causes the voltage to decrease below its rated value before load shedding application.

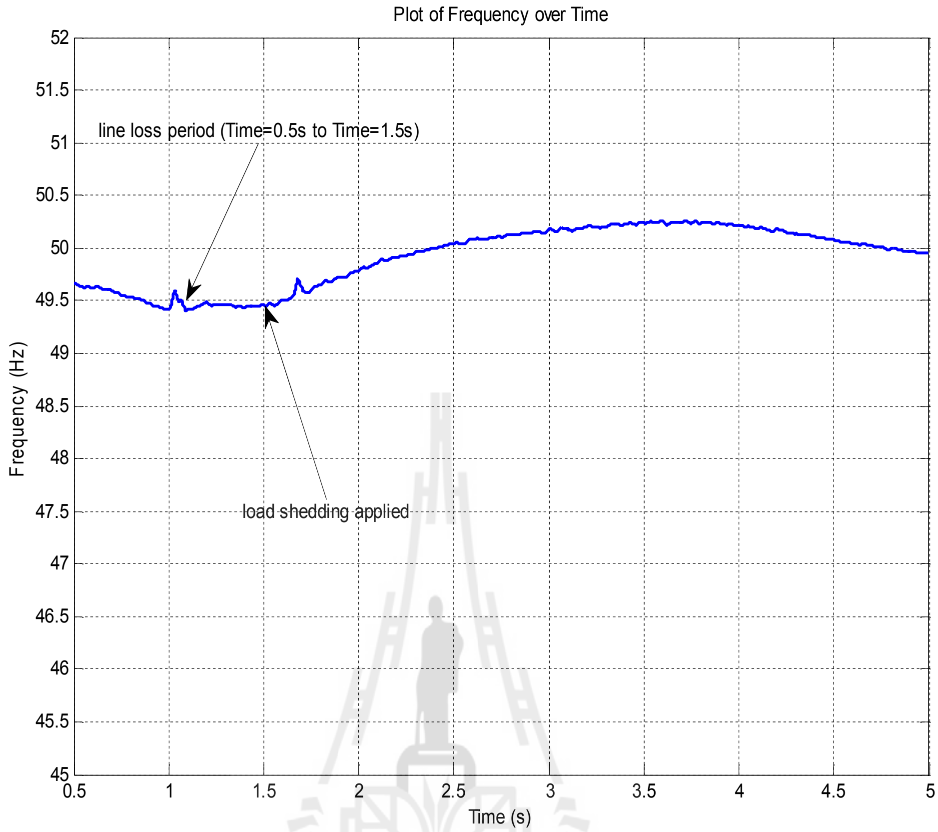


Figure 6.13 Frequency before and after load shedding by Conventional scheme.

- Loss of two lines caused frequency to decline below minimum value. It remaned at that low value until when load shedding was applied at Time = 1.5s which restored it to close to its rated value of 50 Hz at Time = 5s.

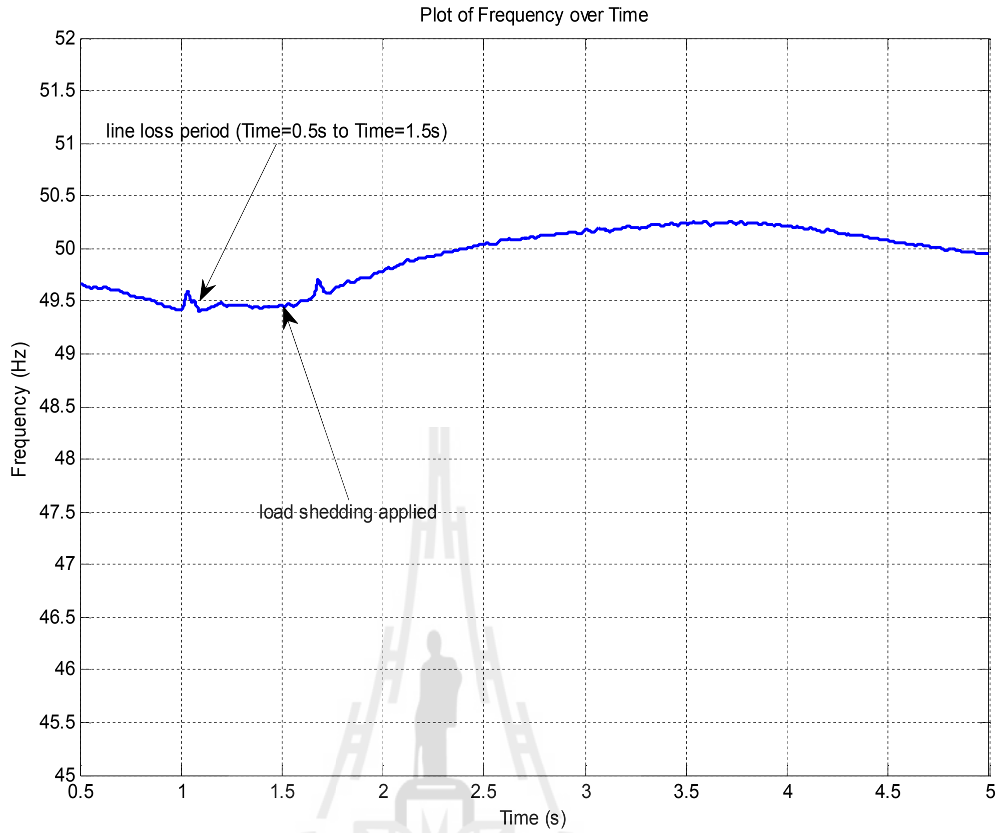


Figure 6.14 Frequency before and after applying Load shedding scheme based on reactive power demand and priority.

- Loss of two lines caused frequency to decline below 47.5 Hz. At Time = 1.5s load shedding was applied which restored it to close to its rated value of 50 Hz at Time = 5s.

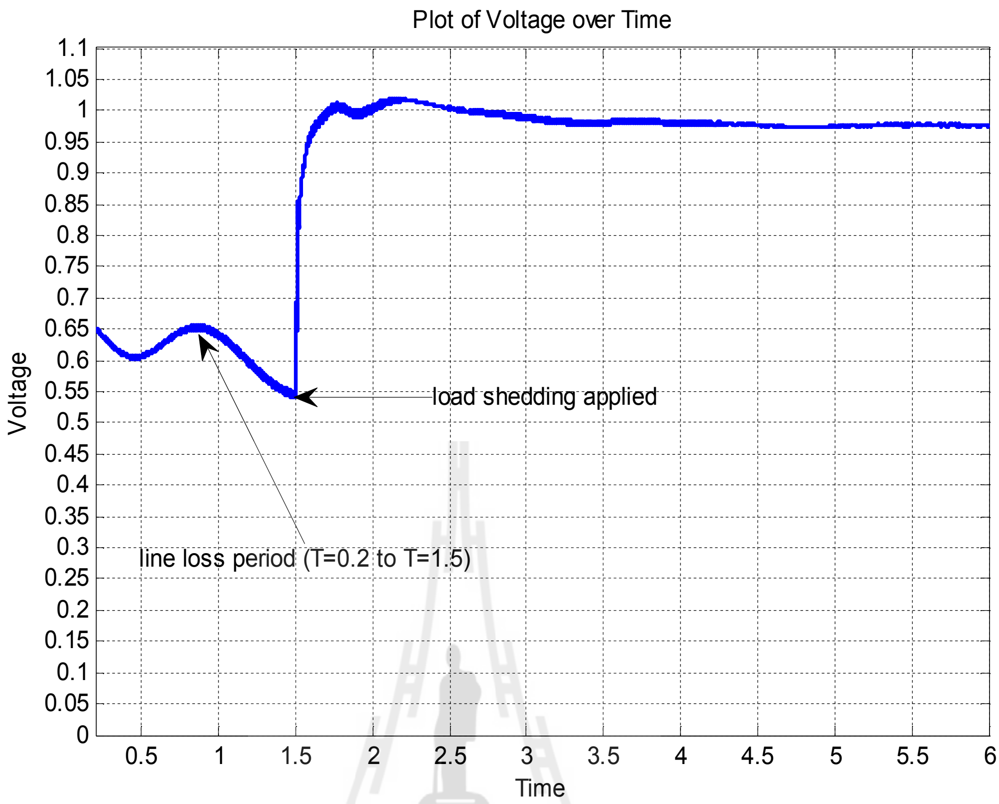


Figure 6.15 Voltage before and after load shedding by Conventional scheme.

- Loss of two lines caused the voltage to drop below its rated value and remained at that small value until load shedding was applied at Time = 1.5s. This actioned increased the voltage up to 0.975 p.u. and stabilized it.

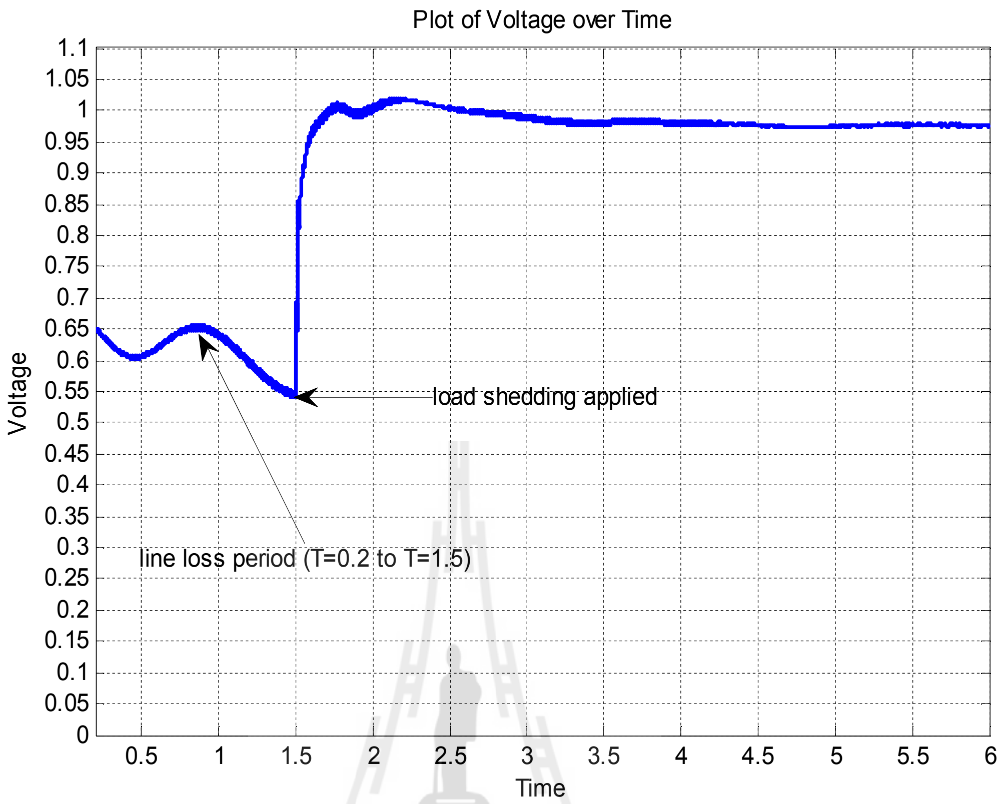


Figure 6.16 Voltage before and after applying Load shedding scheme based on reactive power demand and priority.

- Loss of two lines caused the voltage to drop below its rated value and remained at that small value until load shedding was applied at Time = 1.5s. This actioned increased the voltage up to 0.975 p.u. and stabilized it.

6.3 IEEE 14 bus system

Table 6.5 Active and reactive power demands of loads and their priorities.

Bus number	Activepower demand (MW)	Reactive power demand (MVar)	Priority of loads
2	21.7	12.7	1
3	94.2	19	2
4	47.8	-3.9	3
5	7.6	1.6	5
6	11.2	7.5	10
9	29.5	16.6	11
10	9	5.8	8
11	3.5	1.8	6
12	6.1	1.6	4
13	13.5	5.8	9
14	14.9	5	7
Total	**259**	**73.5**	

Where priority loads are:

- Load bus number 3 - Large industrial facility.
- Load bus number 2 - Hospital.

Load with priority 1 has high priority and load with priority 11 has lowest priority in the system. The scheme shed loads starting with those having high reactive power demand and low priority in descending order.

Table 6.6 Generator bus numbers and their output power.

Bus number	Output power (MW)	Output power (MVar)
1	232.4	-16.9
2	40	42.4
3	0	23.4
6	0	12.2
8	0	17.4
Total	**272.4**	**78.5**

6.3.1 Loss of two generators

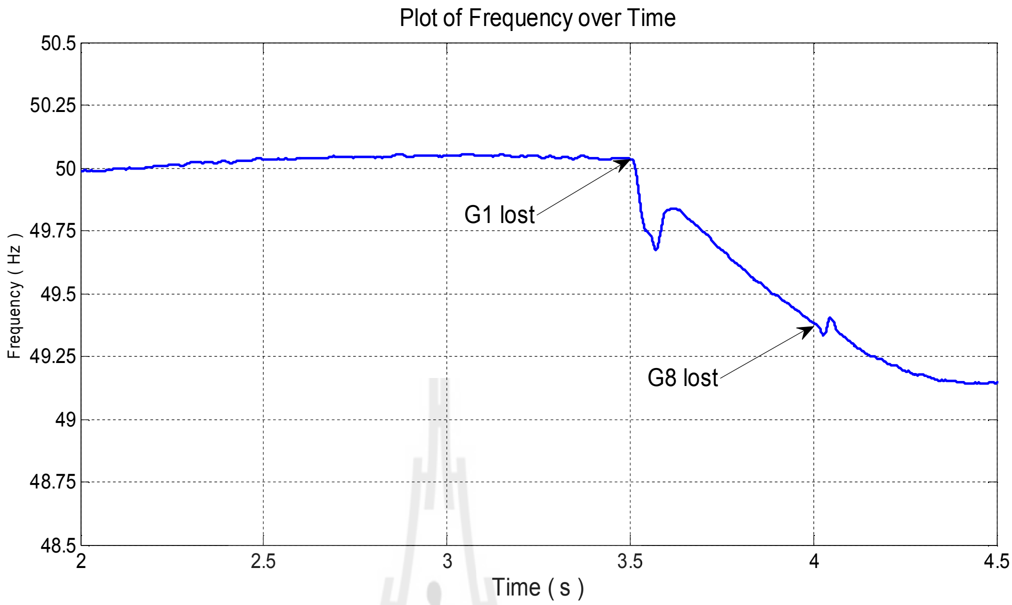


Figure 6.17 Frequency when two generators were lost before load shedding.

- Generators' loss causes the frequency to decline below its rated value of 50 Hz. The first generator was lost at Time = 3.5s. Then, another generator was lost at Time = 4s which further increased frequency instability and finally dropped below 49.55 Hz and stayed within that value up to the end of the simulation at Time = 4.5s. Thus it became necessary to restore the frequency of the system.

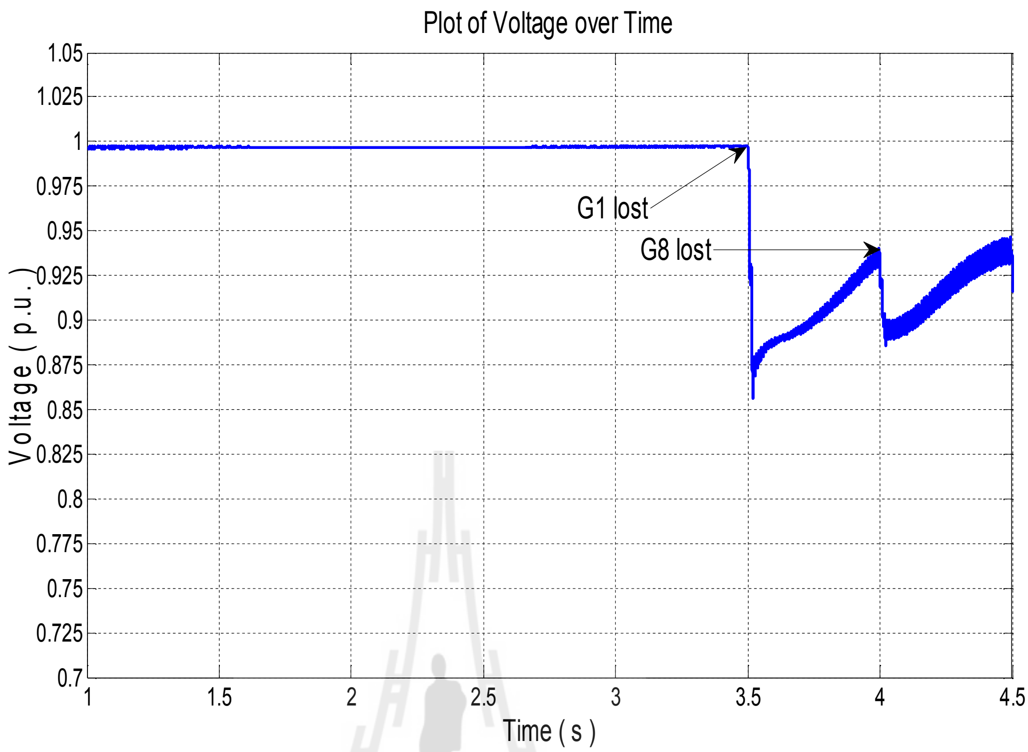


Figure 6.18 Voltage when two generators were lost before load shedding.

- The voltages were also affected by the loss in the generated power. The first generator was lost at Time=3.5s causing the voltage to drop to near 0.85 p.u and increased with some fluctuations before loss of another generator at Time=4s which further decreased the voltage to below 0.9 p.u. and increased again with more fluctuations up to Time=4.5 p.u.

Table 6.7 Loads shed by Convensional scheme and Scheme based on reactive power demand and priority.

Loads shed by Convensional scheme			Loads shed Scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	MVar shed
4	47.8	-3.9	9	29.5	16.6
5	7.6	1.6	6	11.2	7.5
6	11.2	7.5	13	13.5	5.8

Table 6.8 Data of load shedding using Conventional scheme and Scheme based on reactive power demand and priority for IEEE 14-bus.

Disturbance	Time	MW lost	System state	Loads shed by Conventional scheme (No. of loads shed)	Loads shed by scheme based on reactive power demand and priority (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G1 and G8	T=3.5 T=4	232.4	Poor	3	3	0

Table 6.9 Loads shed by Scheme based on reactive power demand and Scheme based on reactive power demand and priority.

Loads shed by Scheme based on reactive power demand			Loads shed by Scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	MVar shed
3	94.2	19	9	29.5	16.6
9	29.5	16.6	6	11.2	7.5
			13	13.5	5.8

Table 6.10 Data about load shedding using Scheme based on reactive power demand and Scheme based on reactive power demand and priority for IEEE 14-bus.

Disturbance	Time	MW lost	System state	Loads shed by scheme based on reactive power demand and priority (No. of loads shed)	Loads shed by scheme based on reactive power demand (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G1 and G8	T=3.5 T=4	232.4	Poor	3	2	1

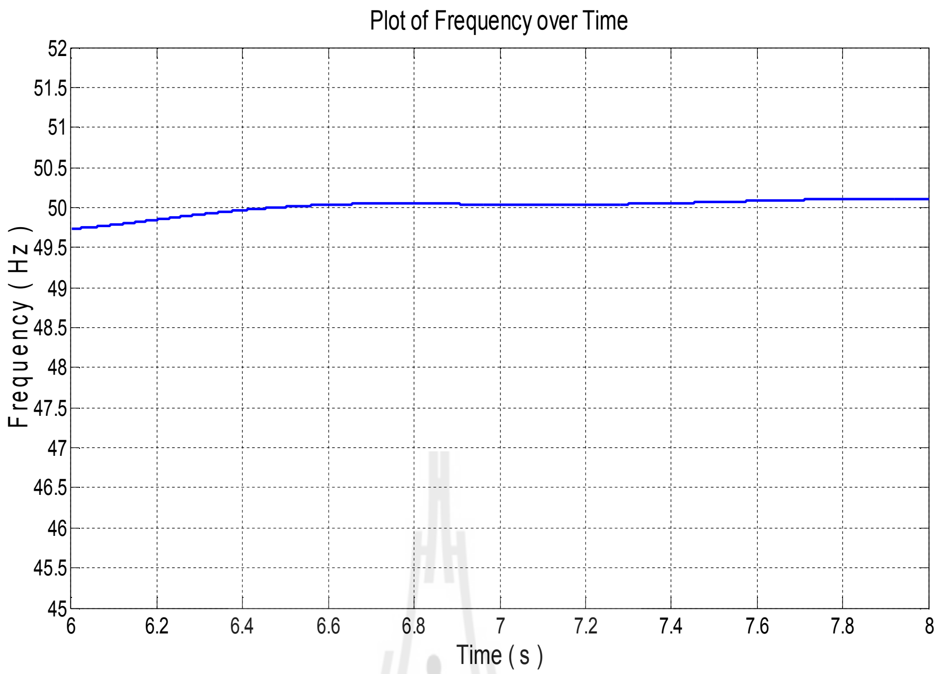


Figure 6.19 Frequency after load shedding by Conventional scheme.

- Frequency of the system after load shedding when three loads were shed to restore balance in the system.

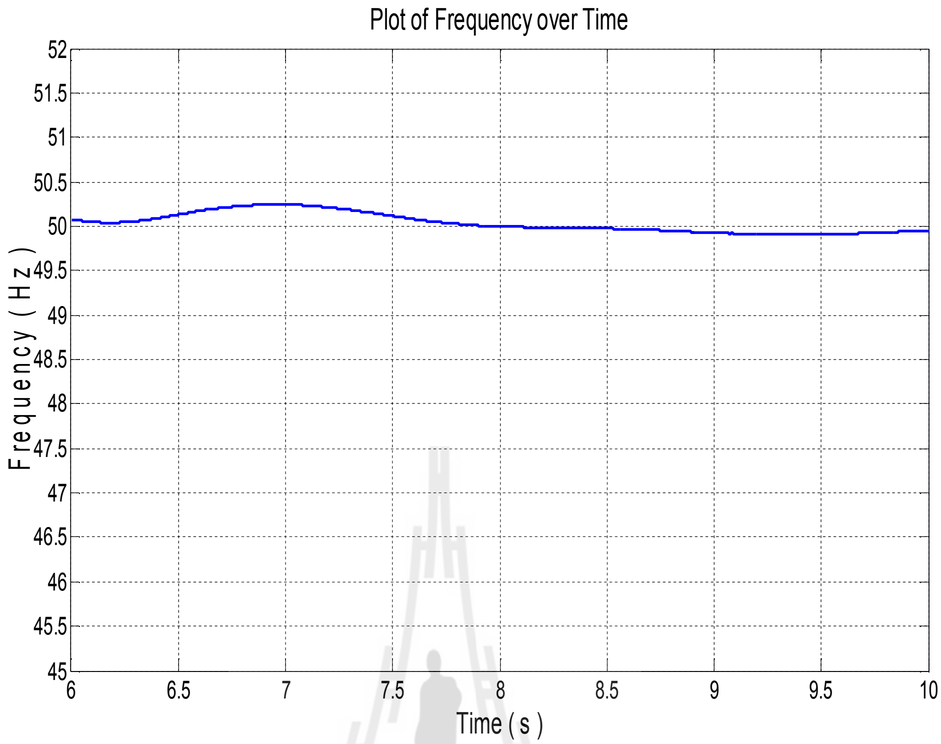


Figure 6.20 Frequency after load shedding by Scheme based on reactive power demand.

- Frequency of the system after load shedding when three loads were shed to restore balance in the system.

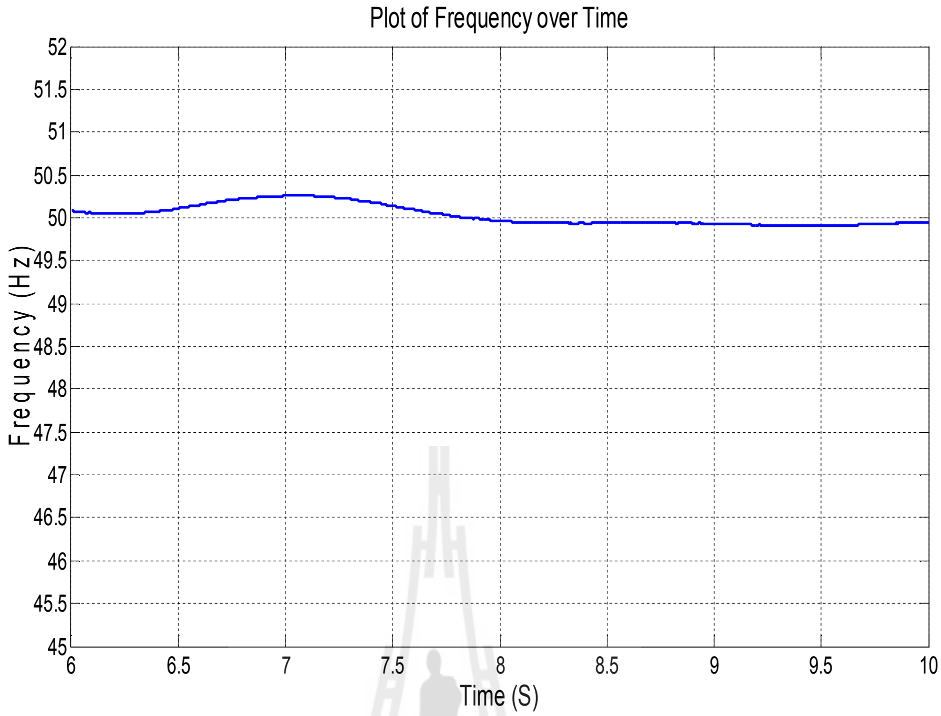


Figure 6.21 Frequency after applying Load shedding scheme based on reactive power demand and priority.

- Frequency of the system after load shedding when three loads were shed to restore balance in the system.

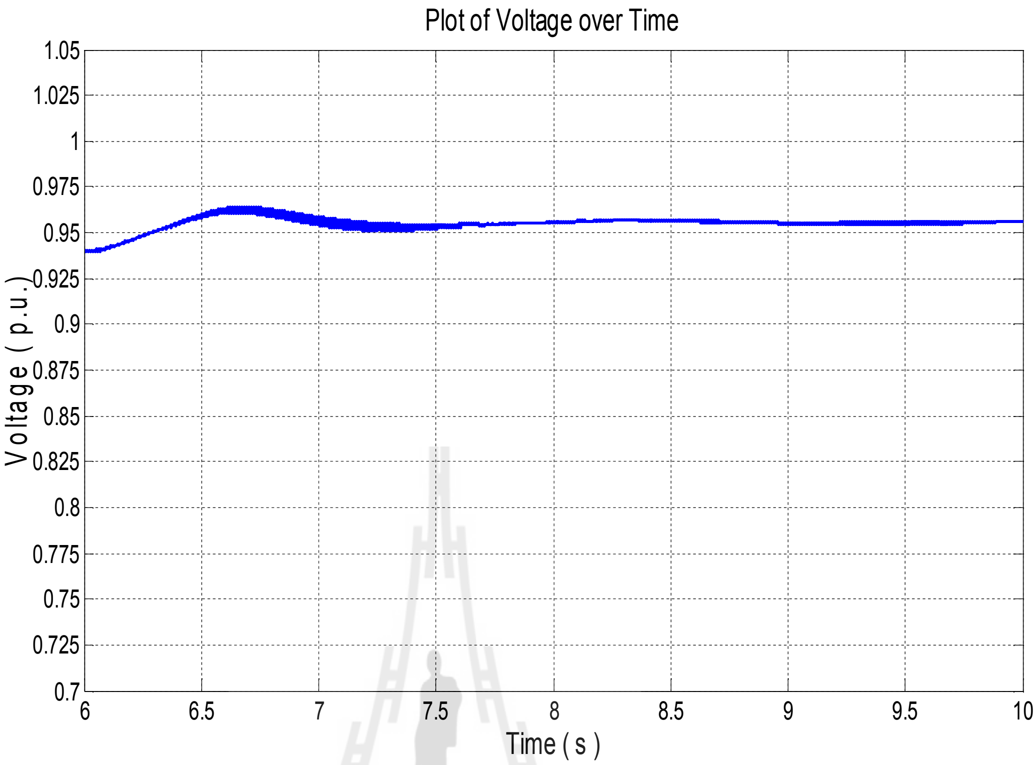


Figure 6.22 Voltage after load shedding by Conventional scheme.

- Voltage improvement after load shedding. The scheme shed three loads regardless of the reactive power demands of the loads.

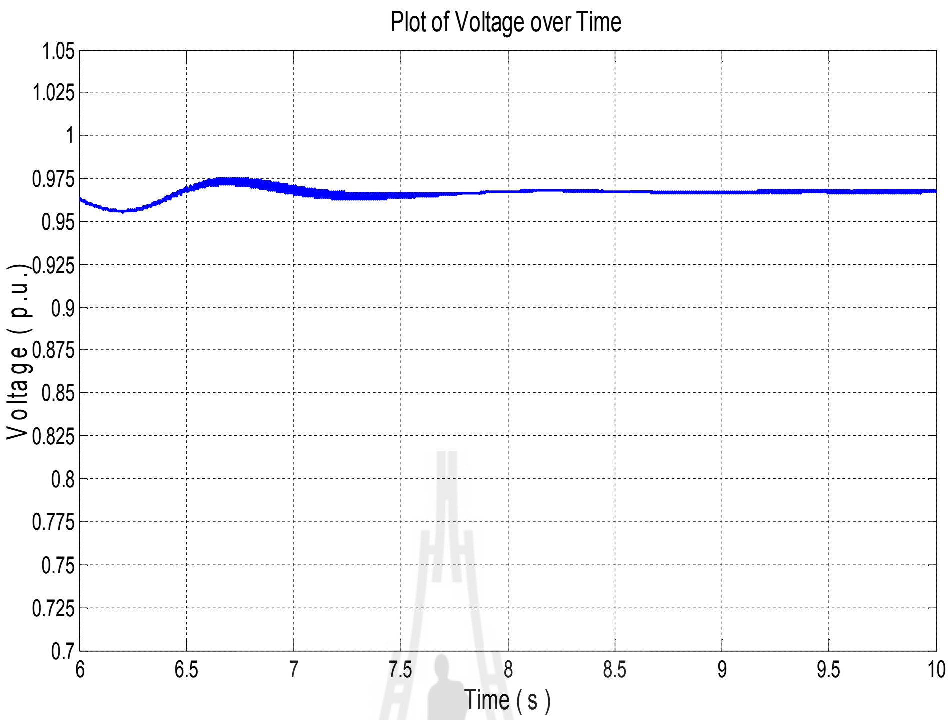


Figure 6.23 Voltage after load shedding by Scheme based on reactive power demand.

- Voltage improvement after load shedding. The scheme shed three loads regardless of the reactive power demands of the loads.

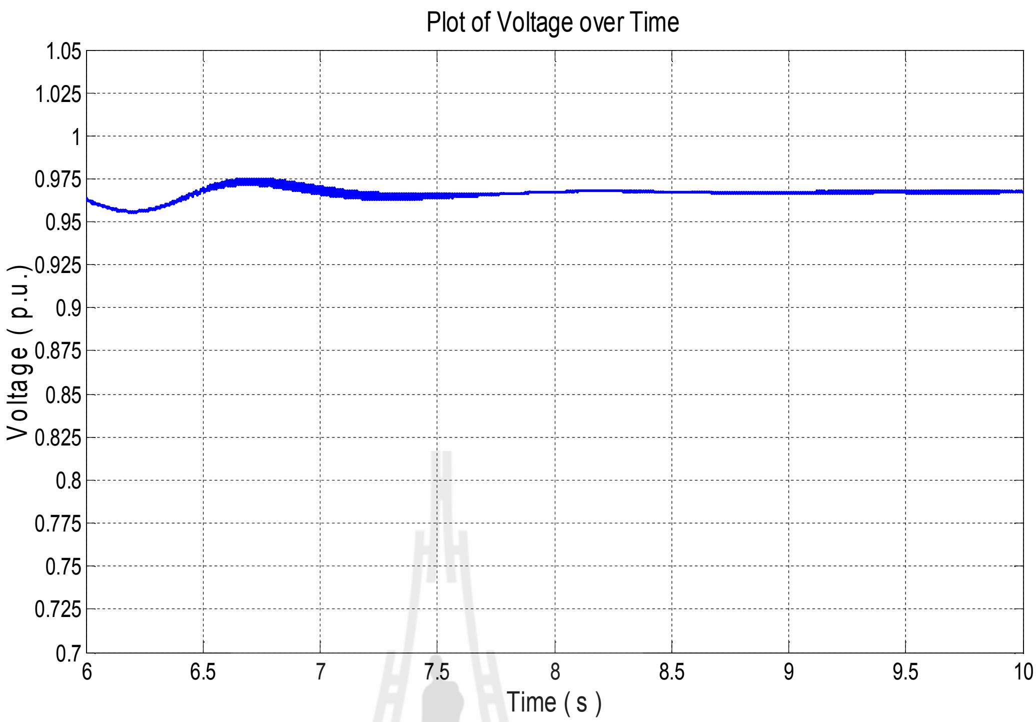


Figure 6.24 Voltage after applying Load shedding scheme based on reactive power demand and priority.

- Voltage improvement after load shedding. The scheme shed three loads based on the reactive power demands of the loads.

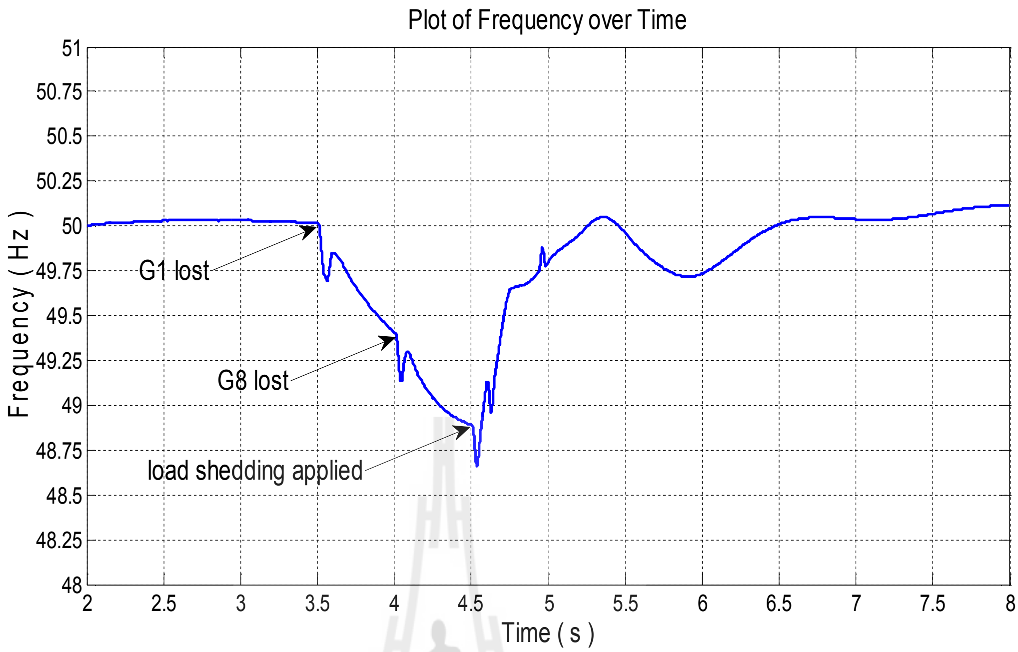


Figure 6.25 Frequency before and after load shedding by Conventional scheme.

- Initially the frequency was within 50 Hz. It remained at that rated value up to Time = 3.5 p.u. when occurred the loss of the first generator which caused frequency to drop to below 49.5 Hz . Another generator loss occurred at Time = 4s. This further decreased system frequency to below 49 Hz at Time=4.5s when load shedding was applied which improved system frequency to near its rated value of 50 Hz at Time = 8s.

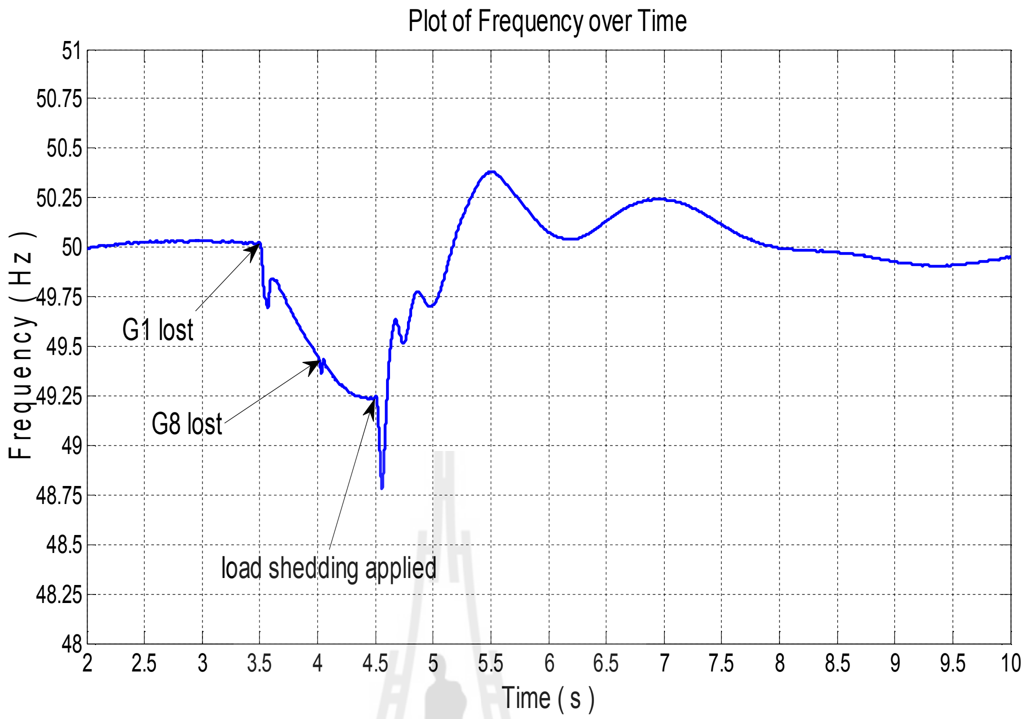


Figure 6.26 Frequency before and after load shedding by Scheme based on reactive power demand.

- Initially the frequency was within 50 Hz. It remained at that rated value up to Time = 3.5 p.u. when occurred the loss of the first generator which caused frequency to drop to below 49.5 Hz . Another generator loss occurred at Time = 4s. This further decreased system frequency to below 49 Hz at Time=4.5s when load shedding was applied which improved system frequency to near its rated value of 50 Hz at Time = 10s.

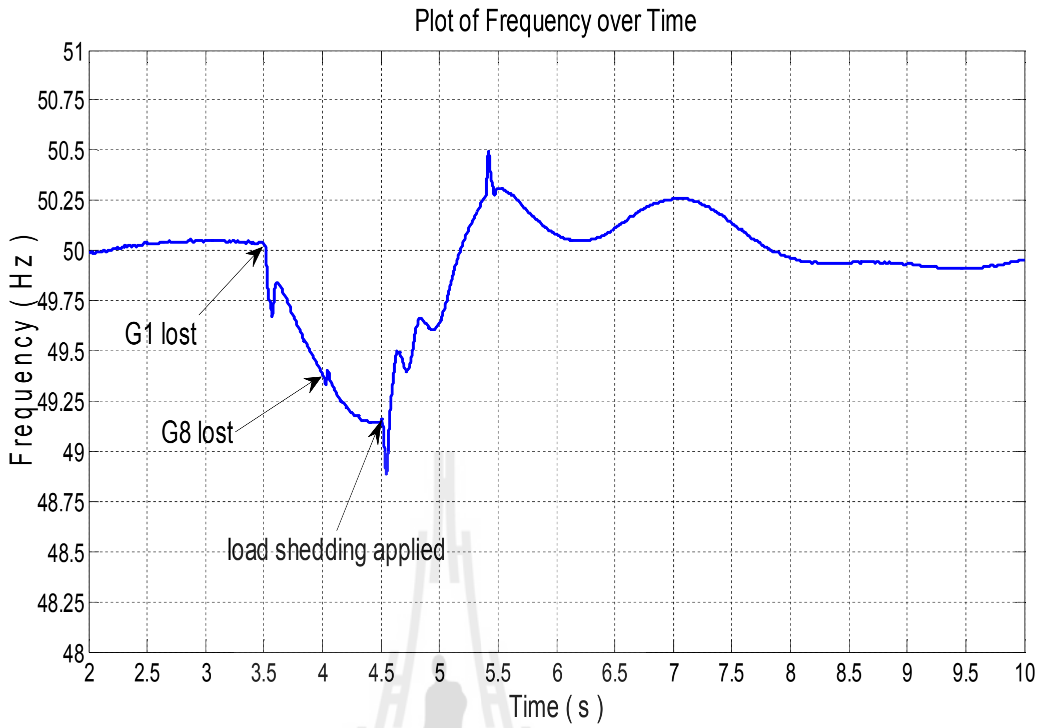


Figure 6.27 Frequency before and after load shedding by Scheme based on reactive power demand and priority.

- Initially the frequency was within 50 Hz. It remained at that rated value up to Time = 3.5 p.u. when occurred the loss of the first generator which caused frequency to drop to below 49.5 Hz . Another generator loss occurred at Time = 4s. This further decreased system frequency to below 49 Hz at Time=4.5s when load shedding was applied which improved system frequency to near its rated value of 50 Hz at Time = 10s.

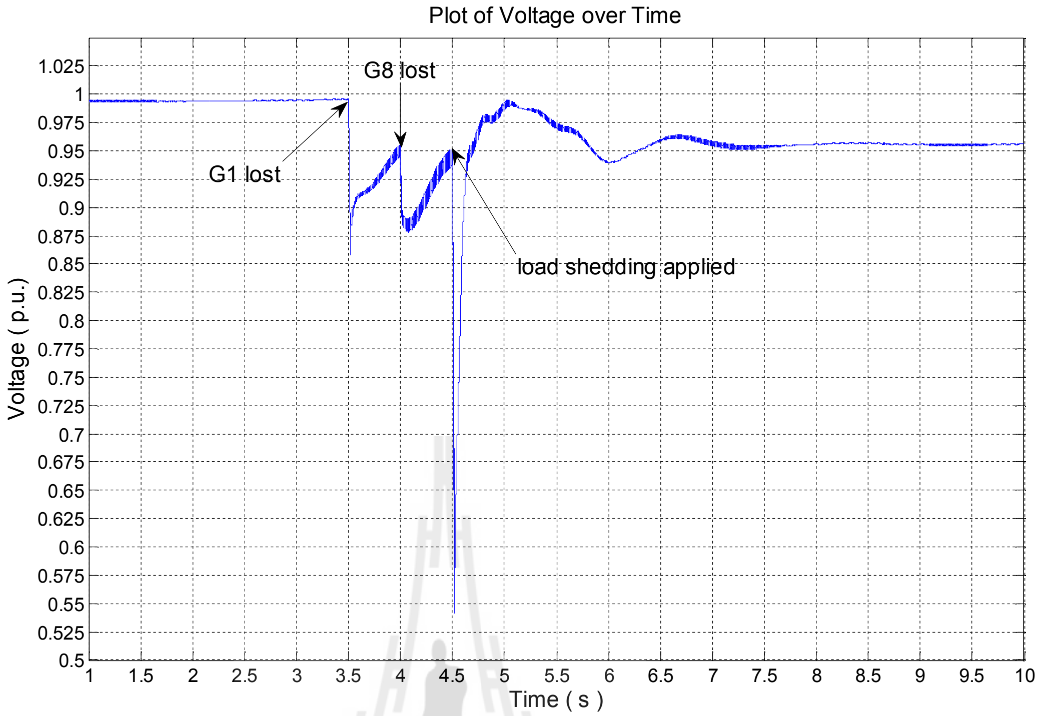


Figure 6.28 Voltage before and after load shedding by Conventional scheme.

- Initially the voltage was near rated value of 1 p.u. It remained on that constant value until at Time= 3.5s when occurred the loss of the first generator which decreased the voltage to near 0.85 p.u. It increased again to just above 0.95 p.u. at Time= 4s. At this time ocurred the loss of another generator which further decreased the voltage to near 0.875 p.u. and then increased again to 0.95 p.u but with high fluctuations at Time = 4.5s when load shedding was applied which increased the voltage to just above 0.95 p.u. at Time=7.5s and from there remained stable up to the end of the simulation.

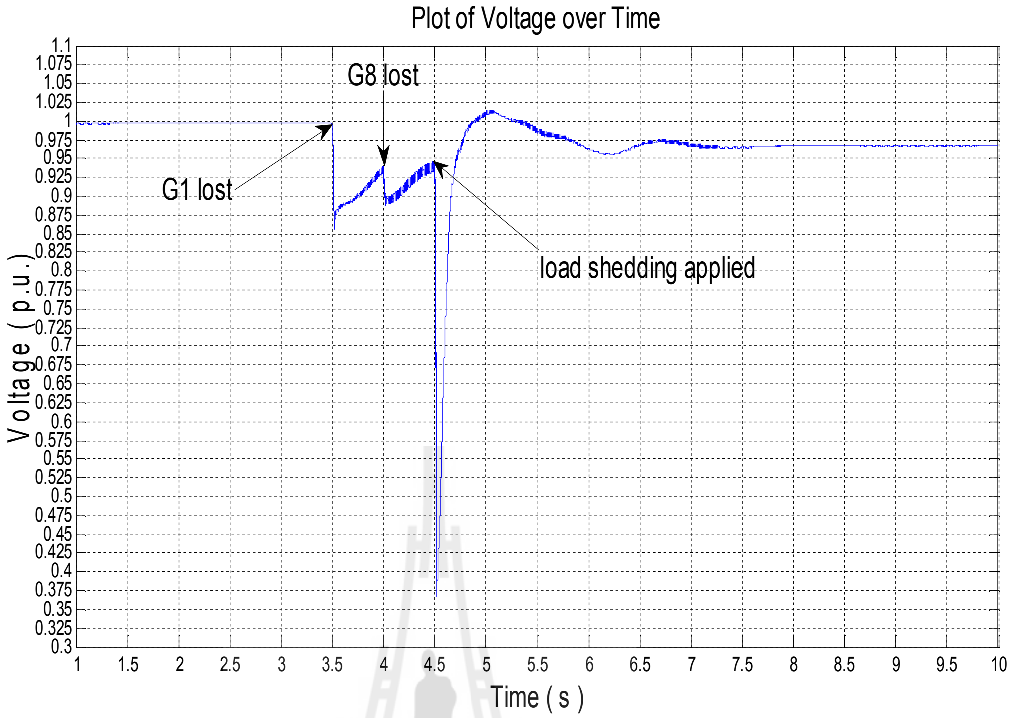


Figure 6.29 Voltage before and after load shedding by Scheme based on reactive power demand.

- Initially the voltage was near rated value of 1 p.u. It remained on that constant value until at Time= 3.5s when occurred the loss of the first generator which decreased the voltage to near 0.85 p.u. It increased again to just above 0.95 p.u. at Time= 4s. At this time ocurred the loss of another generator which further decreased the voltage to near 0.875 p.u. and then increased again to 0.95 p.u but with high fluctuations at Time = 4.5s when load shedding was applied which increased the voltage to near 0.975 p.u. at Time=7.5s and remained at that value up to the end of simulation.

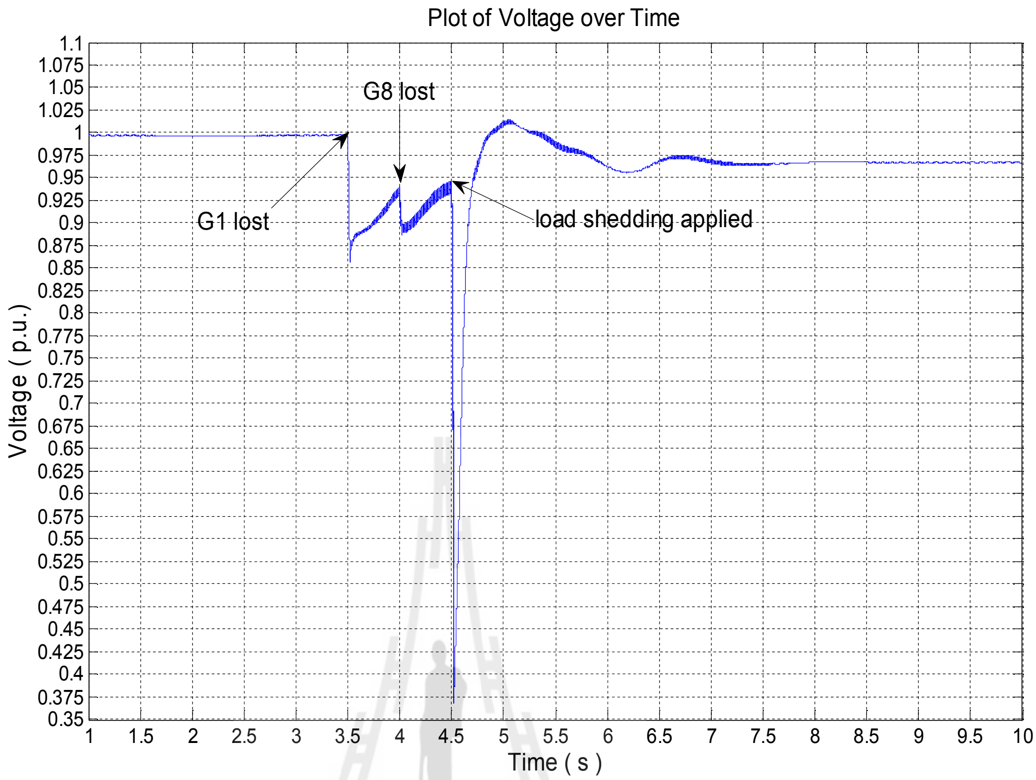


Figure 6.30 Voltage before and after load shedding by Scheme based on reactive power demand and priority.

- Initially the voltage was near rated value of 1 p.u. It remained on that constant value until at Time= 3.5s when occurred the loss of the first generator which decreased the voltage to near 0.85 p.u. It increased again to just above 0.95 p.u. at Time= 4s. At this time ocurred the loss of another generator which further decreased the voltage to near 0.875 p.u. and then increased again to 0.95 p.u but with high fluctuations at Time = 4.5s when load shedding was applied which increased the voltage to loss of another generator which further decreased the voltage to near 0.975 p.u. at Tme=7.5s.

6.3.2 Load shedding using Harmony Search algorithm to compute optimal load to shed for IEEE 14-bus

Table 6.11 Active and reactive power shed from different buses.

Bus number	Active power demand (MW) shed	Reactive power demand (MVar) shed	Priority of loads
2	0	0	1
3	0	0	2
4	35.2666	3.4069	3
5	6.4622	0.4482	5
6	5.3015	4.4235	10
9	26.2202	14.7067	11
10	7.5944	5.0189	8
11	1.7561	1.2801	6
12	4.6177	1.1643	4
13	6.241	1.0467	9
14	14.4532	1.0874	7

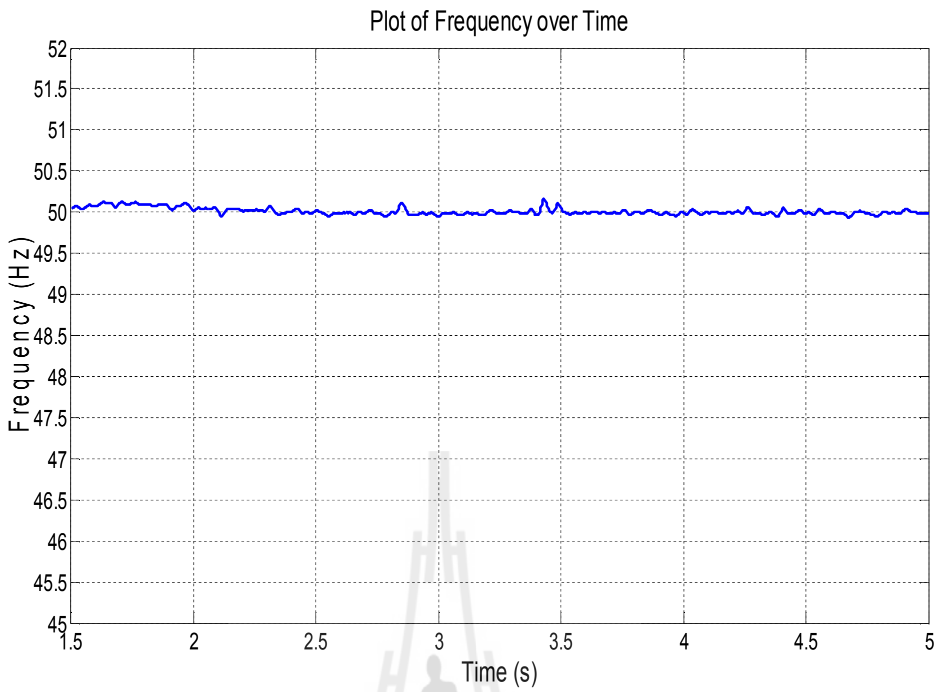


Figure 6.31 Frequency after load shedding by Harmony Search scheme.

- The frequency improves to the rated value of 50 Hz after the application of load shedding. Harmony Search algorithm was used to find optimal amount of load to shed.

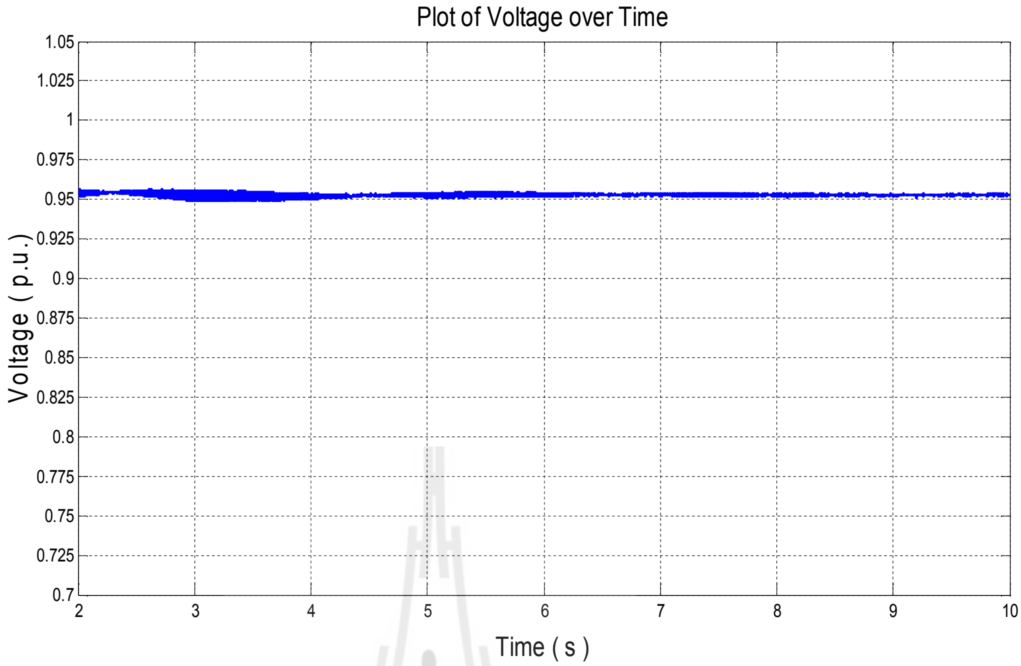


Figure 6.32 Voltage after load shedding by Harmony Search scheme.

- Voltage improves to about 0.95p.u. from its unstable condition after the application of load shedding. Its plot is a smooth sketch showing that it is very stable. Harmony Search algorithm was used to find optimal load to shed from the system to improve it.

6.3.3 Loss of two lines

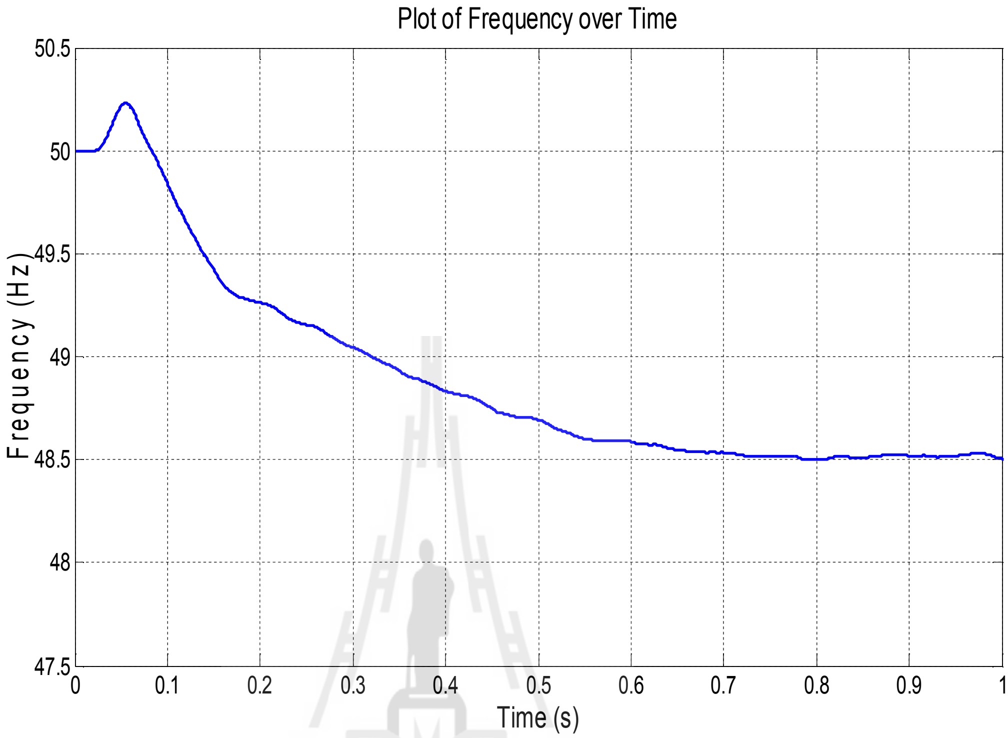


Figure 6.33 Frequency of the system before load shedding.

- Loss of two lines caused the frequency to decline below its rated value of 50Hz without load shedding application. Thus, it became necessary to improve the frequency of the system.

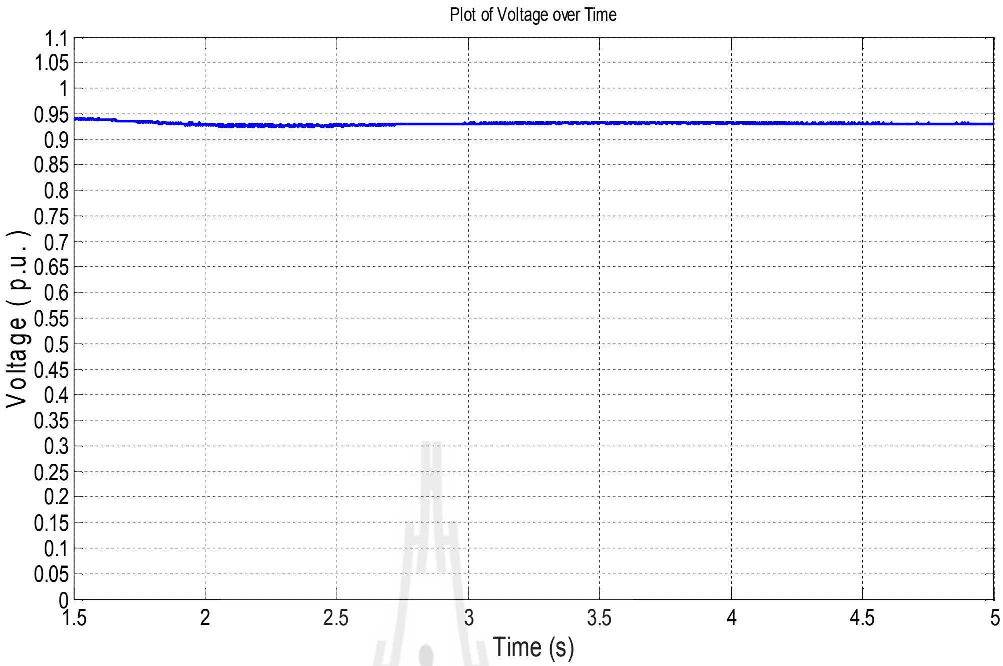


Figure 6.34 Voltage before load shedding.

- Loss of two lines causes the voltage to decrease below its rated value without load shedding application.

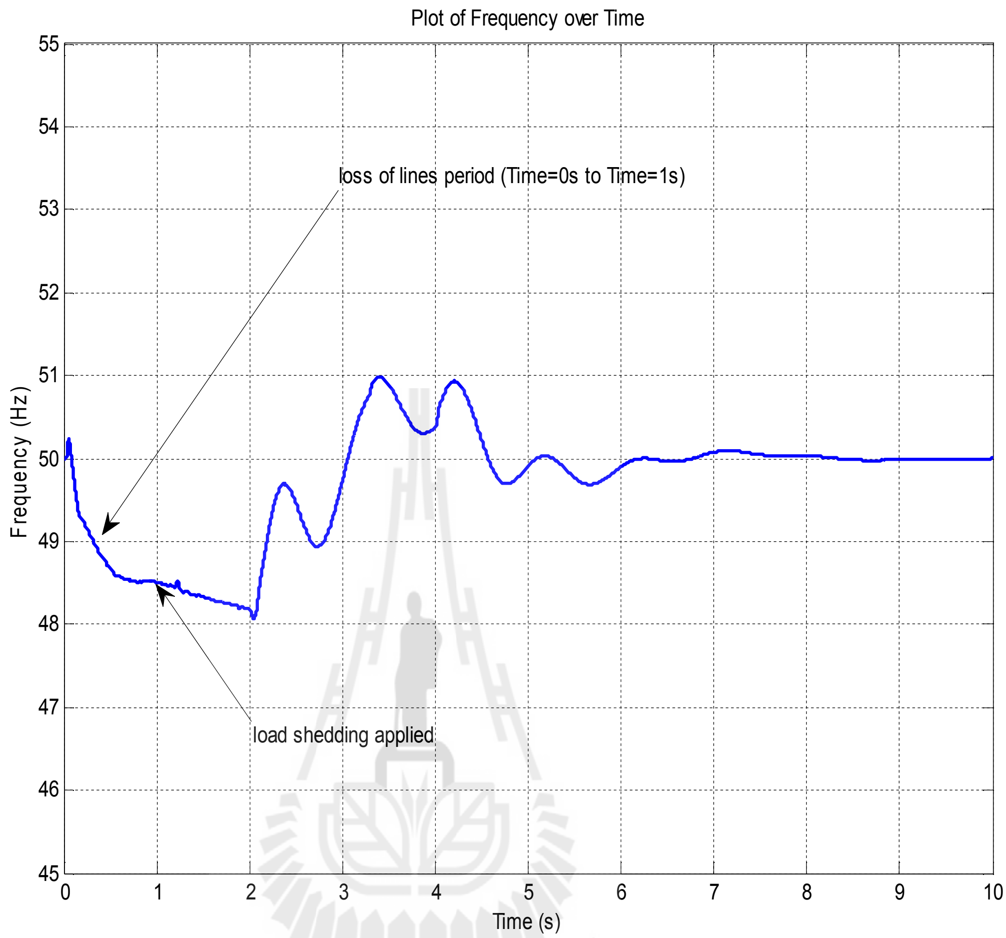


Figure 6.35 Frequency before and after load shedding by Conventional scheme.

- Loss of two lines caused frequency to decline near 47 Hz. At Time = 1s load shedding was applied which restored it to within its rated value of 50 Hz at Time = 6s.

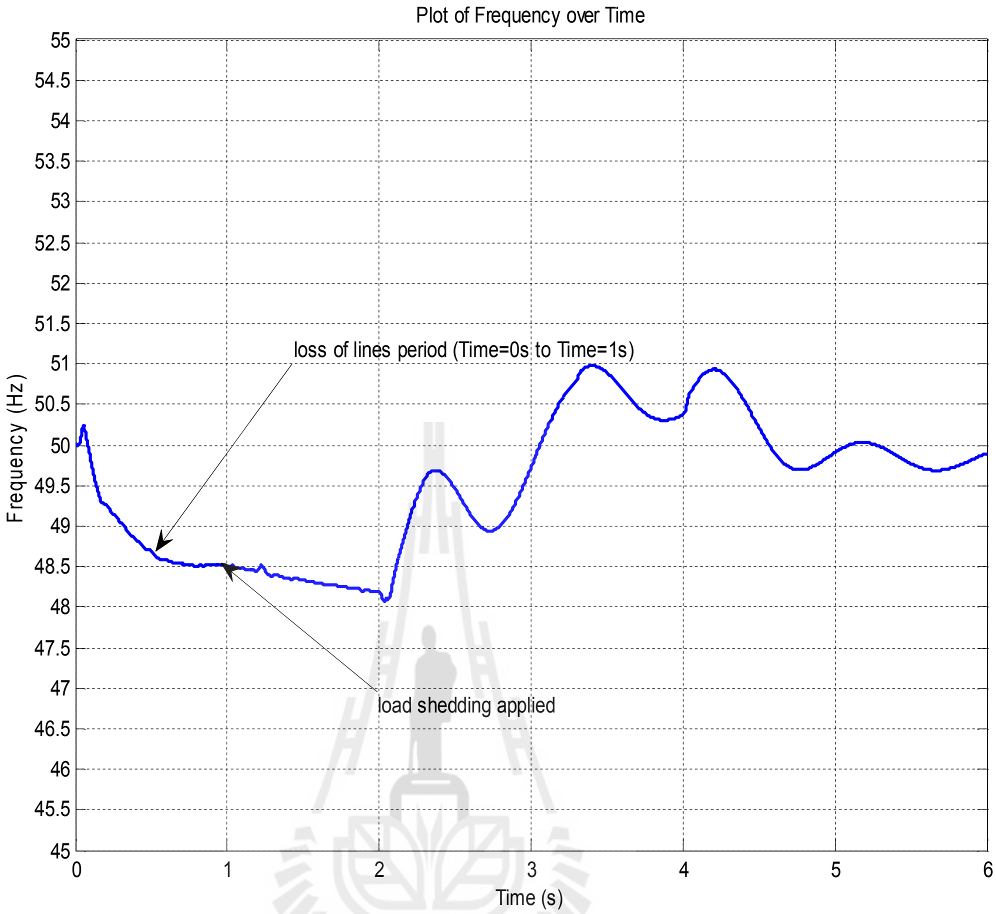


Figure 6.36 Frequency before and after applying Load shedding scheme based on reactive power demand and priority.

- Loss of two lines caused frequency to decline near 48 Hz. At Time = 1s load shedding was applied which restored it to within its rated value of 50 Hz at Time = 6s.

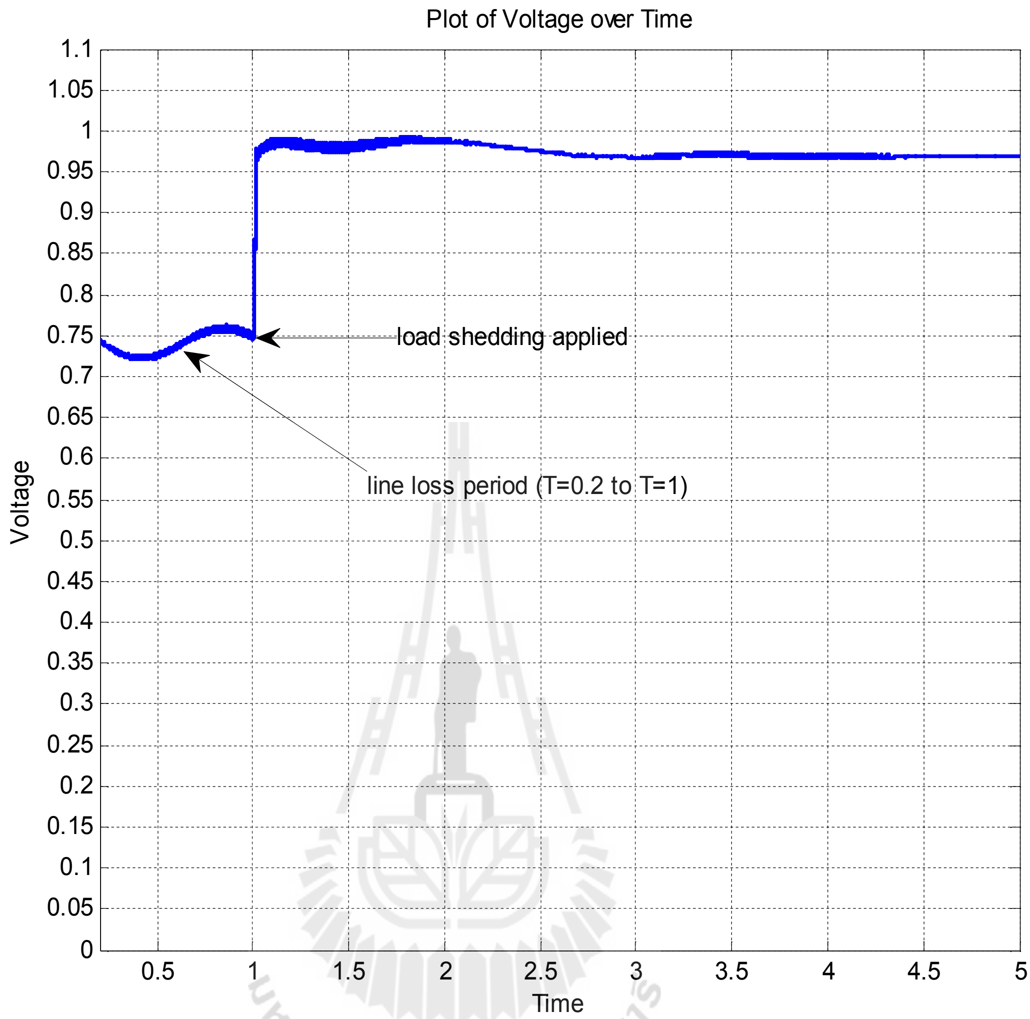


Figure 6.37 Voltage before and after load shedding by Conventional scheme.

- Loss of two lines caused the voltage to drop below its rated with fluctuations until load shedding was applied at Time = 1s. This actione increased the voltage up to 0.966 p.u. and lowered fluctuations at Time= 5s.

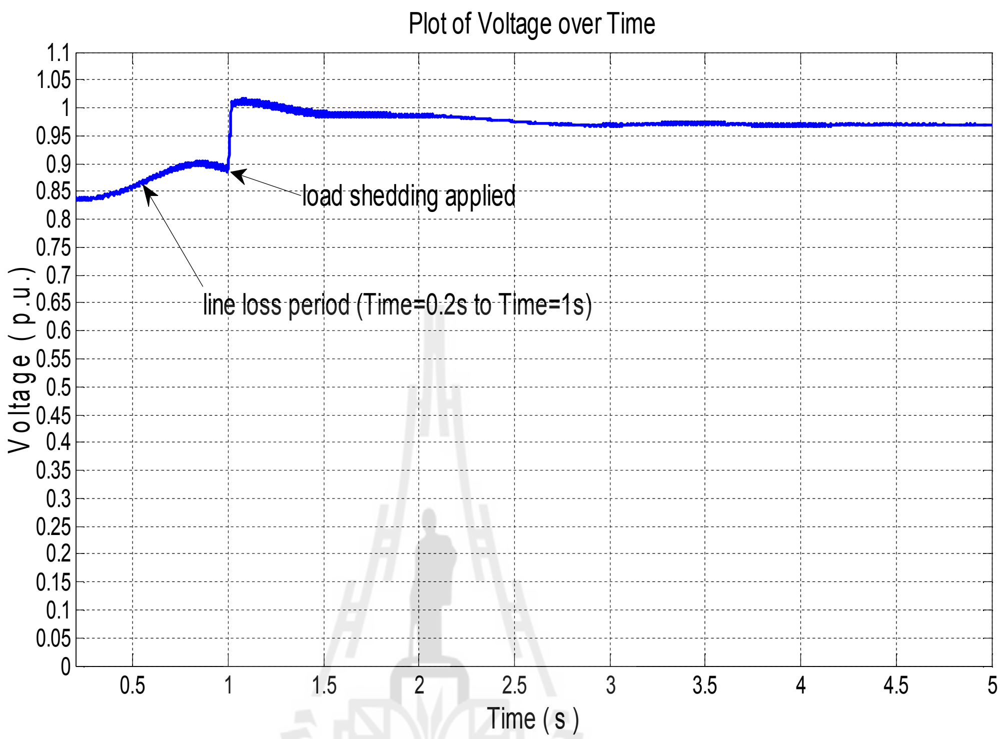


Figure 6.38 Voltage before and after applying Load shedding scheme based On reactive power demand and priority.

- Loss of two lines caused the voltage to drop below its rated value with fluctuations until load shedding was applied at Time = 1s. This actione increased the voltage up to 0.97 p.u. and lowered fluctuations at Time=5s.

6.4 IEEE 30 bus system

Table 6.12 Active and reactive power demands of loads and their priorities

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
2	21.7	12.7	1
3	2.4	1.2	8
4	7.6	1.6	11
5	94.2	19	21
7	22.8	10.9	2
8	30	30	4
10	5.8	2	14
12	11.2	7.5	19
14	6.2	1.6	10
15	8.2	2.5	3
16	3.5	1.8	12
17	9	5.8	17
18	3.2	0.9	7
19	9.5	3.4	16
20	2.2	0.7	5
21	17.5	11.2	20
23	3.2	1.6	9
24	8.7	6.7	18
26	3.5	2.3	15
29	2.4	0.9	6
30	10.6	1.9	13
Total	**283.4**	**126.2**	

Where priority loads are:

Load bus number 8 - Large industrial facility.

Load bus number 2 - Hospital.

Load bus number 7 - Prime minister residence.

Load bus number 15 - Military complex.

Load with priority 1 has highest priority while load with priority 21 has the lowest priority. The scheme shed loads starting with those having high reactive power demand and low priority in descending order.

Table 6.13 Output power of generators at different buses

Bus number	Output power (MW)	Output power (MVar)
1	260.2	-16.1
2	40	50
5	0	37
8	0	37.3
11	0	16.2
13	0	10.6
Total	**300.2**	**135**

6.4.1 Loss of two generators

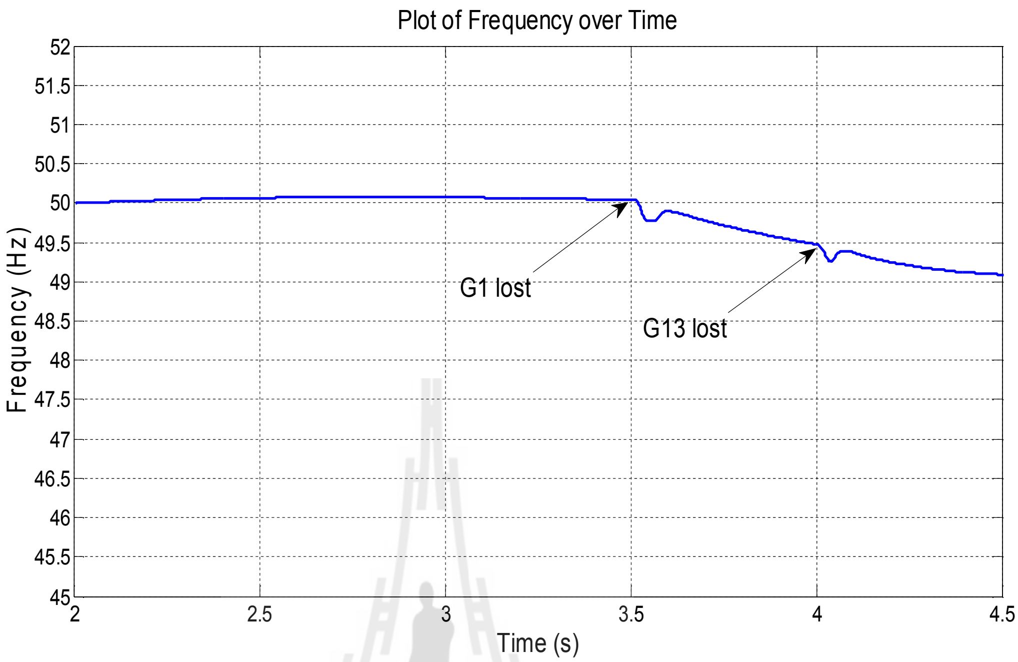


Figure 6.39 Frequency plot with loss of two generators.

- The first generator loss at Time=3.5s caused the frequency to decline below its rated value of 50 Hz with fluctuations. Then, another generator was at Time= 4s which further decreased frequency to near 49 Hz at Time = 4.5s.

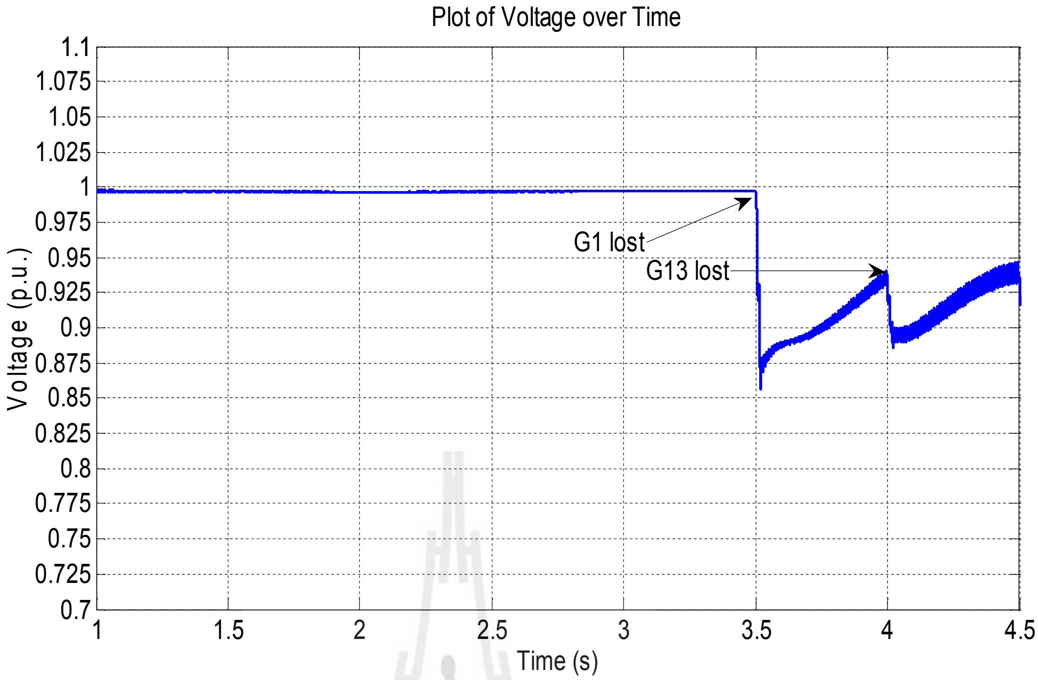


Figure 6.40 Voltage plot when two generators were lost in IEEE 30-bus.

- Besides the frequency, the voltages were also affected by a loss of the generated power. This can be seen on the plot above before the application of load shedding. The voltage was within its rated value of 1 p.u. before the loss of the first generator at Time = 3.5s which decreased it to near 0.85 p.u. It increased to above 0.925 p.u. at Time = 4s when a second generator was lost which caused more fluctuation of voltage and drop to just below 0.95 p.u. at Time = 4.5s.

Table 6.14 Loads shed by Convensional scheme and Scheme based on reactive power demand and priority.

Loads shed by Convensional scheme			Loads shed Scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	MVar shed
3	2.4	1.2	21	17.5	11.2
4	7.6	1.6	12	11.2	7.5
10	5.8	2	24	8.7	6.7
12	11.2	7.5			
14	6.2	1.6			
16	3.5	1.8			

Table 6.15 Load shedding test conditions using Conventional scheme and Load shedding scheme based on reactive power demand and priority for IEEE 30-bus.

Disturbance	Time	MW lost	System state	Loads shed by conventional scheme	Loads shed by scheme based on reactive power demand and priority	Prevention of unnecessary shedding
Outage of G1 & G13	T=3.5, T=4	260.2	Poor	6	3	0

Table 6.16 Loads shed by Load shedding scheme based on reactive power demand and Scheme based on reactive power demand and priority.

Loads shed by Scheme based on reactive power demand			Loads shed by Scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	MVar shed
8	30	30	21	17.5	11.2
5	94.2	19	12	11.2	7.5
			24	8.7	6.7

Table 6.17 Load shedding test conditions using Load shedding scheme based on reactive power demand and Load shedding scheme based on reactive power demand and priority for IEEE 30-bus.

Disturbance	Time	MW lost	System state	Loads shed by scheme based on reactive power demand and priority	Loads shed by scheme based on reactive power demand	Prevention of unnecessary shedding
Outage of G1 & G13	T=3.5, T=4	260.2	Poor	3	2	1

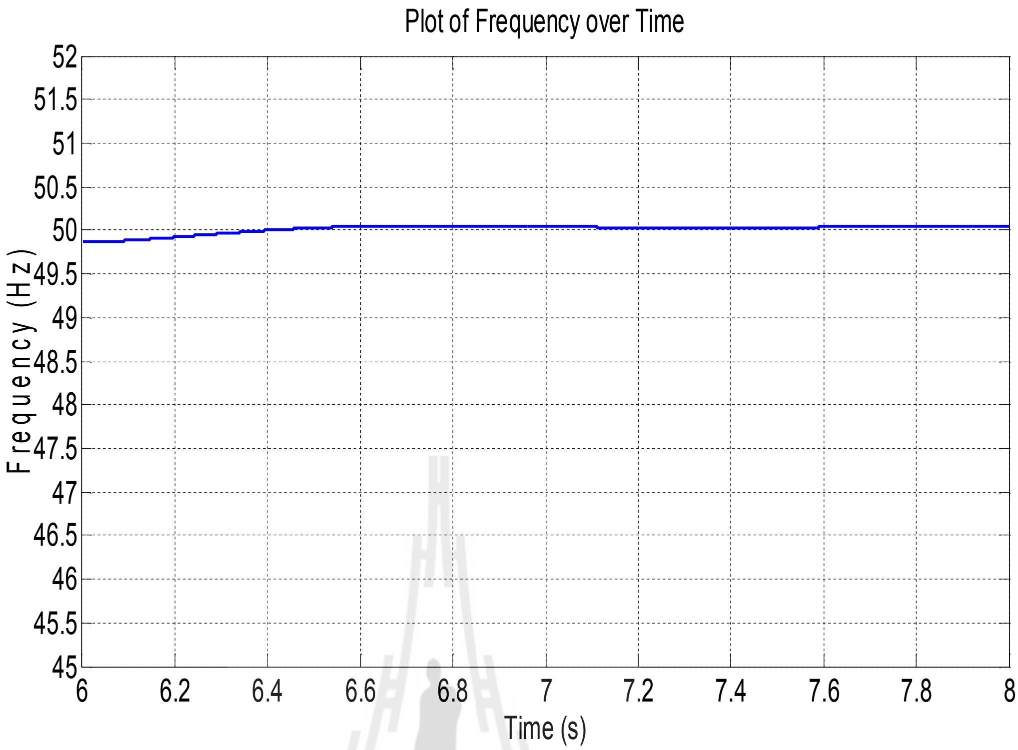


Figure 6.41 Frequency after load shedding by Conventioanl scheme.

- The frequency improves to the rated value of 50 Hz after the application of load shedding.

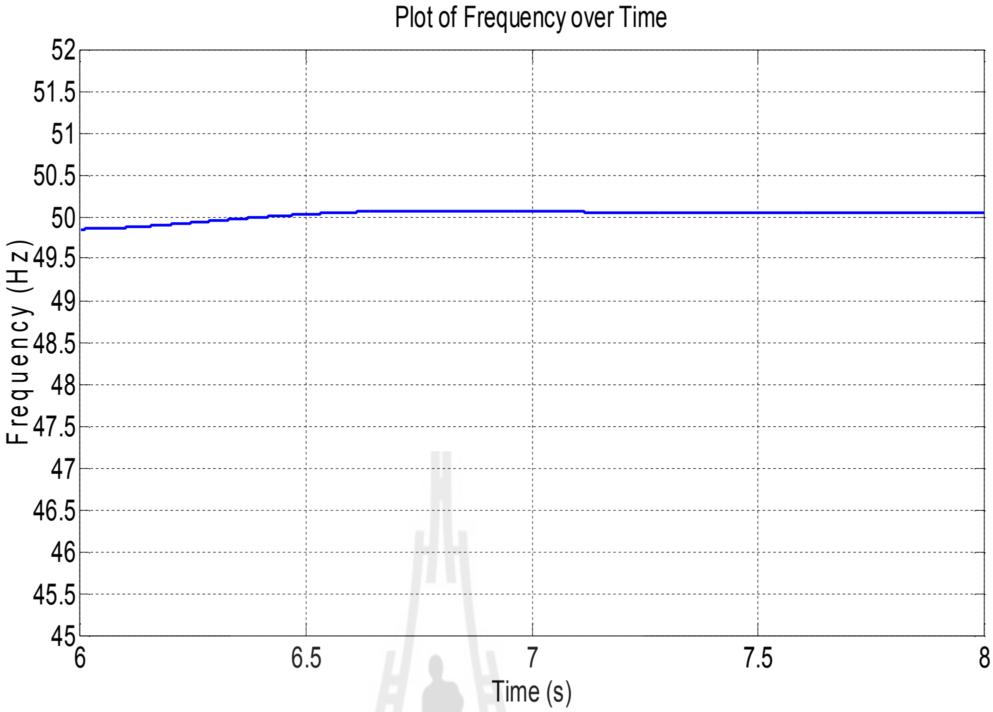


Figure 6.42 Frequency after load shedding by Scheme based on reactive power demand.

- The frequency improves to the rated value of 50 Hz after the application of load shedding.

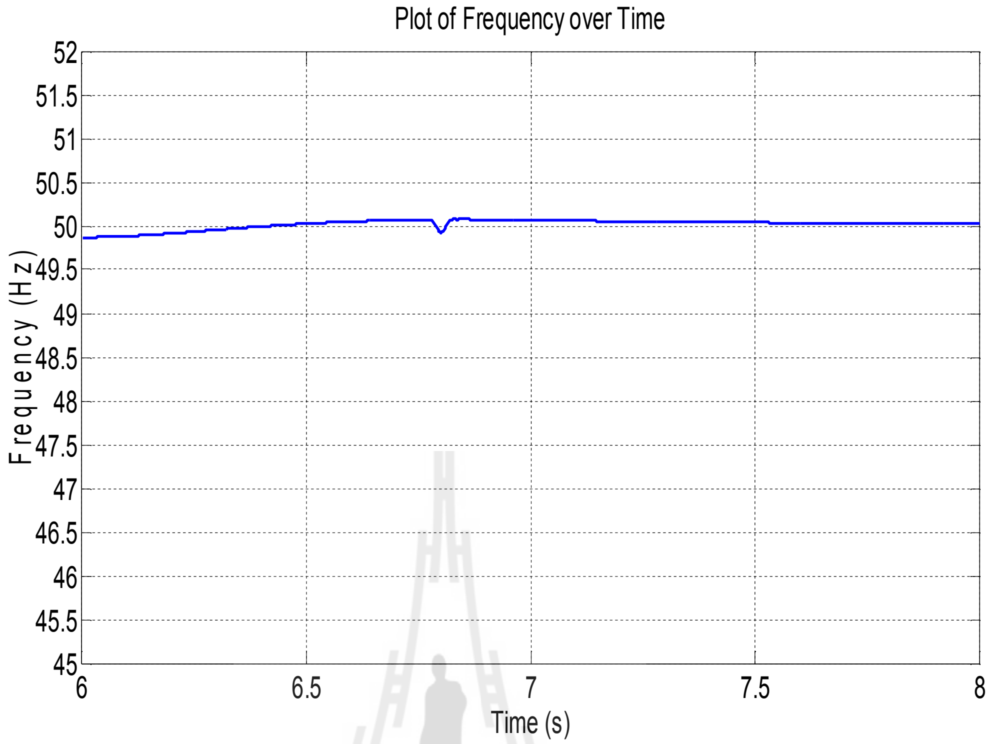


Figure 6.43 Frequency after applying Load shedding scheme based on reactive power demand and priority.

- The frequency of the system improves to the rated value of 50 Hz after the application of load shedding.

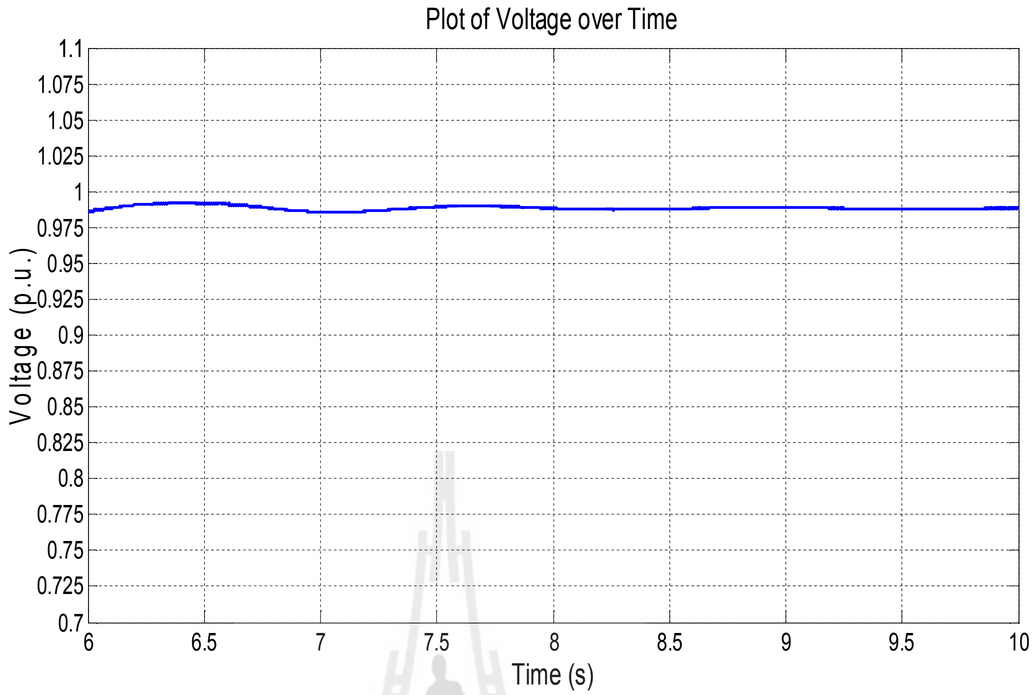


Figure 6.44 Voltage after load shedding by Conventional scheme.

- Voltage plot after load shedding application to the system. Voltage increased to around 0.9875 p.u. and became stable at Time = 8s.

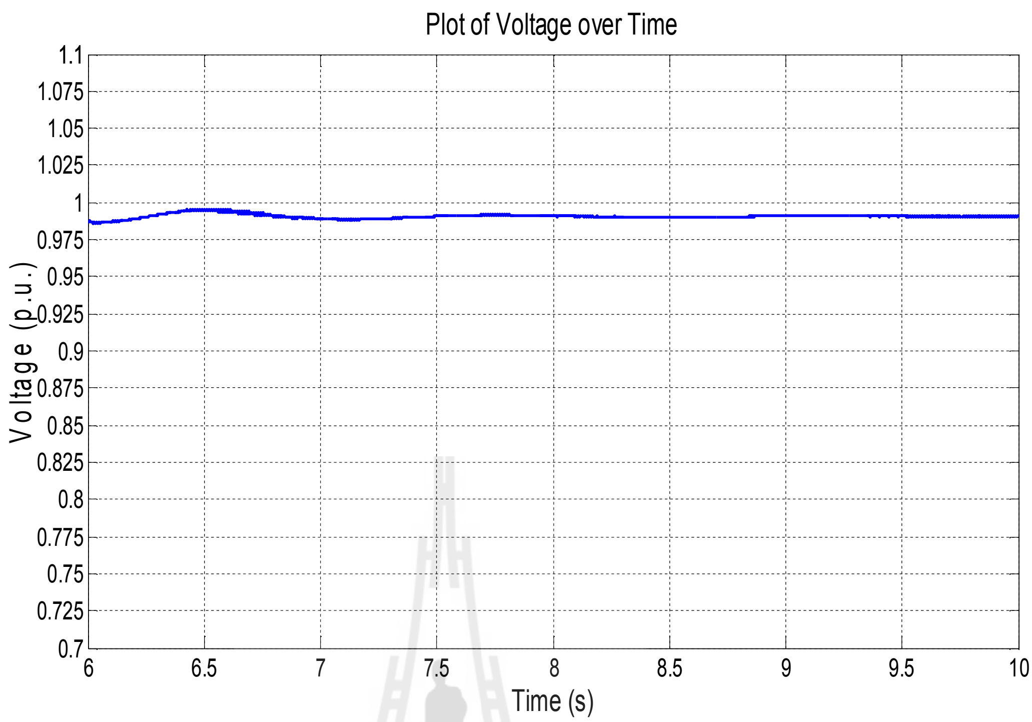


Figure 6.45 Voltage after load shedding by Scheme based on reactive power demand.

- Voltage plot after load shedding application to the system. Voltage increased to 0.9917 p.u. and became stable.

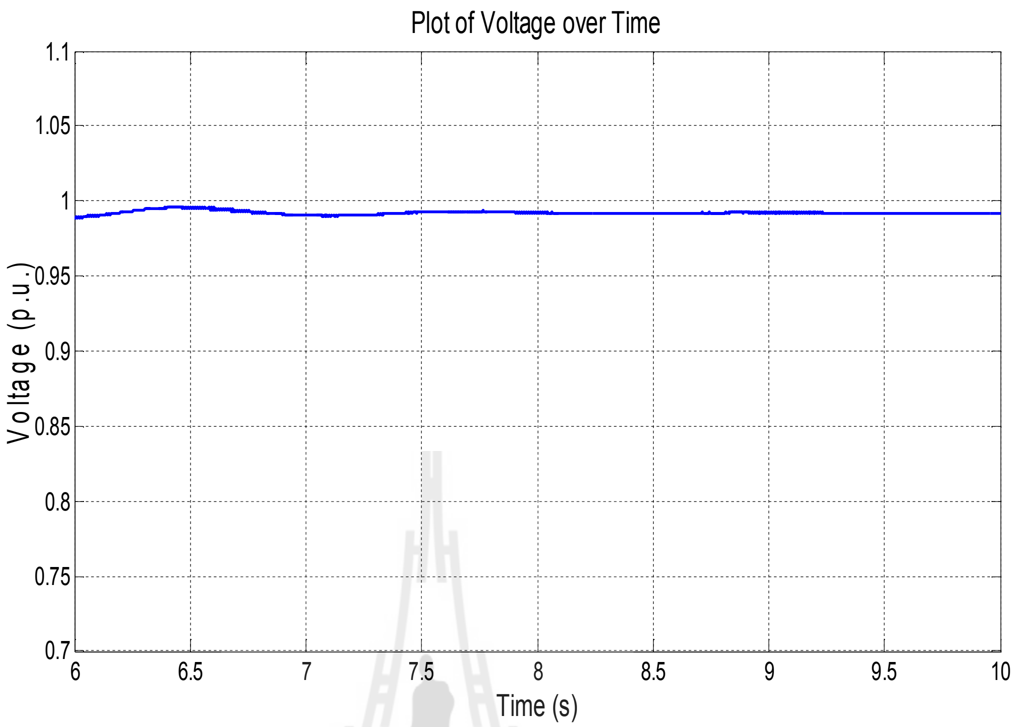


Figure 6.46 Voltage after applying Load shedding scheme based on reactive power demand and priority.

- Voltage plot after load shedding application to the system. Voltage increased to 0.99 p.u. at Time = 8s. Fluctuations diminished and the plot is smooth up to the end of the simulations at Time = 10s.

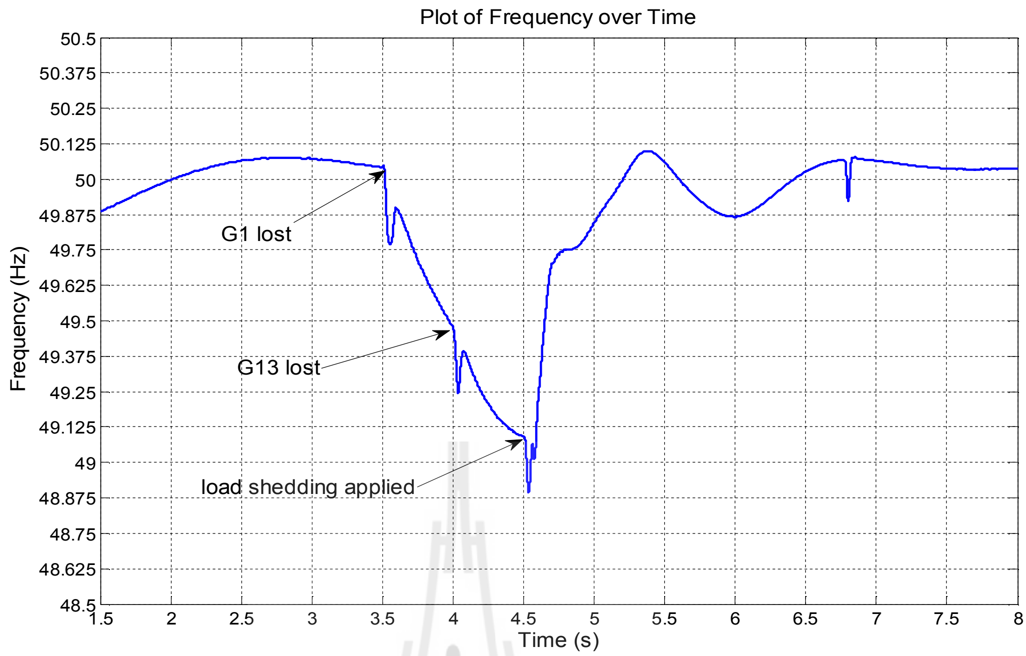


Figure 6.47 Frequency before and after applying load shedding by Conventional scheme.

- Initially the frequency was within 50 Hz. It remained at that rated value up to Time = 3.5s when occurred the loss of the first generator which caused frequency decline to near 49.5 Hz. Another generator loss occurred at Time = 4s. This further decreased the frequency to just below 49.125 Hz and created so many fluctuations in the system frequency before the application of load shedding which improved system frequency to near its rated value of 50 Hz at Time=8s.

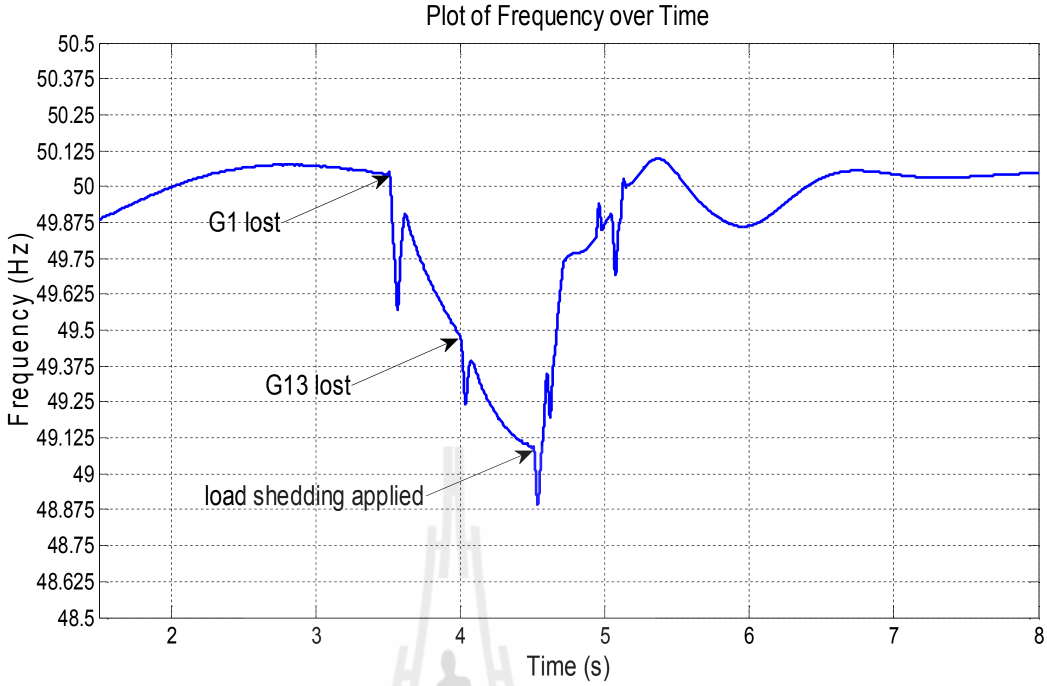


Figure 6.48 Frequency before and after applying load shedding by load shedding scheme based on reactive power demand.

- Initially the frequency was within 50 Hz. It remained at that rated value up to Time = 3.5s when occurred the loss of the first generator which caused frequency decline to near 49.5 Hz. Another generator loss occurred at Time = 4s. This further decreased the frequency to just below 49.125 Hz at T=4.5s and created so many fluctuations in the system frequency before the application of load shedding which improved system frequency to near its rated value of 50 Hz at Time=8s.

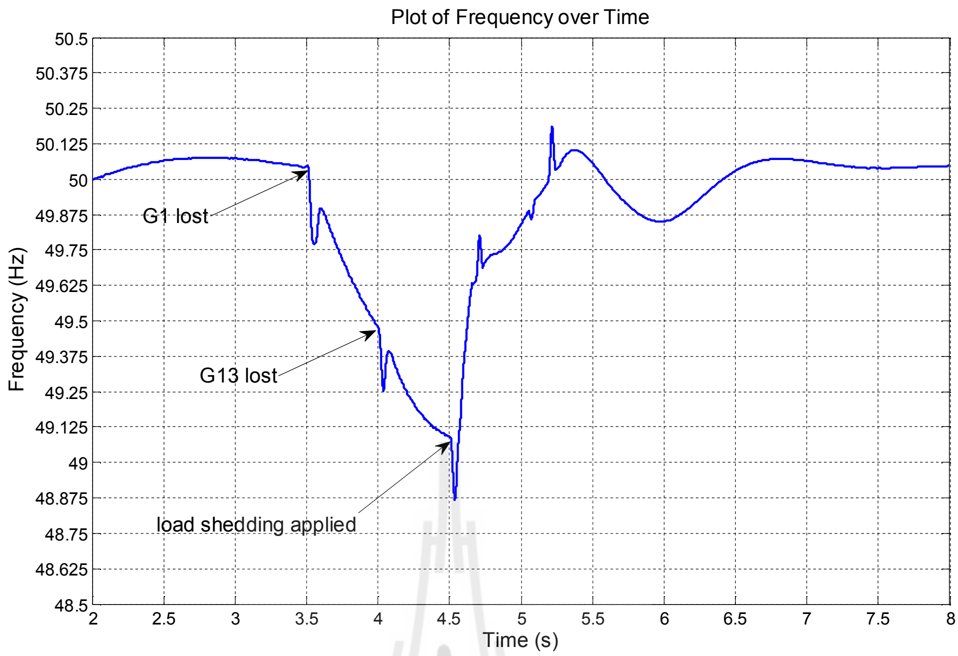


Figure 6.49 Frequency before and after applying load shedding by load shedding based on reactive power demand and priority.

- Initially the frequency was within 50 Hz. It remained at that rated value up to Time = 3.5s when occurred the loss of the first generator which caused frequency decline to near 49.5 Hz. Another generator loss occurred at Time = 4s. This further decreased the frequency to just below 49.125 Hz and created so many fluctuations in the system frequency before the application of load shedding which improved system frequency to near its rated value of 50 Hz at Time=8s.

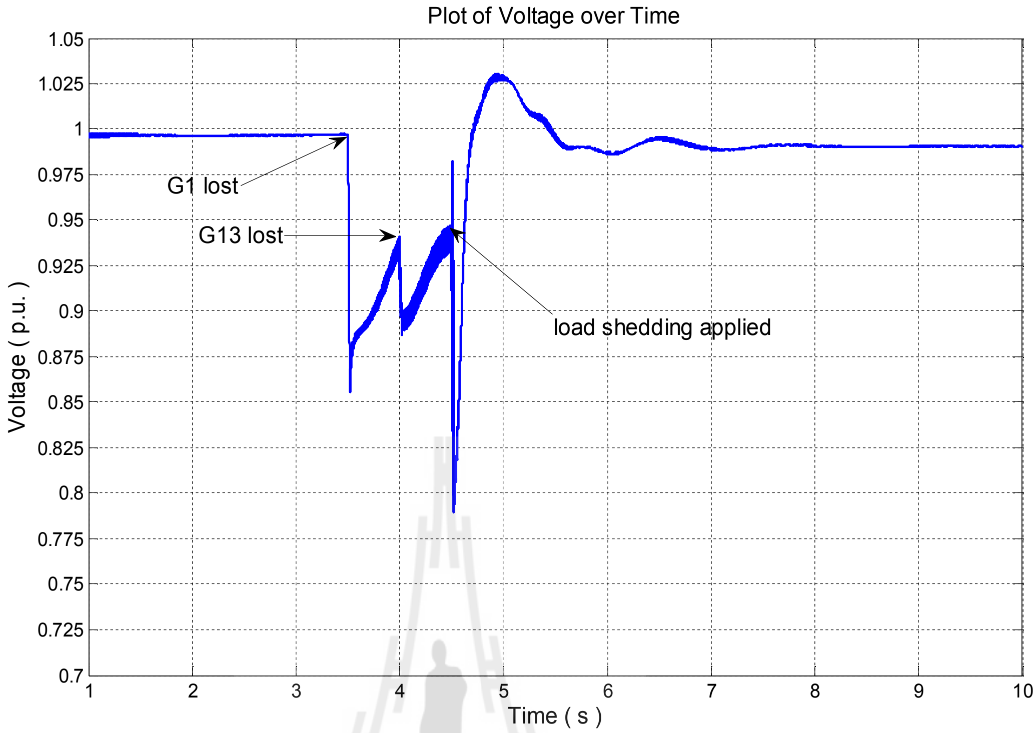


Figure 6.50 Voltage before and after applying Conventional Load shedding scheme.

- Initially the voltage was near 1p.u. until at Time=3.5s when occurred the loss of the first generator which decreased the voltage to near 0.85 p.u. It then increased to 0.9375 p.u. at Time=4s when another generator was lost which decreased it to 0.8875 p.u. and increased again to near 0.95 p.u. at Time=4s with severe fluctuations and load shedding was applied at that time which improved it to 0.98125 p.u. at Time = 7.5s. It remained at this value up to the end of the simulation at Time=10s.

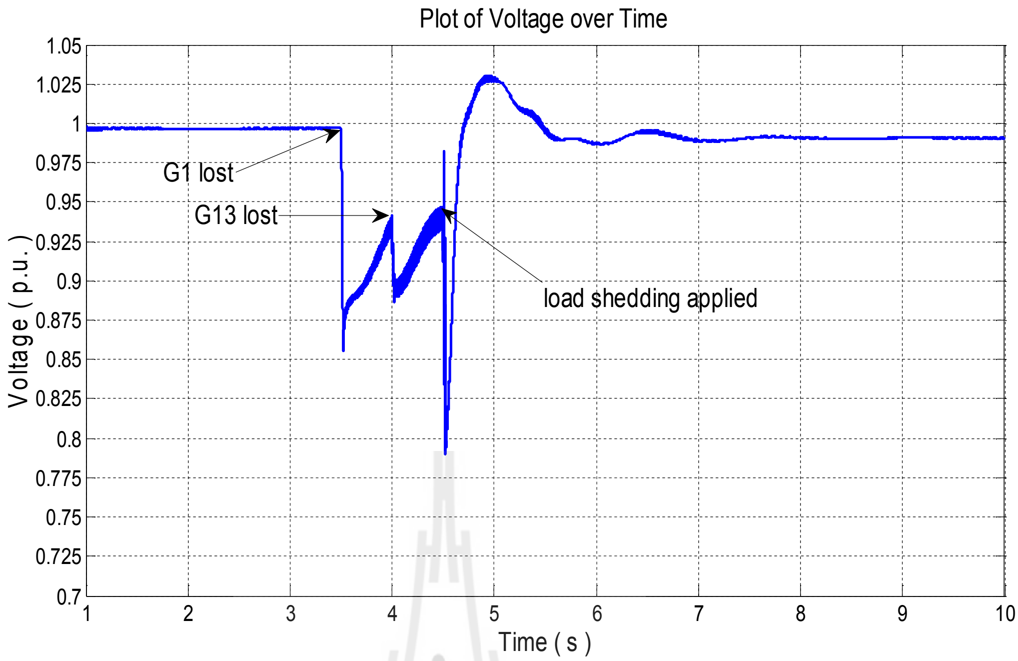


Figure 6.51 Voltage before and after applying Load shedding scheme based on reactive power demand.

- Initially the voltage was near 1p.u. until at Time=3.5s when occurred the loss of the first generator which decreased the voltage to near 0.85 p.u. It then increased to 0.9375 p.u. at Time=4s when another generator was lost which decreased it to 0.8875 p.u. and increased again to near 0.95 p.u. at Time=4s with severe fluctuations and load shedding was applied at that time which improved it to 0.98125 p.u. at Time = 7.5s. It remained at this value up to the end of the simulation at Time=10s.

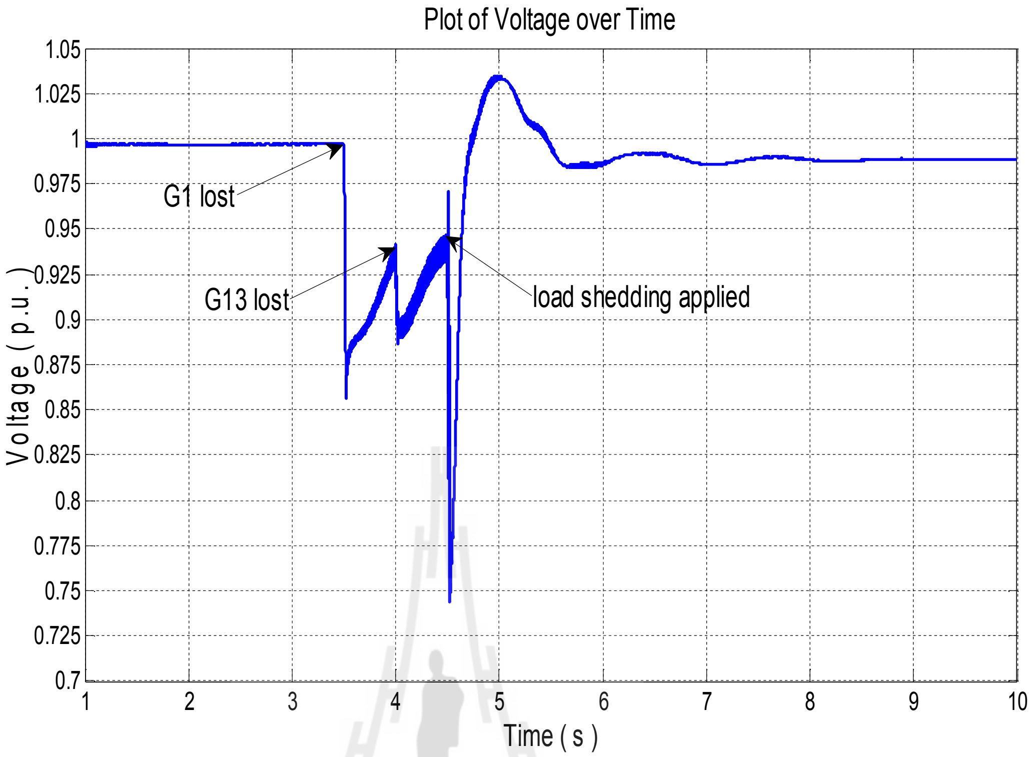


Figure 6.52 Voltage before and after applying Load shedding scheme based on reactive power demand and priority.

- Initially the voltage was 0.9968 p.u. until at Time=3.5s when occurred the loss of the first generator which decreased the voltage to 0.85625 p.u. It then increased to 0.9375 p.u. at Time=4s when another generator was lost which decreased it to 0.8875 p.u. and increased again to near 0.95 p.u. at Time=4s with severe fluctuations and load shedding was applied at that time which improved it to 0.9880 p.u. at Time=8s. It remained at this value up to the end of the simulation at Time=10s.

6.4.2 Load shedding based on Harmony Search algorithm for IEEE 30-bus.

Table 6.18 Active and reactive power shed from different buses.

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
2	0	0	1
3	1.1232	0.0723	8
4	5.0452	0.288	11
5	66.4242	15.8036	21
7	0	0	2
8	0	0	4
10	0.6641	0.6795	14
12	9.2253	6.7094	19
14	1.6788	0.8598	10
15	0	0	3
16	1.5365	1.161	12
17	5.9171	2.374	17
18	1.8606	0.1944	7
19	8.4465	3.2547	16
20	1.6928	0.334	5
21	13.4016	6.9988	20
23	2.9344	0.1414	9
24	8.4798	4.0192	18
26	2.377	1.5887	15
29	1.1952	0.5055	6
30	7.4274	0.5922	13
Total	**283.4**	**126.2**	

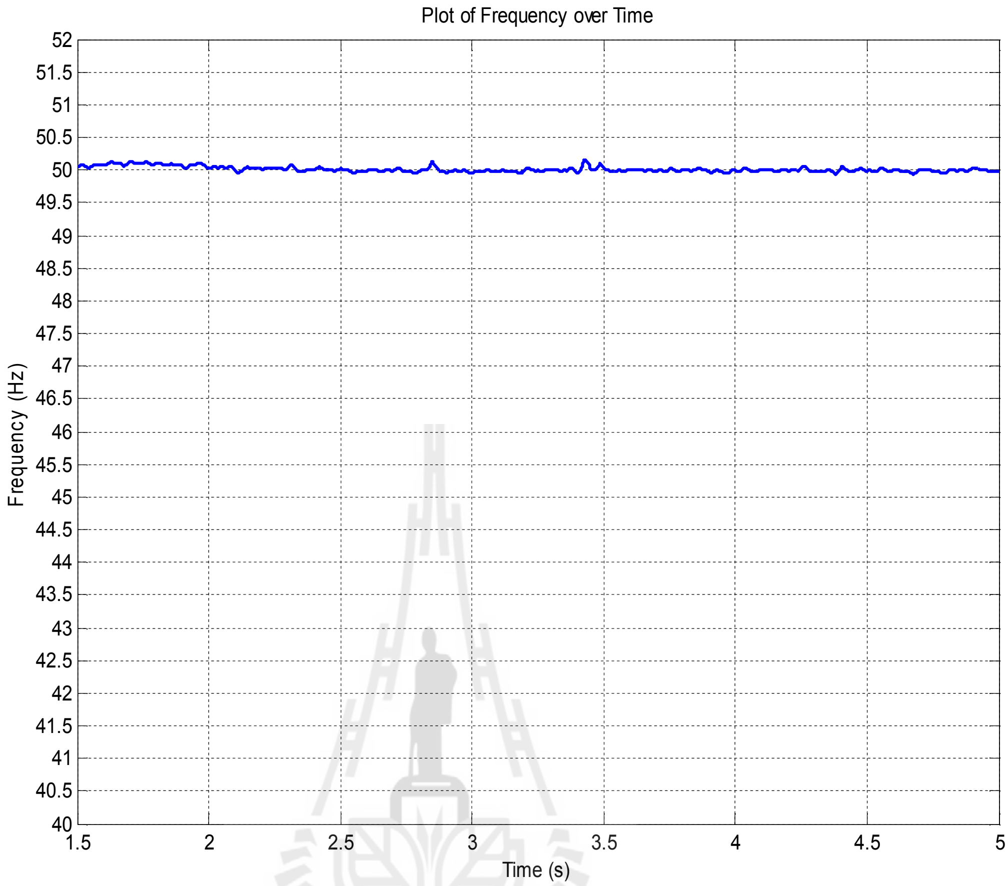


Figure 6.53. Frequency after load shedding by Harmony Search scheme.

- The frequency improves to the rated value of 50 Hz after the application of load shedding. Harmony Search algorithm was used to find optimal load to shed from the system to restore declining system frequency.

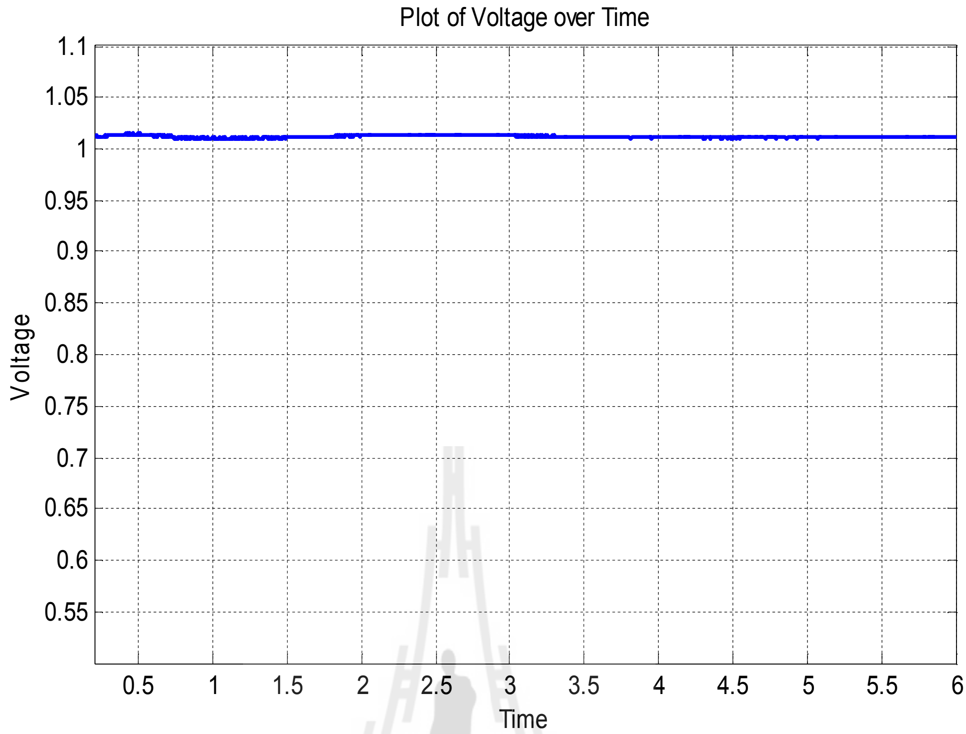


Figure 6.54 Voltage after load shedding by Harmony Search scheme.

- Voltage improves to about 0.95 p.u. from its unstable condition after the application of load shedding. Its plot is a smooth sketch showing that it is very stable. Harmony Search algorithm was used to find optimal load to shed from the system to improve it.

6.5 IEEE 57 bus system

Table 6.19 Active and reactive power demand of loads and their priorities.

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
1	55	17	3
2	3	88	5
3	41	21	2
5	13	4	30
6	75	2	16
8	150	22	4
9	121	26	1
10	5	2	15
12	377	24	42
13	18	2.3	22
14	10	5.3	33
15	22	5	32
16	43	3	27
17	42	8	36
18	27.2	9.8	38
19	3.3	0.6	7
20	2.3	1	10
23	6.3	2.1	18
25	6.3	3.2	28
27	9.3	0.5	6
28	4.6	2.3	21
29	17	2.6	23
30	3.6	1.8	12
31	5.8	2.9	24
32	1.6	0.8	8
33	3.8	1.9	14
35	6	3	26
38	14	7	35
41	6.3	3	25
42	7.1	4.4	31
43	2	1	9
44	12	1.8	13
47	29.7	11.6	41
49	18	8.5	37
50	21	10.5	40

Table 6.19 Active and reactive power demand of loads and their priorities (cont.).

Bus number	Active power demand (MW)	Reactive power demand (MW)	Priority of loads
51	18	5.3	34
52	4.9	2.2	19
53	20	10	39
54	4.1	1.4	11
55	6.8	3.4	29
56	7.6	2.2	20
57	6.7	2	17
Total	**1250.3**	**336.4**	

Where priority loads are:

- Load at bus number 2 – Large industrial facility.
- Load number 9 – Hospital.
- Load number 8 – University
- Load bus number 1 - Military complex
- Load bus number 3 – Mornach palace

Load with priority 1 has highest priority while load with priority 38 has the lowest priority. Loads are shed starting with those having high reactive power demand and low priority in descending order. This means that load bus number 50 would be shed first and load bus number 9 would be last to shed.

Table 6.20. Output power of generators at different buses.

Bus number	Output power (MW)	Output power (MVar)
1	128.9	-16.1
2	0	-0.8
3	40	-1.0
6	0	0.8
8	450	62.1
9	0	2.2
12	310	128.5
Total	**928.9**	**175.7**

6.5.1 Loss of three generators at Time=3s, Time=3.25s, Time=3.5s.

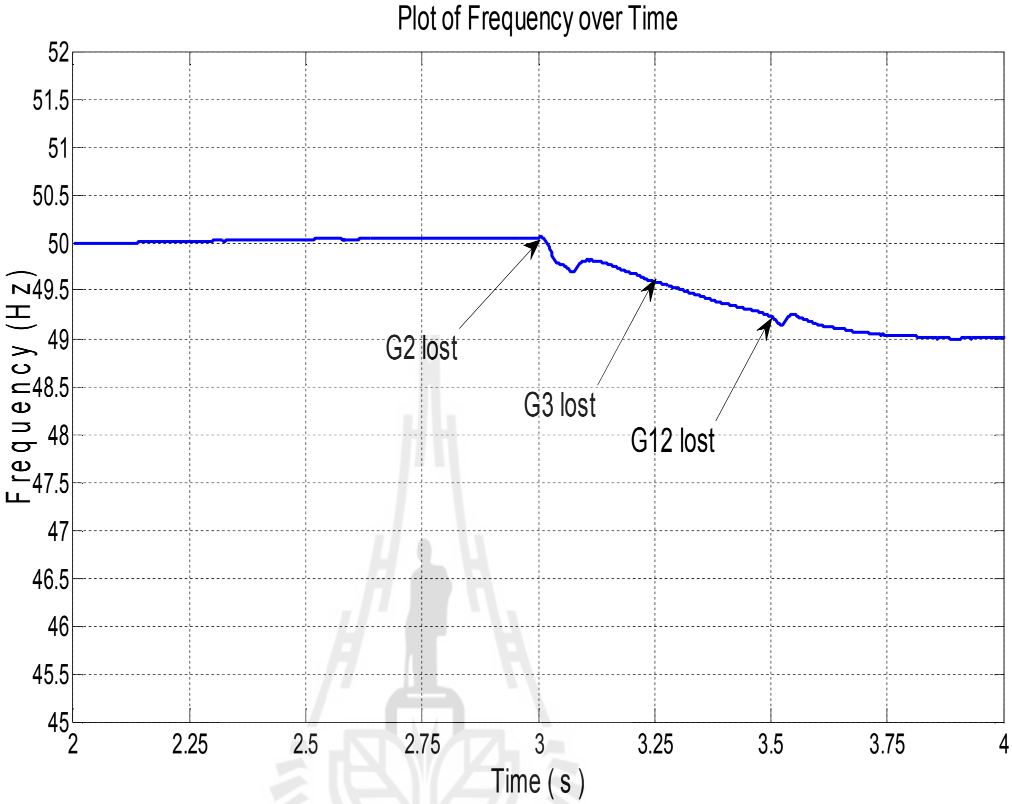


Figure 6.55 System Frequency due to the loss of three generators.

- The first generator was lost at Time = 3s which caused the frequency to decline to near 49.5 Hz. Second generator was lost at Time = 3.25s which decreased the frequency to near 49.25 Hz. A third generator was lost at Time = 3.5s which further decreased the frequency to 49 Hz. Thus, it became necessary to improve the frequency of the system.

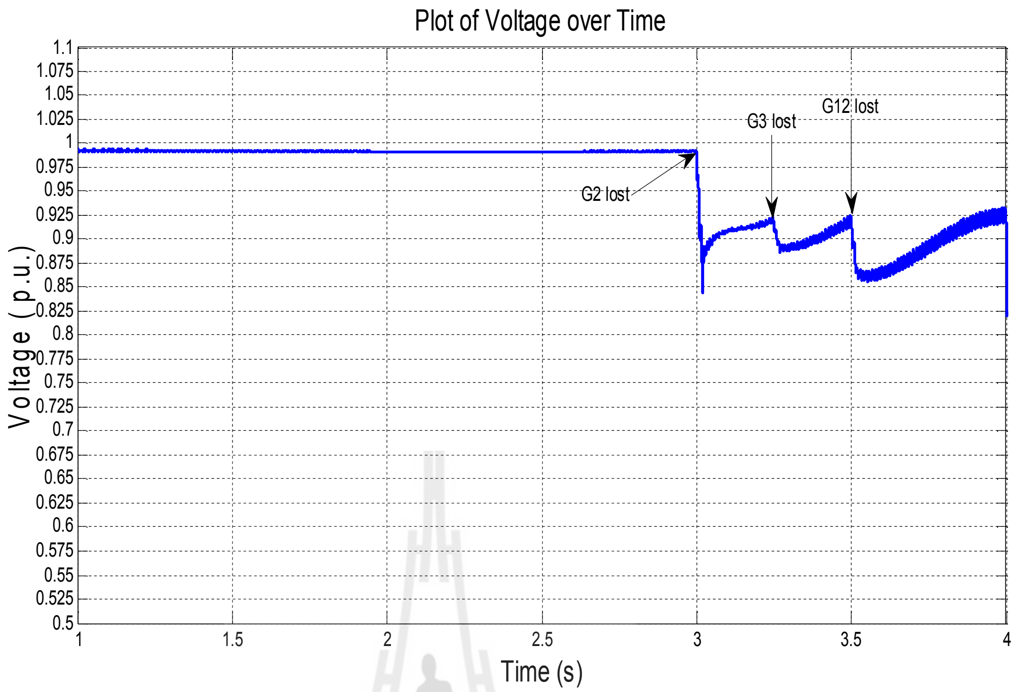


Figure 6.56 Voltage when there was a loss of three generators.

- Voltage was also affected by the loss of the generators. Initially the voltage was near 1p.u. until at Time = 3s when the first generator was lost which decreased the voltage to just below 0.85 p.u. and then increased to near 0.925 p.u. at Time= 3.25s with fluctuations. At this time occurred the loss of another generator decreased the voltage to 0.8833 p.u. and increased again to 0.925 p.u. at Time = 3.5s when a third generator was lost which dropped the voltage to near 0.85 p.u. with severe fluctuations up to Time = 4s.

Table 6.21 Loads shed by Conventional scheme and Scheme based on reactive power demand and priority.

Conventional scheme			Load shedding scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	Mvar shed
5	13	4	12	377	24
6	75	2	47	29.7	11.6
10	5	2	50	21	10.5
12	377	24	53	20	10
13	18	2.3	18	27.2	9.8
14	10	5.3	49	18	8.5
15	22	5	17	42	8
16	43	3	38	14	7
17	42	8	51	18	5.3

Table 6.22 Data about load shedding using Conventional scheme and Load sheddding scheme based on reactive power demand and priority for IEEE 57-bus.

Disturban ce	Time	MW lost	System state	Load shed by Conventional scheme (No. of loads shed)	Load shed by Proposed scheme (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G2, G3, G12	T=3 T=3.5 T=4	350	Poor	9	9	0

Table 6.23 Loads shed by Scheme based on reactive power demand and Scheme based on reactive power demand and priority.

Load shedding scheme based on reactive power demand			Load shedding scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	Mvar shed
2	3	88	12	377	24
9	121	26	47	29.7	11.6
12	377	24	50	21	10.5
8	150	22	53	20	10
			18	27.2	9.8
			49	18	8.5
			17	42	8
			38	14	7
			51	18	5.3

Table 6.24 Data about load shedding using Load shedding scheme based on reactive power demand and Load sheddding scheme based on reactive power demand and priority for IEEE 57-bus.

Disturbance	Time	MW lost	System state	Load shed by scheme based on reactive power demand and priority (No. of loads shed)	Load shed by Scheme based on reactive power demand (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G2, G3, G12	T=3 T=3.5 T=4	350	Poor	9	4	5

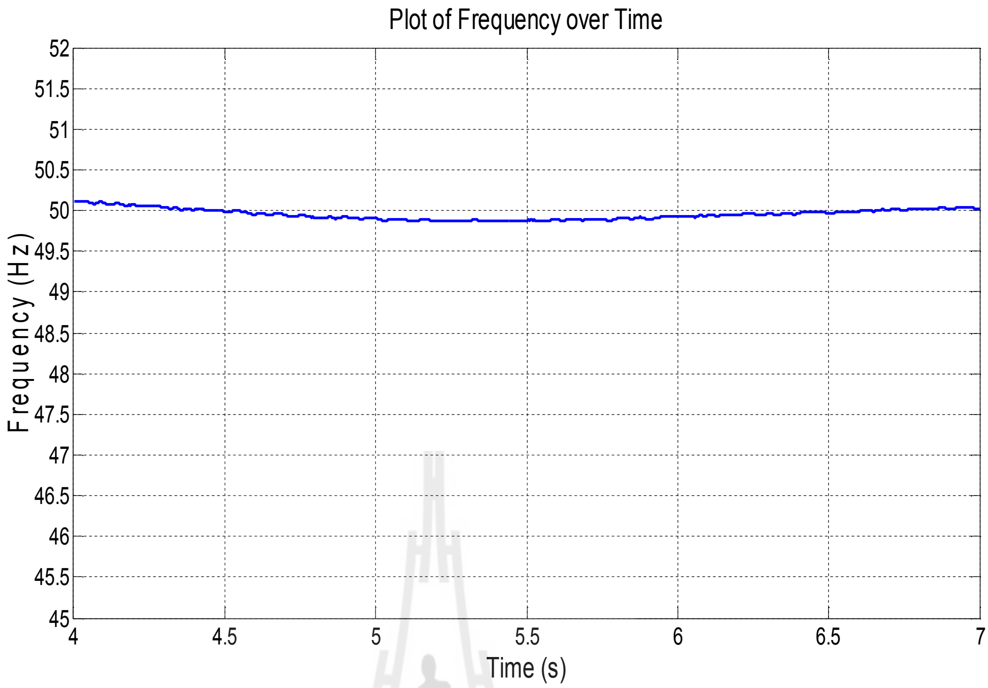


Figure 6.57 Frequency after load shedding by Conventional scheme.

- The figure shows the frequency of the system after load shedding, when nine loads were shed to restore balance in the system.

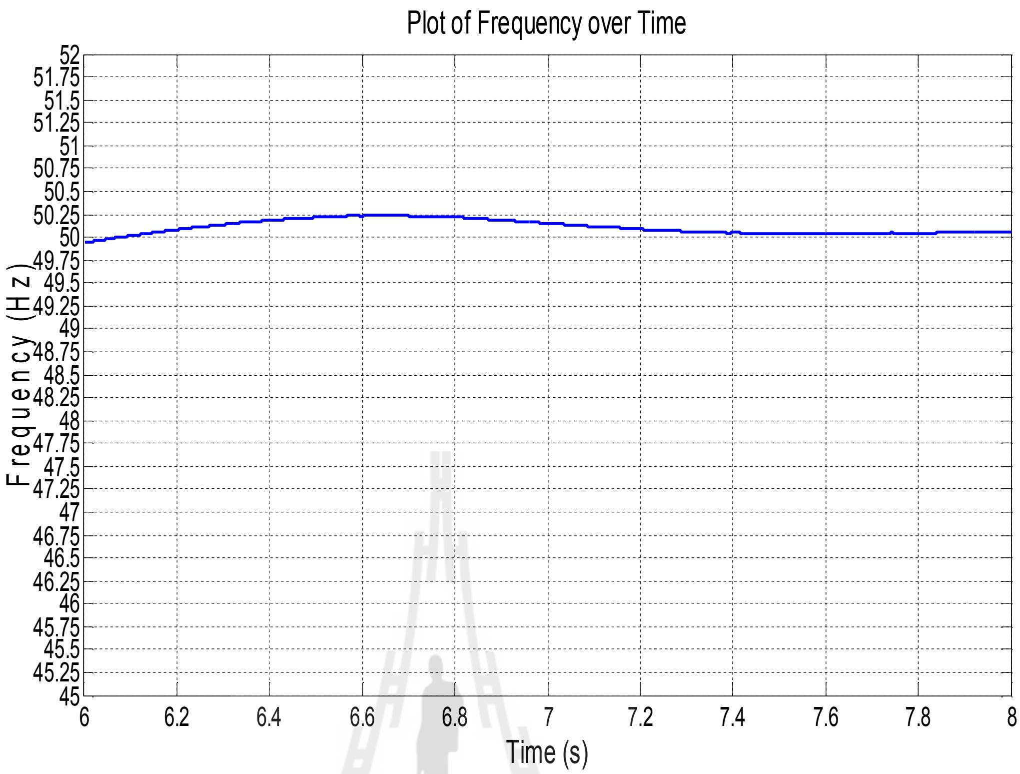


Figure 6.58 Frequency after load shedding by Scheme based on reactive power demand.

- The figure shows the frequency of the system after load shedding, when nine loads were shed to restore balance in the system.

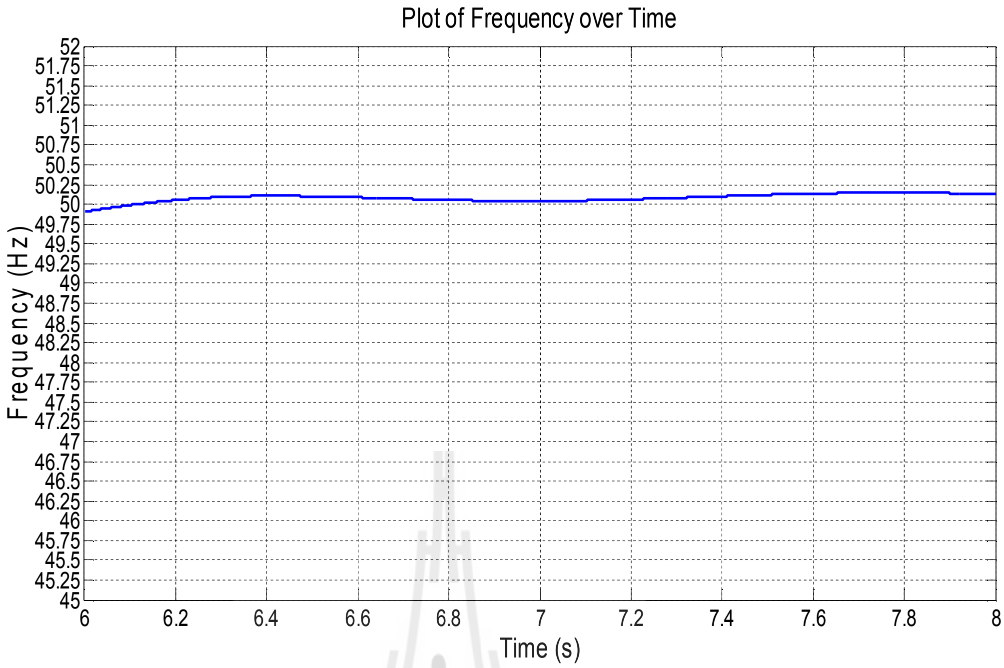


Figure 6.59 Frequency after applying Load shedding scheme based on reactive power demand and priority.

- The frequency improves above the specified lower limit. It settles at a value close to 50 Hz. Scheme shed nine loads based on the reactive power demand of the of loads.

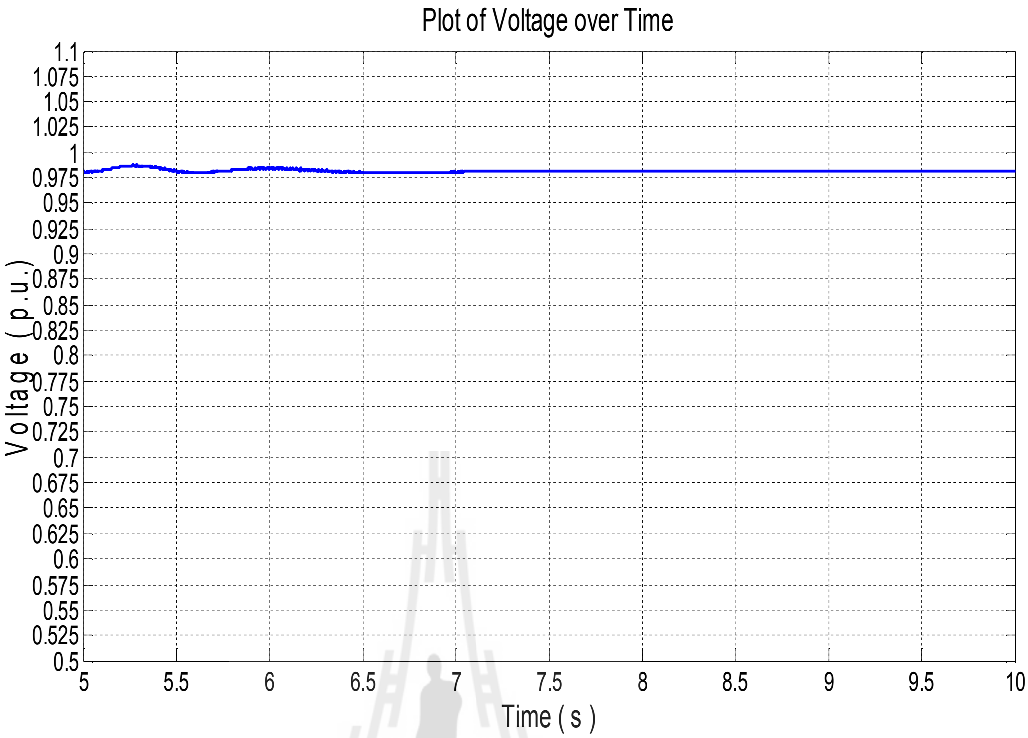


Figure 6.60 Voltages after load shedding by Conventional scheme.

- The voltage plot shows an improvement as well. Voltage fluctuations and voltage drop at the buses shown in figure 70 has been improved due to the appropriate amount of load shedding.

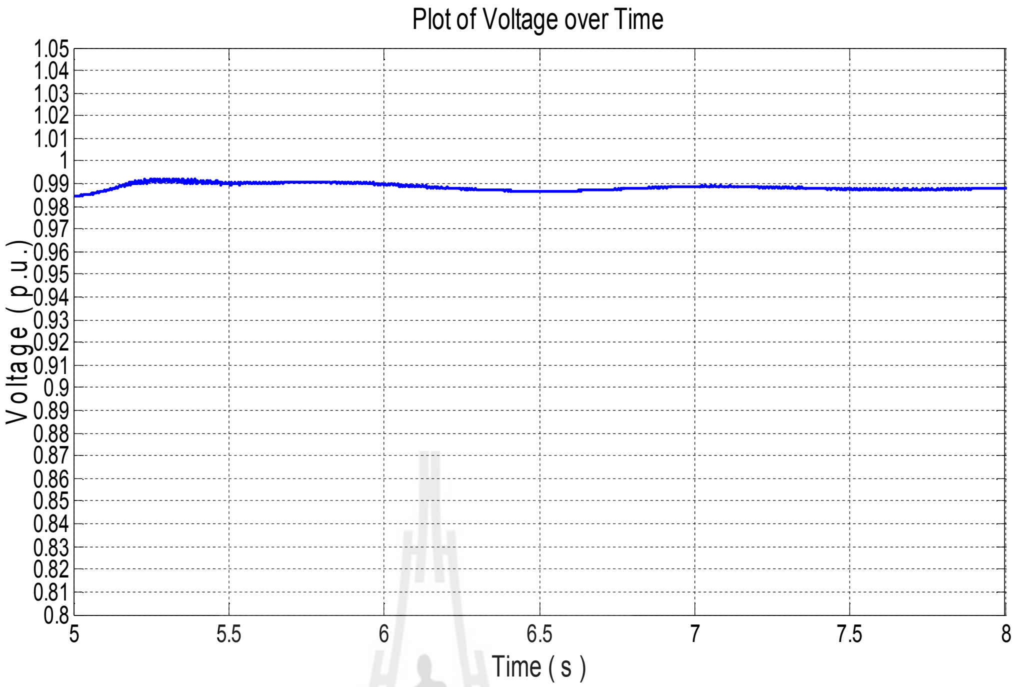


Figure 6.61 Voltages after load shedding by Scheme based on reactive power demand.

- The voltage plot shows an improvement as well. Voltage fluctuations and voltage drop at the buses shown in figure 70 has been improved due to the appropriate amount of load shedding.

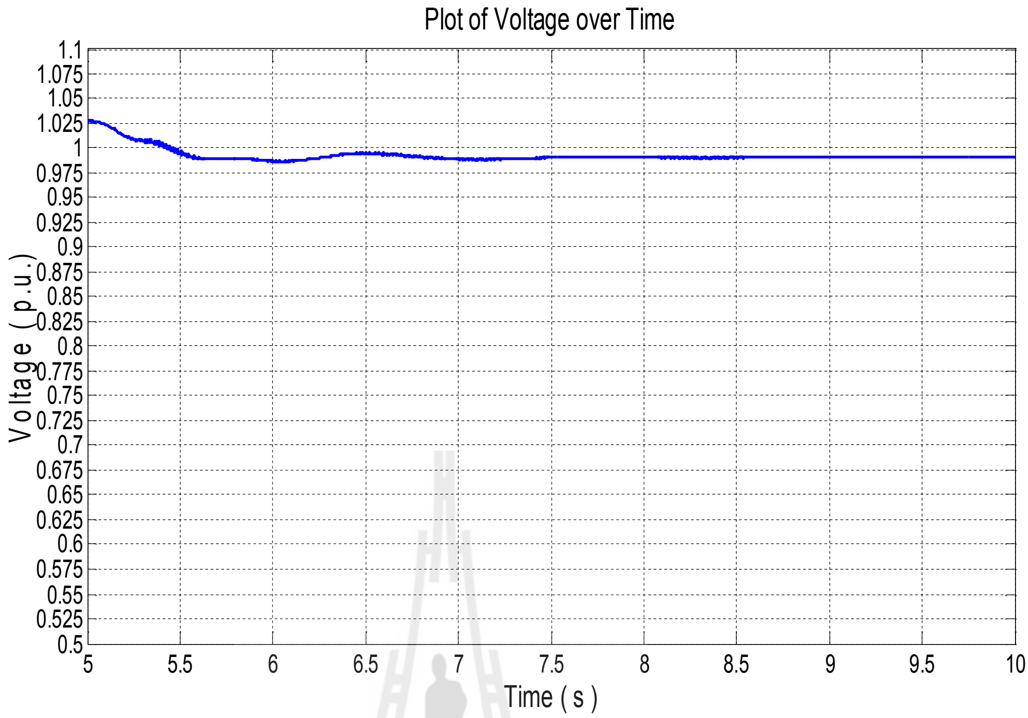


Figure 6.62 Voltages after applying Load shedding scheme based on reactive power demand and priority.

- The voltage plot shows an improvement as well. The voltage fluctuations and dropping at the buses shown in figure 70 has been improved due to the appropriate amount of load shedding.

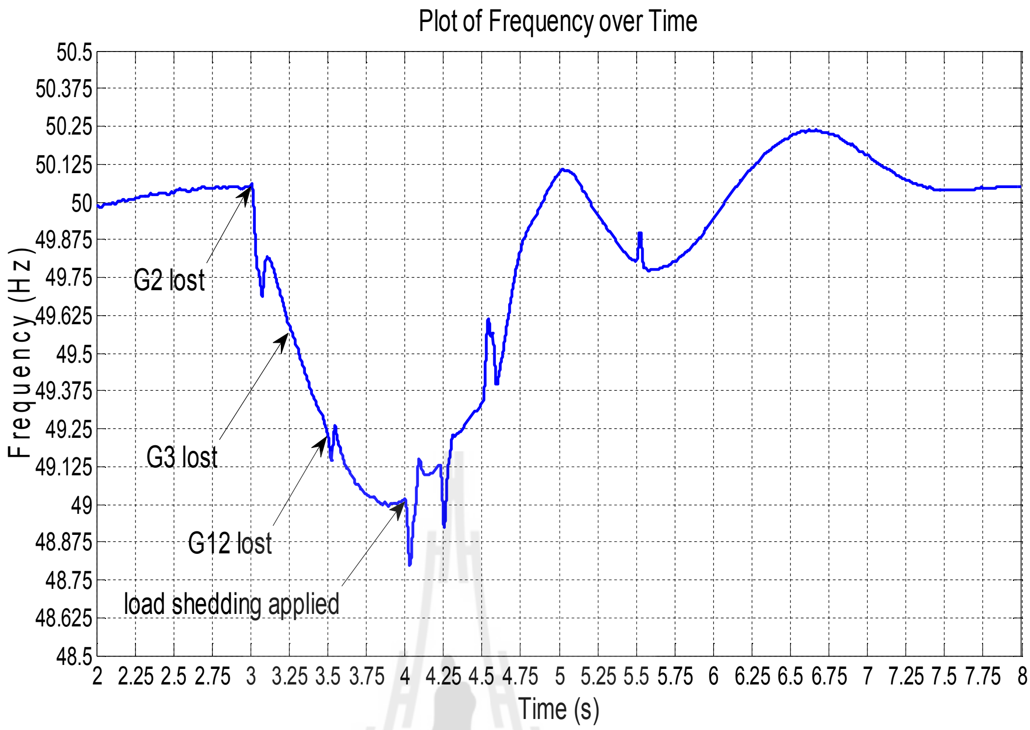


Figure 6.63 Frequency before and after load shedding by Conventional scheme.

- The frequency was near its rated value of 50 Hz at Time=3s when the first generator was lost. It decreased to below 49.625 Hz at Time= 3.25s. At this time another generator was lost which caused frequency to decline to below 49.25 Hz at Time = 3.5s when occurred the loss of the third generator which decresed the frequency to 49 Hz at Time=4s. At this point load shedding was applied which improved system frequency to just above its rated value of 50 Hz at Time=7.5s. The frequency remained at that constant value up to the end of the simulation at Time=8s.

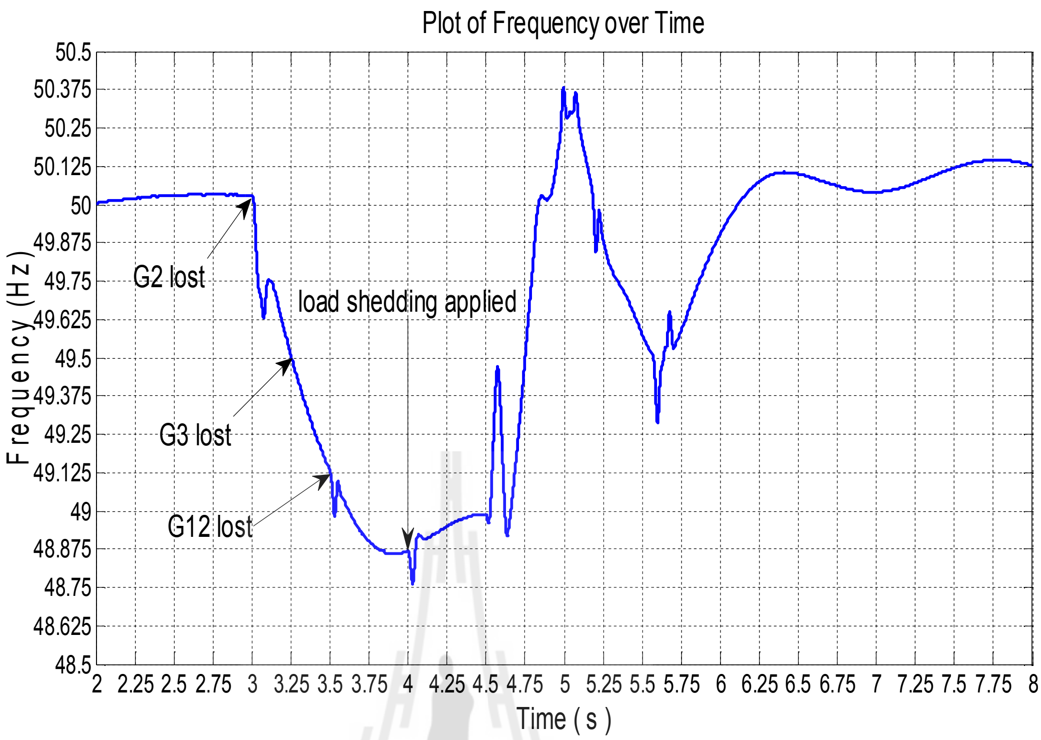


Figure 6.64 Frequency before and after load shedding by Scheme based on reactive power demand.

- The frequency was near its rated value of 50 Hz at Time=3s when the first generator was lost. It decreased to below 49.625 Hz at Time= 3.25s. At this time another generator was lost which caused frequency to decline to below 49.25 Hz at Time = 3.5s when occurred the loss of the third generator which decresed the frequency to 49 Hz at Time=4s. At this point load shedding was applied which improved system frequency to 50.125 Hz at Time=7.5s. Then there was small increment and then dropped to 50 Hz at Time=8s.

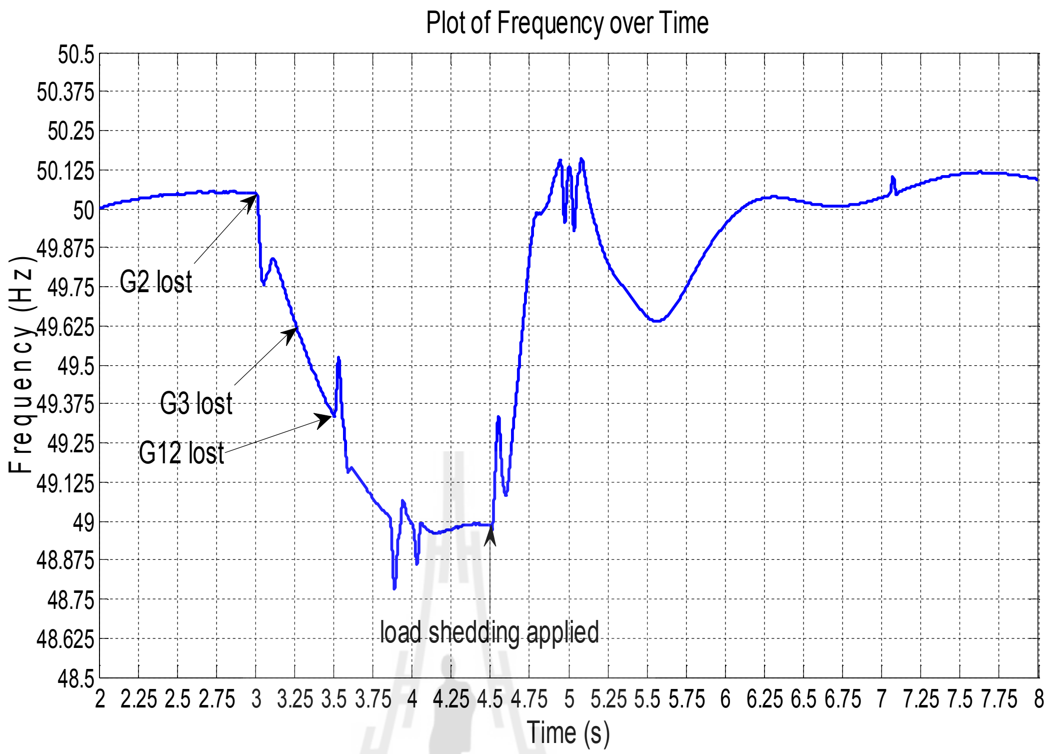


Figure 6.65 Frequency before and after applying Load shedding scheme based on reactive power demand and priority.

- The frequency was near its rated value of 50 Hz at Time=3s when the first generator was lost. It decreased to below 49.625 Hz at Time= 3.25s. At this time another generator was lost which caused frequency to decline to below 49.25 Hz at Time = 3.5s when occurred the loss of the third generator which decresed the frequency to 49 Hz at Time=4s. At this point load shedding was applied which improved system frequency to very close to 50.125 Hz at Time=7.5s. It then dropped just below 50.125 Hz at Time=8s.

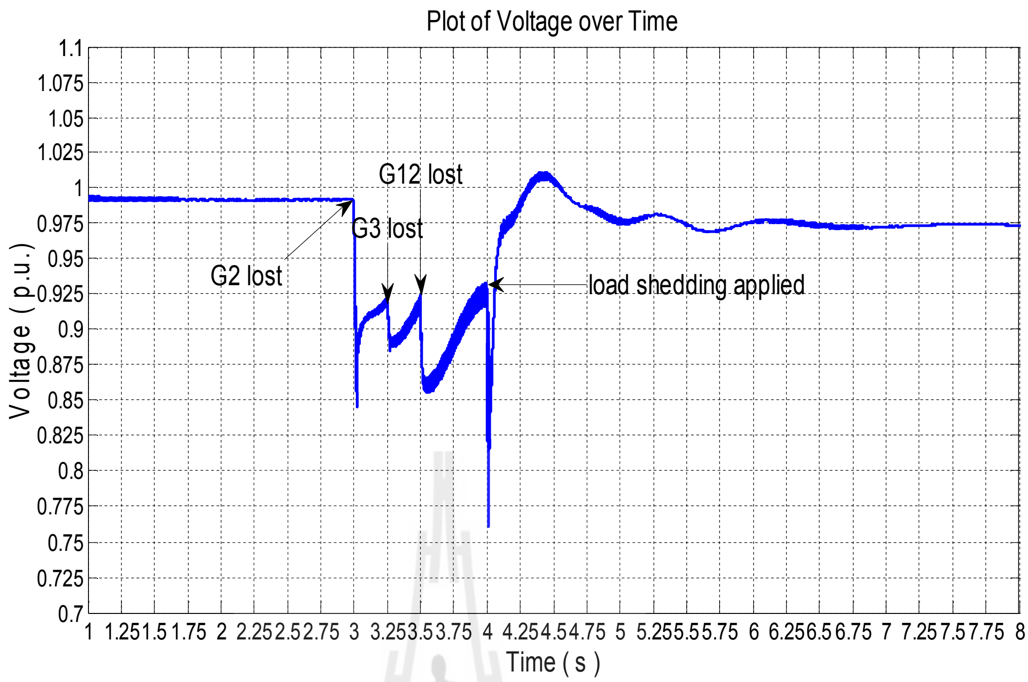


Figure 6.66 Voltage of the system before and after load shedding by Conventional scheme.

- Voltage was also affected by the loss of the generators. Initially the voltage was 0.99375 p.u. until at Time = 3s when the first generator was lost which decreased the voltage to just below 0.85 p.u. and then increased to near 0.925 p.u. at Time= 3.25s with fluctuations. At this time occurred the loss of another generator decreased the voltage to 0.8833 p.u. and increased again to 0.925 p.u. at Time = 3.5s when a third generator was lost which dropped the voltage to near 0.85 p.u. and increased again with severe fluctuations up to above 0.925 p.u. at Time = 4s when load shedding was applied which improved the voltage to 0.975 p.u. at Time=5.5s and remained within that value up to the end of the simulation.

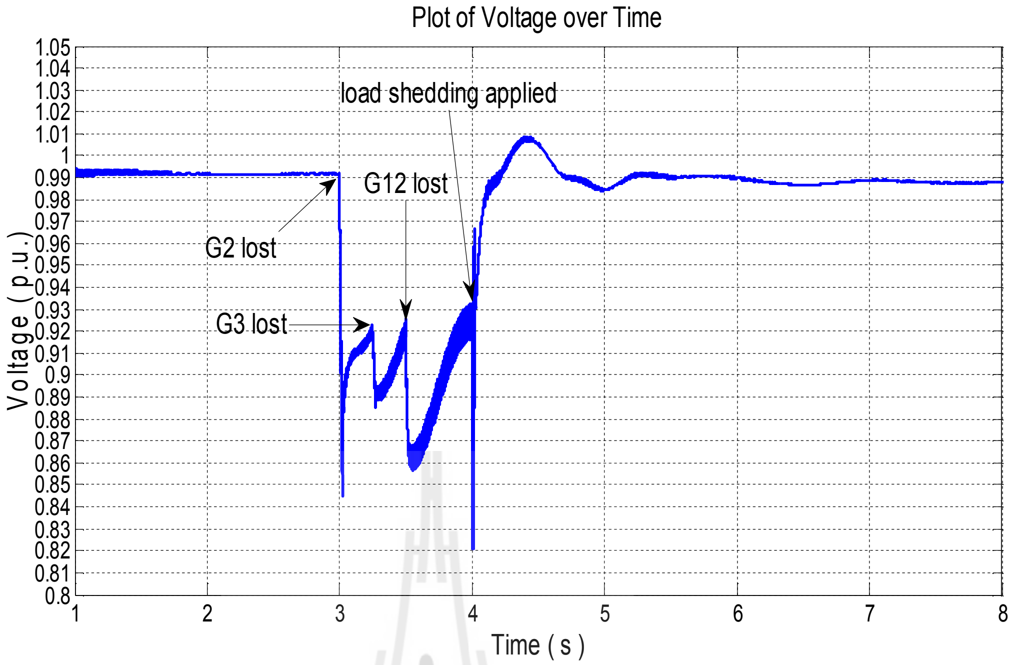


Figure 6.67 Voltage of the system before and after load shedding by Scheme based on reactive power demand.

- Voltage was also affected by the loss of the generators. Initially the voltage was 0.99375 p.u. until at Time = 3s when the first generator was lost which decreased the voltage to just below 0.85 p.u. and then increased to near 0.925 p.u. at Time= 3.25s with fluctuations. At this time occurred the loss of another generator decreased the voltage to 0.8833 p.u. and increased again to 0.925 p.u. at Time = 3.5s when a third generator was lost which dropped the voltage to near 0.85 p.u. and increased again with severe fluctuations up to above 0.925 p.u. at Time = 4s when load shedding was applied which improved the voltage to 0.99 p.u. at Time=5.25s and remained within that value up to the end of the simulation.

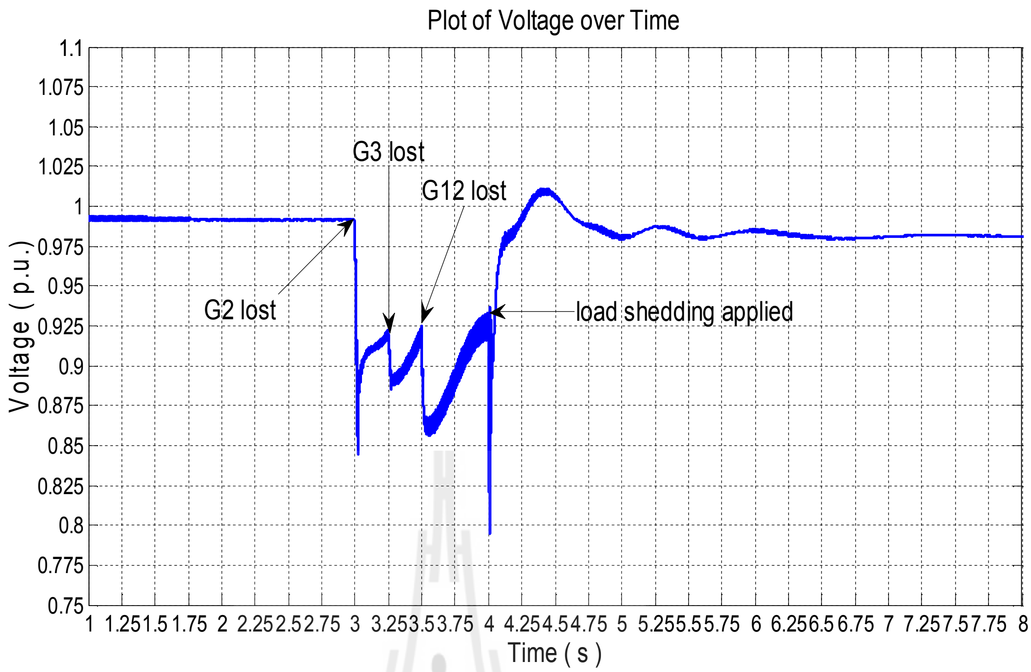


Figure 6.68 Voltage of the system before and after load shedding by Scheme based on reactive power demand and priority.

- Voltage was also affected by the loss of the generators. Initially the voltage was 0.99375 p.u. until at Time = 3s when the first generator was lost which decreased the voltage to just below 0.85 p.u. and then increased to near 0.925 p.u. at Time= 3.25s with fluctuations. At this time occurred the loss of another generator decreased the voltage to 0.8833 p.u. and increased again to 0.925 p.u. at Time = 3.5s when a third generator was lost which dropped the voltage to near 0.85 p.u. and increased again with severe fluctuations up to above 0.925 p.u. at Time = 4s when load shedding was applied which improved the voltage to just above 0.975 p.u. at Time=5s and remained within that value up to the end of the simulation.

6.6 80 bus power system

Table 6.25 Active and reactive power demands of loads and their priorities for 80-bus power system.

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
1	51	27	57
2	20	9	30
3	39	10	36
4	39	12	41
6	52	22	47
7	19	2	13
8	28	0	10
11	70	23	51
12	47	10	3
13	34	16	44
14	14	1	12
15	90	30	60
16	25	10	33
17	11	3	15
18	60	34	63
19	45	25	53
20	18	3	18
21	14	8	27
22	10	5	22
23	7	3	14
24	13	0	9
27	71	13	42
28	17	7	25
29	24	4	21
31	43	27	56
32	59	23	50
33	23	9	31
34	59	26	54
35	33	9	32
36	31	17	45
39	27	11	39
40	66	23	2
41	37	10	35
42	96	23	52
43	18	7	24

Table 6.25 Active and reactive power of loads and their priorities (cont.).

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
44	16	8	28
45	53	22	48
46	28	10	34
47	34	0	11
48	20	11	37
49	87	30	5
50	17	4	20
51	17	8	29
52	18	5	23
53	23	11	38
54	113	32	62
55	63	22	49
56	84	18	4
57	12	3	16
58	12	3	17
59	277	113	65
60	78	3	19
62	77	14	43
66	39	18	46
67	28	7	26
70	66	20	1
72	12	0	8
73	6	0	7
74	68	27	58
75	47	11	40
76	68	36	64
77	61	28	59
78	71	26	6
79	39	32	61
80	130	26	55
Total	**2974**	**1010**	

Where priority loads are:

- Load bus number 49 - Large industrial facility.
- Load bus number 70 - Hospital.
- Load bus number 56 - University.

- Load bus number 12 - Military complex.
- Load bus number 40 - Presidential palace.

Load with priority 1 has highest priority while load with priority 65 has the lowest priority. Loads are shed starting with those having high reactive power demand and low priority in descending order. This means that load bus number 59 would be shed first and load bus number 70 would last to shed.

Table 6.26 Bus numbers of generators and their output power.

Bus number	Output power (MW)
10	450
12	85
25	22
26	314
31	7
46	19
49	204
54	48
59	155
61	160
65	391
66	392
69	516.4
80	477
Total	**3240.4**

6.6.1 Loss of three generators at Time=3s, Time=3.5s and Time=4s.

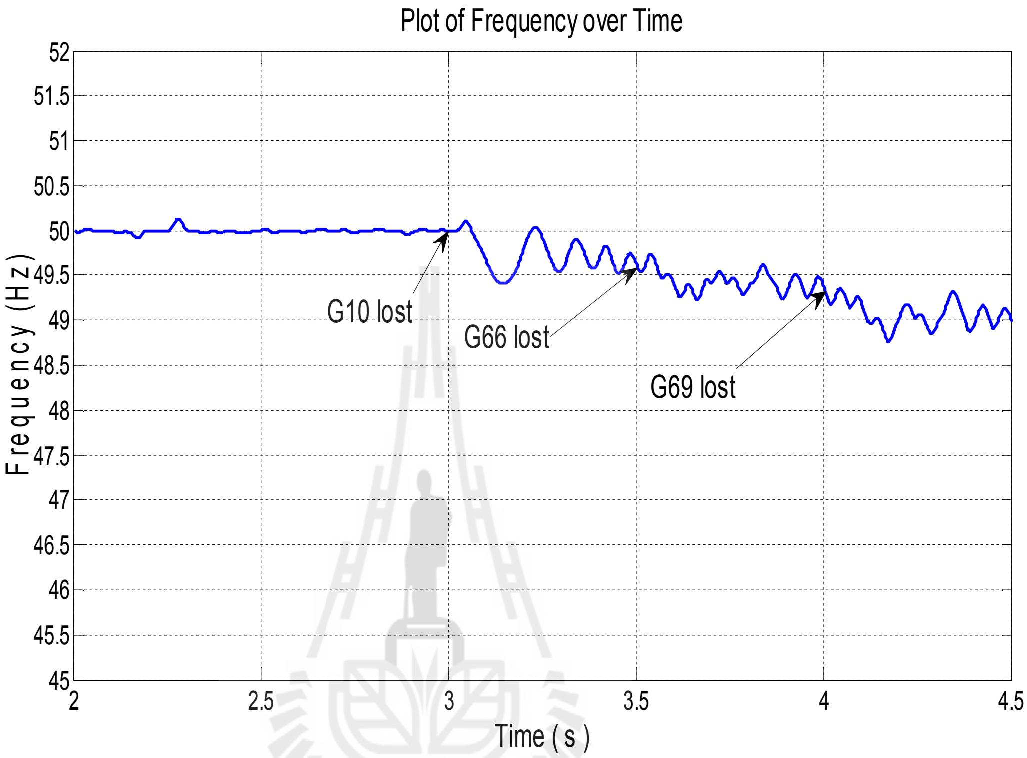


Figure 6.69 System Frequency due to the loss of three generators.

- Loss of the first generator at Time=3s caused frequency to decline to 49.5 Hz with some fluctuations. Another generator was lost at Time=3.5s which dropped the frequency further to near 49.25 Hz. Finally a third generator was lost at Time=4s and dropped the frequency to 49 Hz with severe fluctuations.

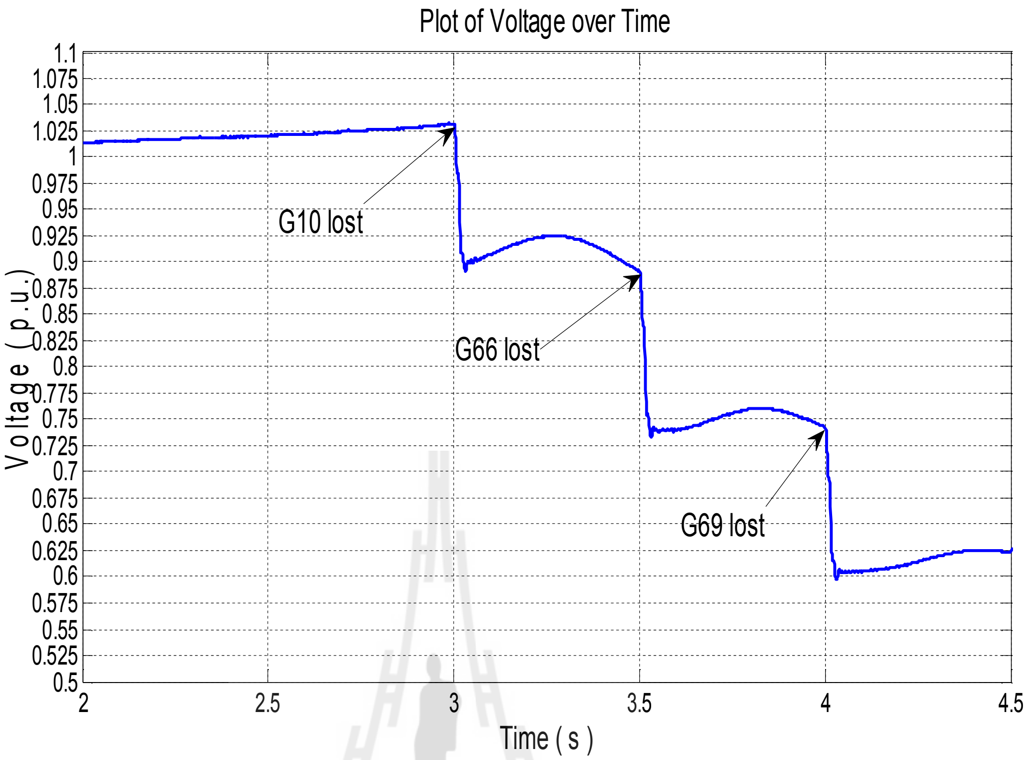


Figure 6.70 Voltages at the buses when there was a loss of three generators.

- Voltage was also affected by the loss of the generators. Initially the voltage was near 1.0125 p.u. until at Time = 3s when the first generator was lost which decreased the voltage to just below 0.9 p.u. and then increased to near 0.925 p.u. at Time= 3.25s with fluctuations. Then the votage dropped to just below 0.9 p.u. at Time=3.5s. At this time occurred the loss of another generator which decreased the voltage to 0.7375 p.u. It remained at this value until when Time = 4s when a third generator was lost which dropped the voltage to near 0.6 p.u. and increased again with severe fluctuations up to above 0.625 p.u. at Time = 4.5s.

Table 6.27 Loads shed by conventional and loads shed by scheme based on reactive power demand and priority.

Loads shed by Conventional scheme			Loads shed by scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	Mvar shed
1	51	27	59	277	113
2	20	9	76	68	36
3	39	10	18	60	34
4	39	12	54	113	32
6	52	22	79	39	32
7	19	2	75	42	31
8	28	0	11	39	30
11	70	23	15	90	30
12	47	10			
13	34	16			
14	14	1			
15	90	30			
16	25	10			
17	11	3			
18	60	34			
19	45	25			
20	18	3			
21	14	8			

Table 6.28 Load shedding test conditions data using Conventional scheme and Scheme based on reactive power demand and priority for IEEE 80-bus.

Disturbance case	Time	MW lost	State	Load shed by Conventional scheme (No. of loads shed)	Load shed by Scheme based on reactive power demand (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G10, G66, G69	T=3 T=3.5 T=4	1358.4	Poor	18	8	10

Table 6.29 Loads shed by Scheme based on reactive power demand and loads shed by scheme based on reactive power demand and priority.

Loads shed by Scheme based on reactive power demand			Loads shed by Scheme based on reactive power demand and priority		
Bus no.	MW shed	MVar shed	Bus no.	MW shed	Mvar shed
59	277	113	59	277	113
76	68	36	76	68	36
18	60	34	18	60	34
54	113	32	54	113	32
79	39	32	79	39	32
75	42	31	75	42	31
11	39	30	11	39	30
15	90	30	15	90	30

Table 6.30 Load shedding test conditions data using Scheme based on reactive power demand and Load sheddding scheme based on reactive power demand and priority for IEEE 80-bus.

Disturbance case	Time	MW lost	State	Load shed by Scheme based on reactive power demand (No. of loads shed)	Load shed by Scheme based on reactive power demand and priority (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G10, G66, G69	T=3 T=4 T=5	1358.4	Poor	8	8	0

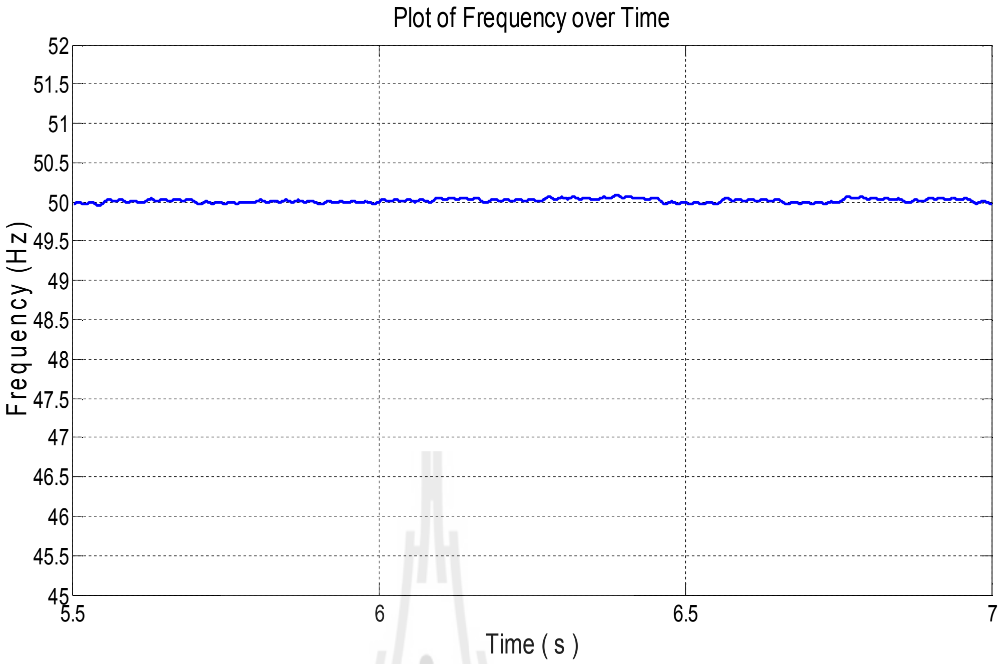


Figure 6.71 Frequency after load shedding by Conventional scheme.

- The frequency improves above the specified lower limit after the application of load shedding. It settles at rated value of 50 Hz.

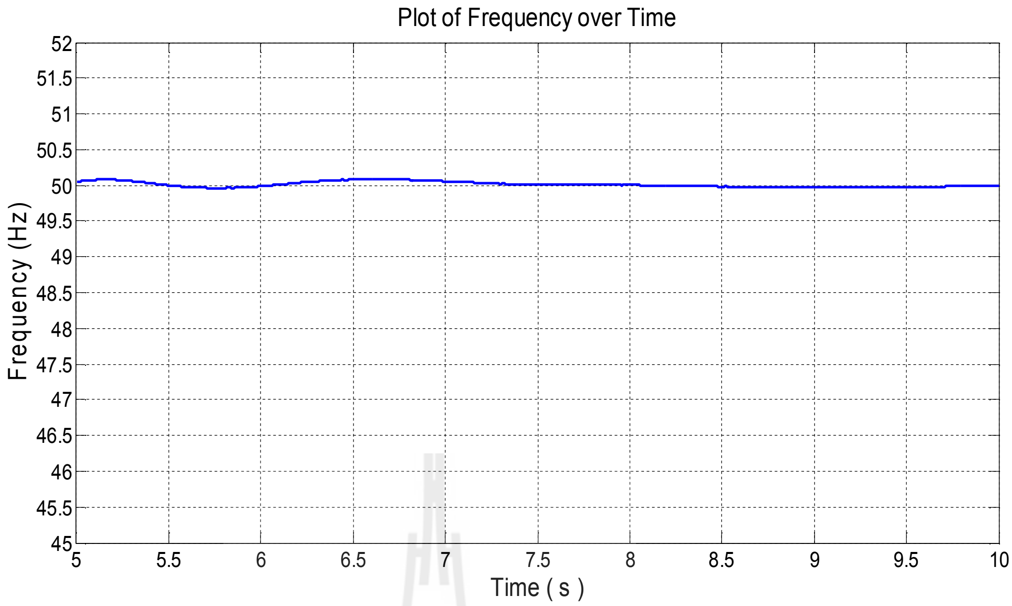


Figure 6.72 Frequency after load shedding by Scheme based on reactive power demand.

- The frequency improves above the specified lower limit after the application of load shedding. It settles at rated value of 50 Hz.

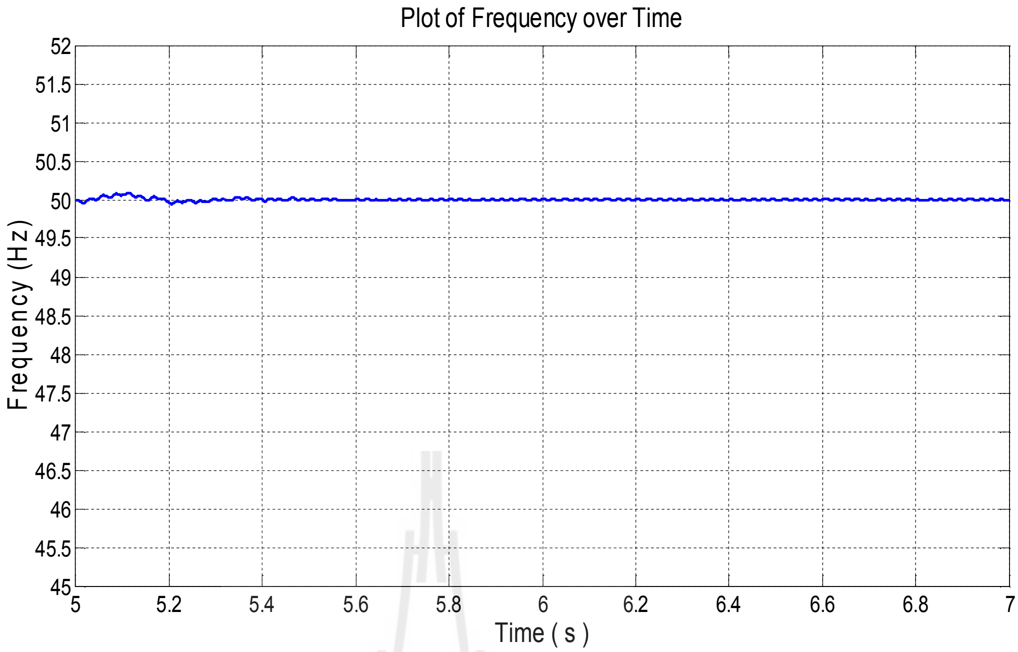


Figure 6.73 Frequency before and after applying Load shedding scheme based on reactive power demand and priority.

- The frequency improves above the specified lower limit after the application of load shedding. It settles at a value around 50 Hz.

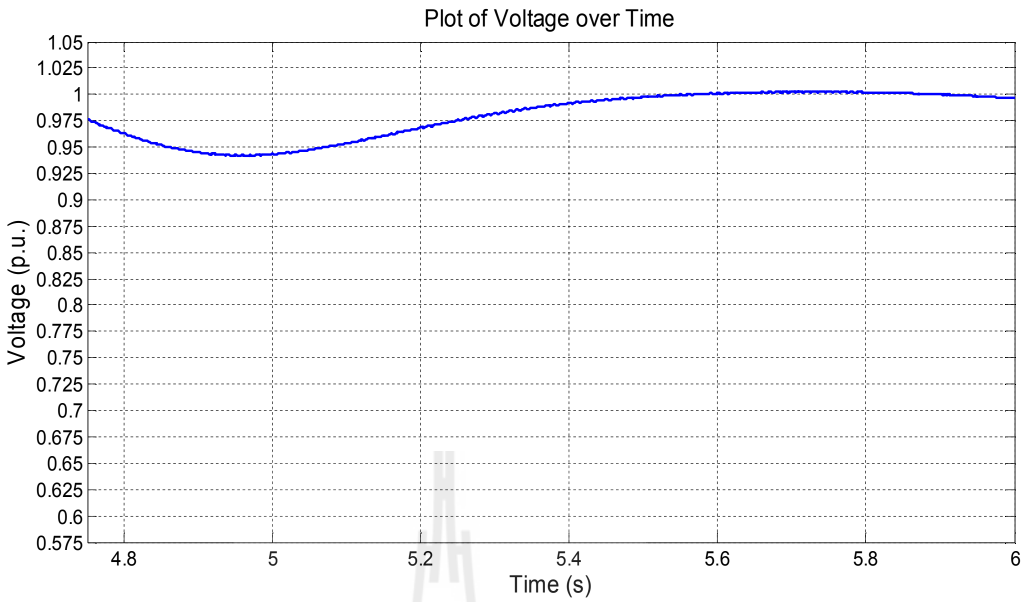


Figure 6.74 Voltage after load shedding by Conventional scheme.

- The voltage plot shows an improvement as well. The voltage fluctuations and dropping at the buses shown in figure 84 has been improved by appropriate amount of load shedding.

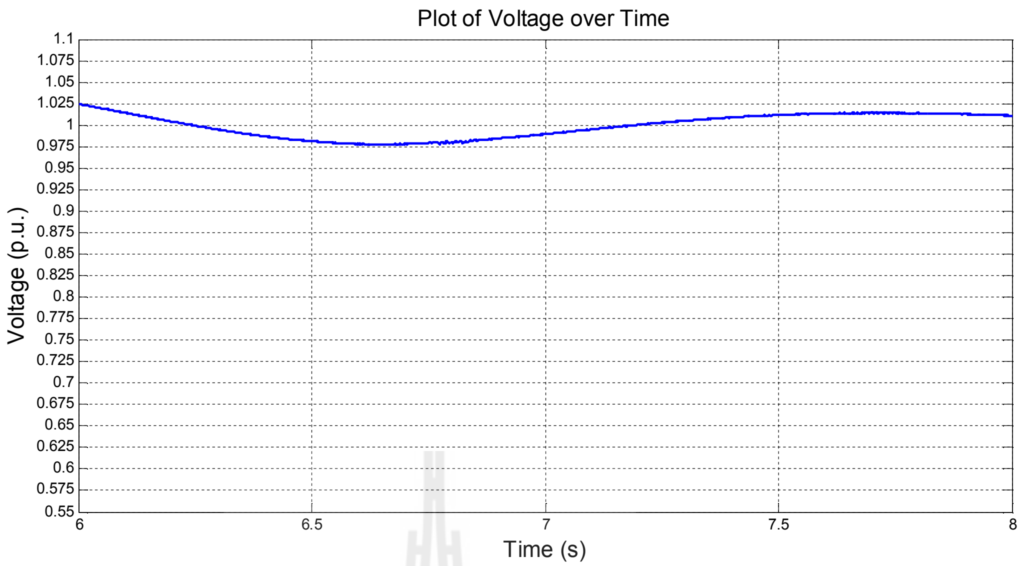


Figure 6.75 Voltage after load shedding by Scheme based on reactive power demand.

- The voltage plot shows an improvement as well. The voltage fluctuations and dropping at the buses shown in figure 84 has been improved by appropriate amount of load shedding.

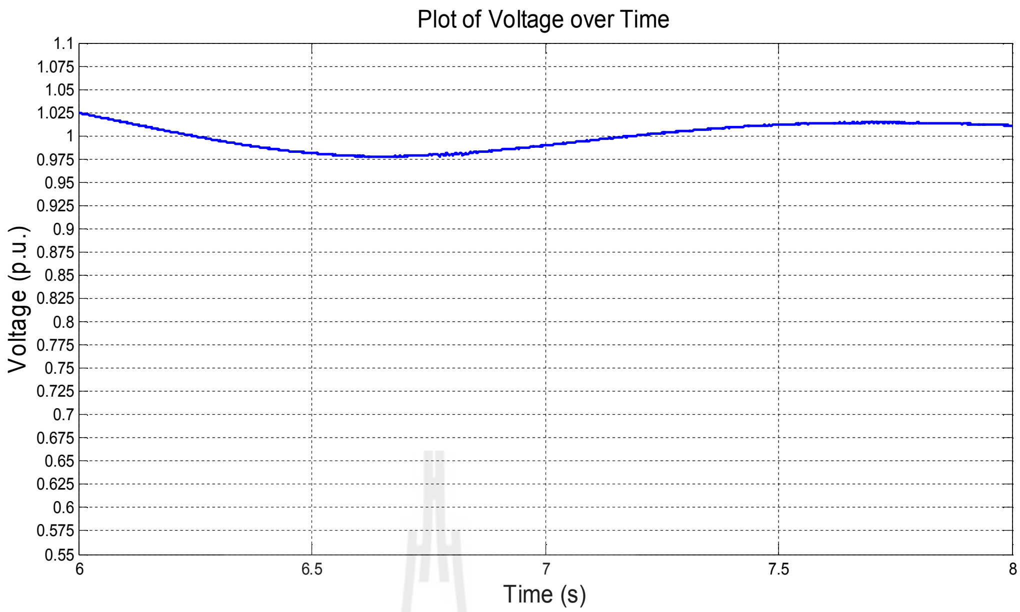


Figure 6.76 Voltage at the buses after applying Load shedding scheme based on reactive power demand and priority.

- The voltage plot shows an improvement as well. The voltage fluctuations and dropping at the buses shown in figure 84 has been improved by appropriate amount of load shedding.

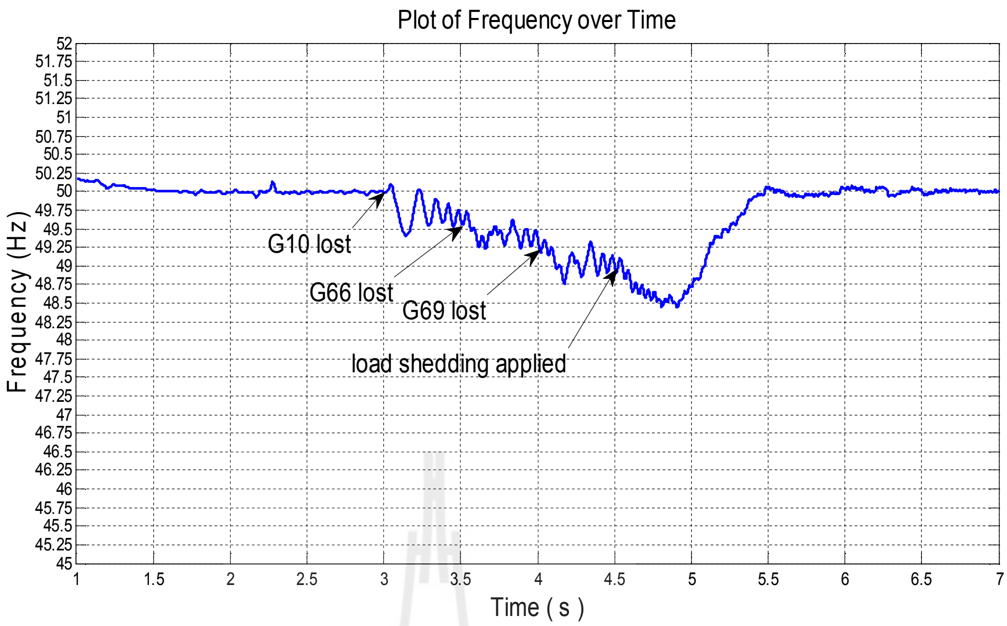


Figure 6.77 Frequency before and after load shedding by Conventional scheme.

- Loss of the first generator at Time=3s caused frequency dropped the frequency to 49.5 Hz. Another generator was lost at Time=3.5s which caused the frequency to decline to just below 49.25 Hz. Finally a third generator was lost at Time=4s and dropped the frequency further to 49 Hz at Time=4.5s. At this time load shedding was applied which restored it to just above above 50 Hz at Time=7s.

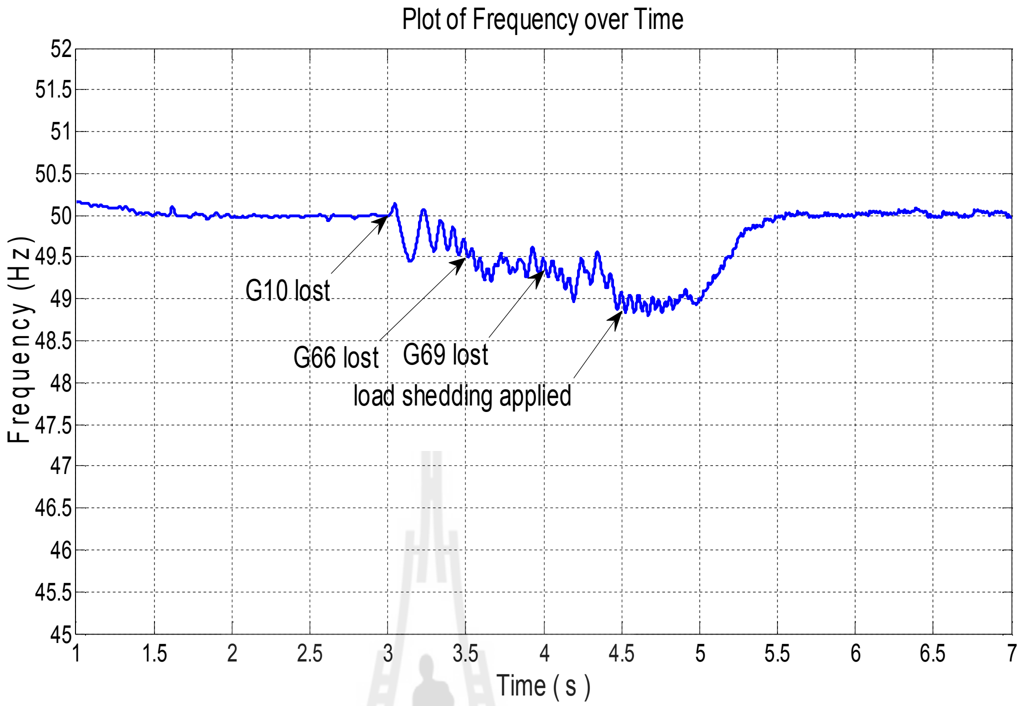


Figure 6.78 Frequency before and after load shedding by Scheme based on reactive power demand.

- Loss of the first generator at Time=3s caused frequency dropped the frequency to 49.5 Hz. Another generator was lost at Time=3.5s which caused the frequency to decline to just below 49.25 Hz. Finally a third generator was lost at Time=4s and dropped the frequency further to 49 Hz at Time=4.5s. At this time load shedding was applied which restored it to just above above 50 Hz at Time=7s.

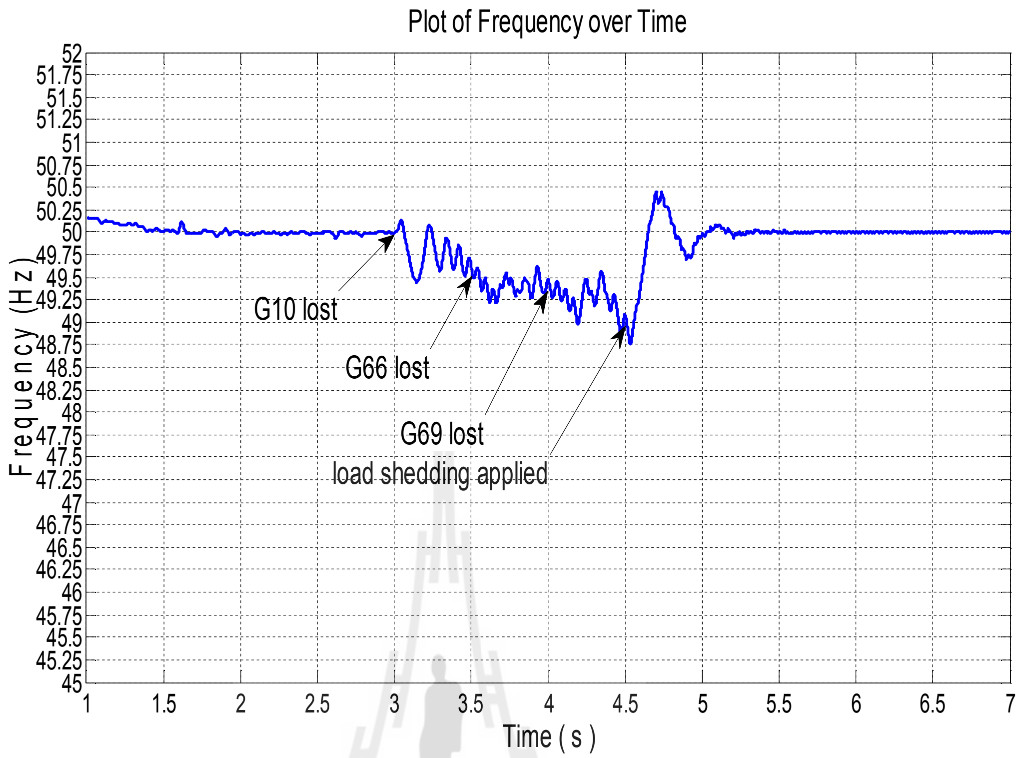


Figure 6.79 Frequency before and after load shedding by Load shedding scheme based on reactive power demand and priority.

- Loss of the first generator at Time=3s caused frequency dropped the frequency to 49.5 Hz. Another generator was lost at Time=3.5s which caused the frequency to decline to just below 49.25 Hz. Finally a third generator was lost at Time=4s and dropped the frequency further to 49 Hz at Time=4.5s. At this time load shedding was applied which restored it to just above above 50 Hz at Time=7s.

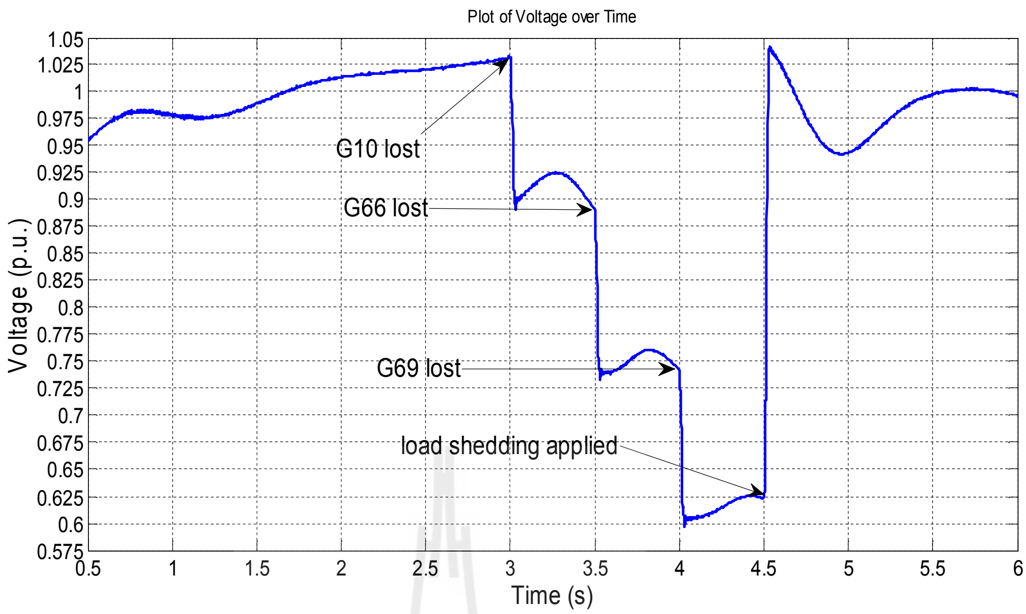


Figure 6.80 Voltage of the system before and after load shedding by Conventional scheme.

- Initially the voltage was 0.965 p.u. It increased to 1.03 p.u. at Time= 3s. At this time occurred the loss of the first generator which decreased the voltage to 0.89 p.u. Another generator was lost at Time=3.5s which decreased the voltage to 0.7375 p.u. A third generator was lost at Time=4s which decreased the voltage to 0.615 p.u. Load shedding was applied at Time=4.5s which increased the voltage to 0.99 p.u. at Time=6s.

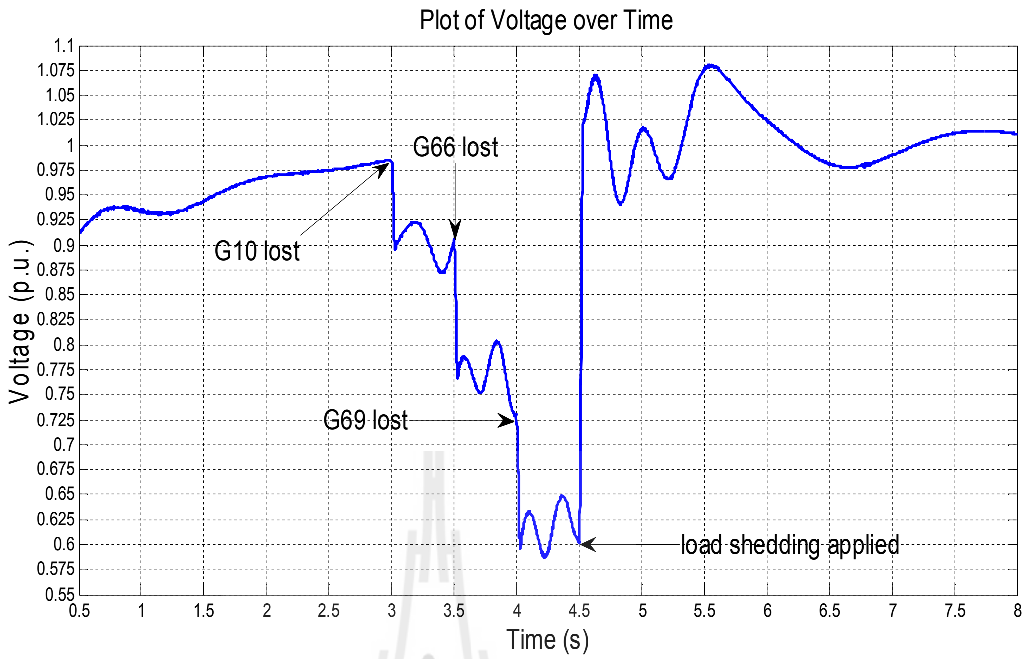


Figure 6.81 Voltage of the system before and after load shedding by Scheme based on reactive power demand.

- Initially the voltage was 0.965 p.u. It increased to 1.03 p.u. at Time= 3s. At this time occurred the loss of the first generator which decreased the voltage to 0.89 p.u. Another generator was lost at Time=3.5s which decreased the voltage to 0.7375 p.u. A third generator was lost at Time=4s which decreased the voltage to 0.615 p.u. Load shedding was applied at Time=4.5s which increased the voltage to 1.0125 p.u. at Time=8s.

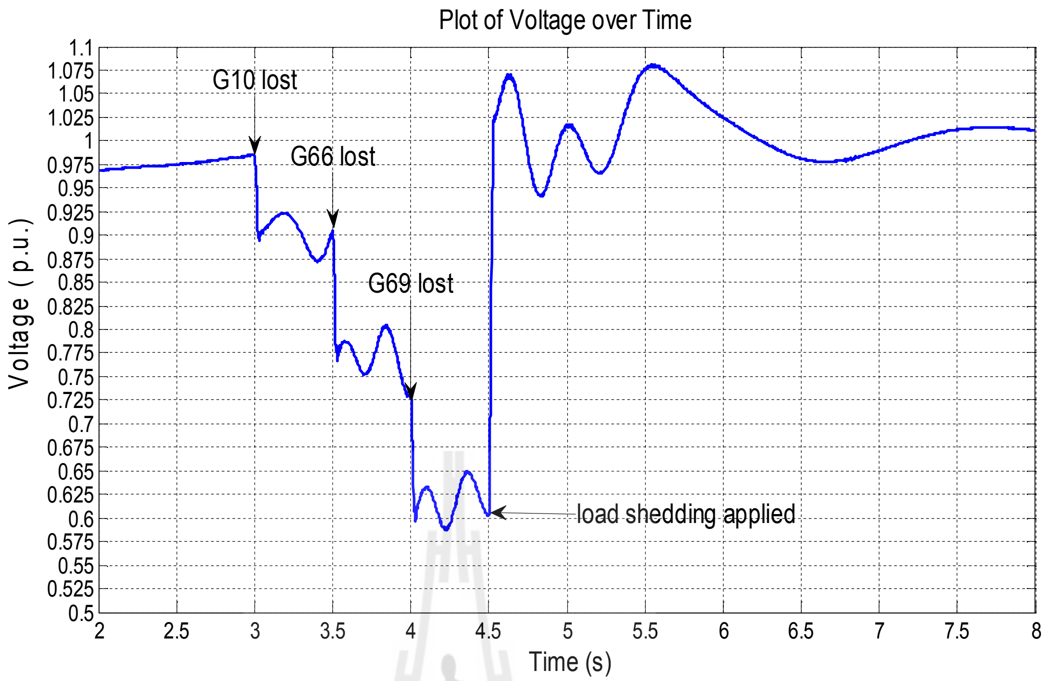


Figure 6.82 Voltage before and after applying Load shedding scheme based on reactive power demand and priority.

- Initially the voltage was 0.9125 p.u. It increased to 0.9875 p.u. at Time= 3s. At this time occurred the loss of the first generator which decreased the voltage to 0.89 p.u. Another generator was lost at Time=3.5s which decreased the voltage to 0.765 p.u. A third generator was lost at Time=4s which decreased the voltage below 0.60 p.u. Load shedding was applied at Time=4.5s which increased the voltage to just below 1.0125 p.u. at Time=8s.

6.7 IEEE 118 bus system

Table 6.31 Active and reactive power demand of loads and their priorities

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
1	51	27	89
2	20	9	45
3	39	10	54
4	39	12	58
6	52	22	74
7	19	2	17
8	28	0	14
11	70	23	80
12	47	10	51
13	34	16	67
14	14	1	16
15	90	30	91
16	25	10	49
17	11	3	26
18	60	34	94
19	45	25	81
20	18	3	25
21	14	8	38
22	10	5	29
23	7	3	24
24	13	0	13
27	71	13	60
28	17	7	36
29	24	4	28
31	43	27	86
32	59	23	78
33	23	9	44
34	59	26	88
35	33	9	45
36	31	17	68
39	27	11	56
40	66	23	2
41	37	10	52
42	96	23	76
43	18	7	34

Table 6.31 Active and reactive power demand of loads and their priorities (cont.).

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
44	16	8	41
45	53	22	79
46	28	10	51
47	34	0	12
48	20	11	59
49	87	30	93
50	17	4	27
51	17	8	40
52	18	5	30
53	23	11	57
54	113	32	97
55	63	22	77
56	84	18	4
57	12	3	23
58	12	3	22
59	277	113	99
60	78	3	21
62	77	14	62
66	39	18	73
67	28	7	35
70	66	20	75
72	12	0	11
73	6	0	10
74	68	27	90
75	47	11	55
76	68	36	98
77	61	28	92
78	71	26	85
79	39	32	96
80	130	26	84
82	54	27	87
83	20	10	50
84	11	7	31
85	24	15	66
86	21	10	47
88	48	10	48
90	163	42	5
91	10	0	9
92	65	10	49

Table 6.31 Active and reactive power demand of loads and their priorities (cont.).

Bus number	Active power demand (MW)	Reactive power demand (MVar)	Priority of loads
93	12	7	32
94	30	16	71
95	42	31	95
96	38	15	65
97	15	9	43
98	34	8	39
99	42	0	8
100	37	18	72
101	22	15	64
102	5	3	20
103	23	16	69
104	38	25	82
105	31	26	83
106	43	16	70
107	50	12	61
108	2	1	15
109	8	3	19
110	39	30	1
112	68	13	3
113	6	0	7
114	8	3	18
115	22	7	33
116	184	0	6
117	20	8	37
118	33	15	63
Total	**4242**	**1438**	

Where priority loads are:

- Load bus number 90 - Large industrial facility.
- Load bus number 110 - Hospital.
- Load bus number 56 - University.
- Load bus number 112 - Military complex.
- Load bus number 40 - Presidential palace.

Load bus number 110 with priority 1 has highest priority while load bus number 59 with priority 97 has the lowest priority. The scheme would shed loads starting with the one having highest reactive power demand and lowest priority in descending order. This means load bus number 59 would be shed first while load bus number 110 would be last to shed.

Table 6.32 Output power of generators at different buses.

Bus number	Output power (MW)
10	450
12	85
25	22
26	314
31	7
46	19
49	204
54	48
59	155
61	160
65	391
66	392
69	516.4
80	477
87	4
89	607
100	252
103	40
111	36
Total	**4179.4**

6.7.1 Loss of three generators at Time=3s, Time=3.25s and Time=3.5s.

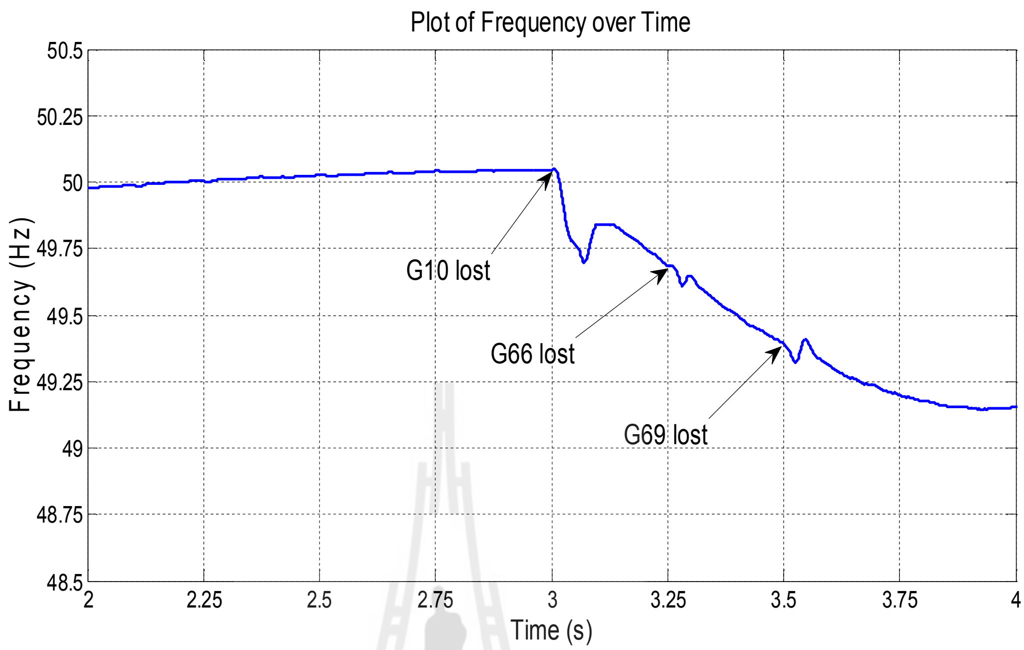


Figure 6.83 Frequency decline due to the loss of a generator.

- Loss of the first generator at Time=3s caused frequency to decline to just below 49.75 Hz with some fluctuations. Another generator was lost at Time=3.25s which decreased the frequency to just above 49.2625 Hz at Time=3.5s and a third generator was lost at that time which dropped the frequency further to above 49.125 Hz at Time=4s.

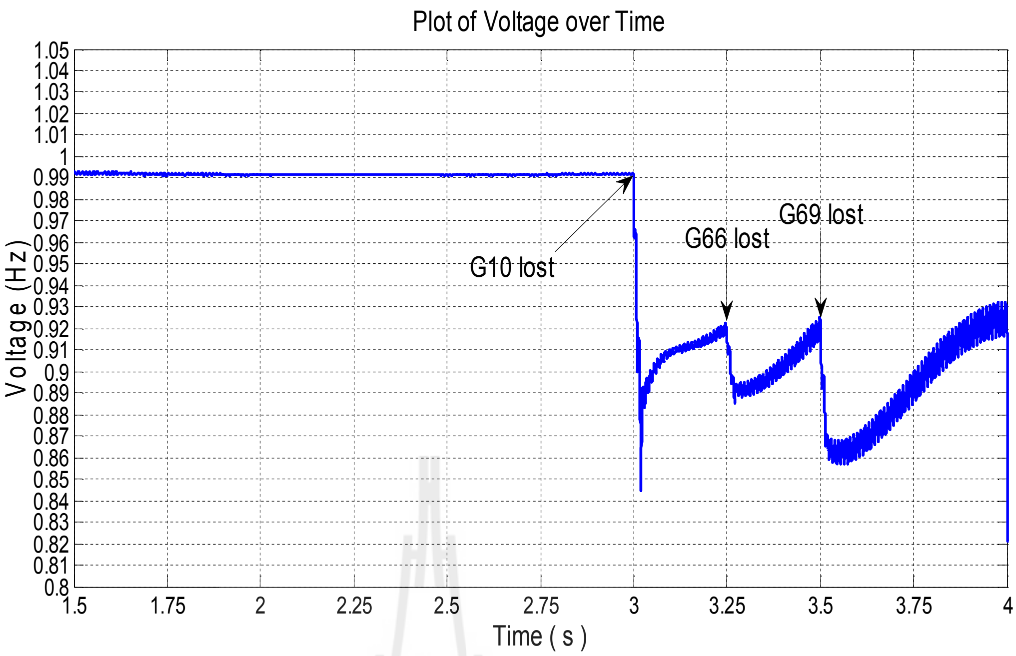


Figure 6.84 Voltage plot after loss of three generators.

- Voltage was 0.99375 p.u. until at Time=3s when the first generator was lost which caused voltage to drop to just below 0.85 p.u. and increased to near 0.925 p.u. at Time=3.25s when the second generator was lost. This decreased the voltage to 0.8875 p.u. and increased to 0.925 p.u. at Time= 3.5s with fluctuations. At this time occurred the loss of the third generator which decreased the voltage to 0.9167 p.u. Another generator was lost at Time=3.5s which decreased the voltage just below 0.86 p.u. and increased again to within 0.93 p.u. at Time=4s but very unstable.

Table 6.33 Loads shed by Conventional scheme and Scheme based on reactive power demand and priority.

Loads shed by Convensional scheme			Loads shed by Scheme based on reactive power demand and priority		
Bus number	MW shed	MVar shed	Bus number	MW shed	MVar shed
1	51	27	59	277	113
2	20	9	76	68	36
3	39	10	18	60	34
4	39	12	54	113	32
6	52	22	79	39	32
7	19	2	95	42	31
8	28	0	15	90	30
11	70	23	49	87	30
12	47	10	77	61	28
13	34	16	1	51	27
14	14	1	31	43	27
15	90	30	74	68	27
16	25	10	82	54	27
17	11	3	80	130	26
18	60	34			
19	45	25			
20	18	3			
21	14	8			
22	10	5			
23	7	3			
24	13	0			
27	71	13			
28	17	7			
29	24	4			
31	43	27			
32	59	23			
33	23	9			
34	59	26			
35	33	9			
36	31	17			
39	27	11			
41	66	23			

Table 6.34 Test conditions data of load shedding using Conventional scheme and Load sheddding scheme based on reactive power demand and priority.

Disturbance	Time	MW lost	System state	Loads shed by Conventional scheme (No. of loads shed)	Loads shed by Proposed scheme (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G10, G66, G69	T=3 T=3.5 T=4	1358.4	Poor	32	14	18

Table 6.35 Loads shed by Scheme based on reactive power demand and Scheme based on reactive power demand and priority.

Loads shed by Scheme based on reactive power demand			Loads shed by Scheme based on reactive power demand and priority		
Bus number	MW shed	MVar shed	Bus number	MW shed	MVar shed
59	277	113	59	277	113
90	163	42	76	68	36
76	68	36	18	60	34
18	60	34	54	113	32
40	66	33	79	39	32
54	113	32	95	42	31
79	39	32	15	90	30
95	42	31	49	87	30
15	90	30	77	61	28
49	87	30	1	51	27
110	39	30	31	43	27
77	61	28	74	68	27
1	51	27	82	54	27
			80	130	26

Table 6.36 Test conditions data of load shedding using Scheme based on reactive power demand and Scheme based on reactive power demand and priority.

Disturbance	Time	MW lost	System state	Loads shed by Scheme based on reactive power demand and priority (No.of loads shed)	Loads shed by Scheme based on reactive power demand (No.of loads shed)	Prevention of unnecessary shedding (No. of loads shed)
Outage of G10, G66, G69	T=3 T=3.5 T=4	1358.4	Poor	14	13	1

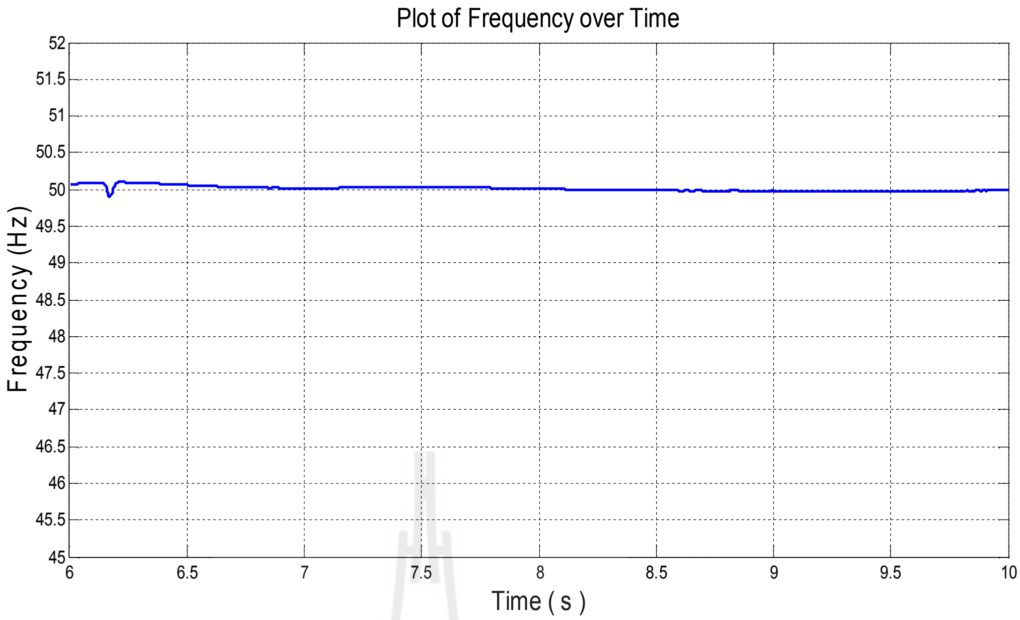


Figure 6.85 Frequency after load shedding by Conventional scheme.

- The frequency improves above the specified lower limit. It settles at a value close to 50 Hz. Scheme shed loads regardless of the reactive power demand of the of loads. The scheme shed 39 loads to restore balance in the system.

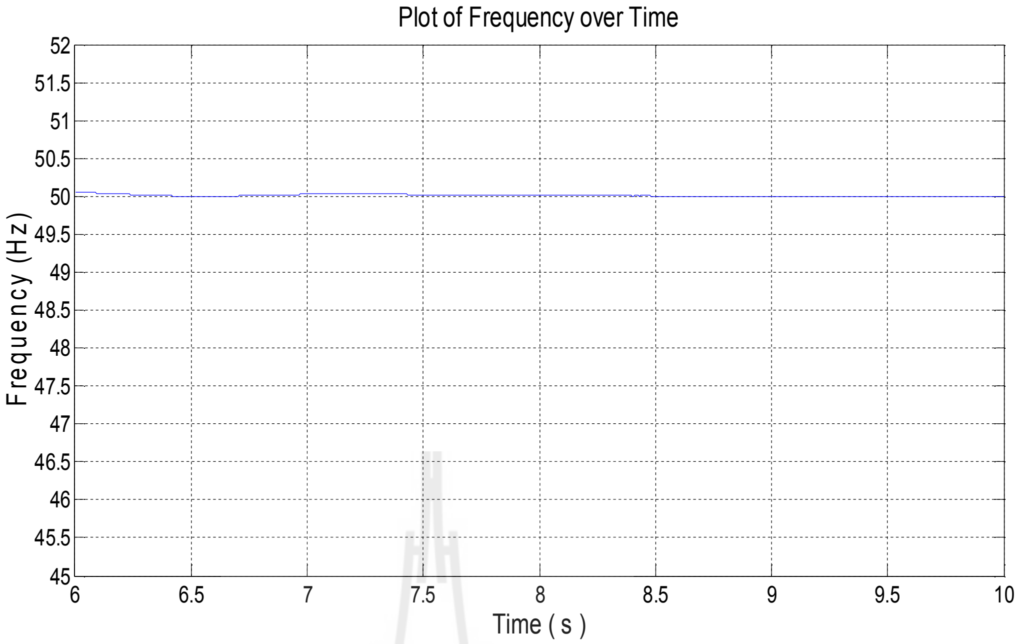


Figure 6.86 Frequency after load shedding by Scheme based on reactive power demand.

- The frequency improves above the specified lower limit. It settles at a value close to 50 Hz. Scheme shed loads regardless of the reactive power demand of the of loads. The scheme shed 39 loads to restore balance in the system.

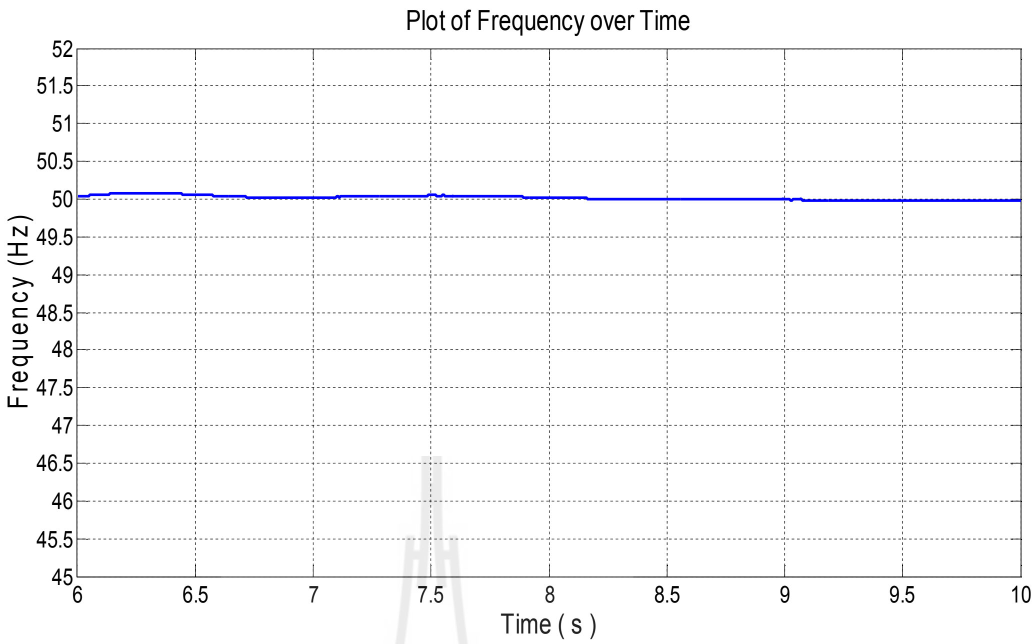


Figure 6.87 Frequency after load shedding by scheme based on reactive power demand and priority.

- The frequency improves above the specified lower limit. It settles at a value close to 50 Hz. Scheme shed loads based on the reactive power demand of the of loads. The scheme shed 14 loads.

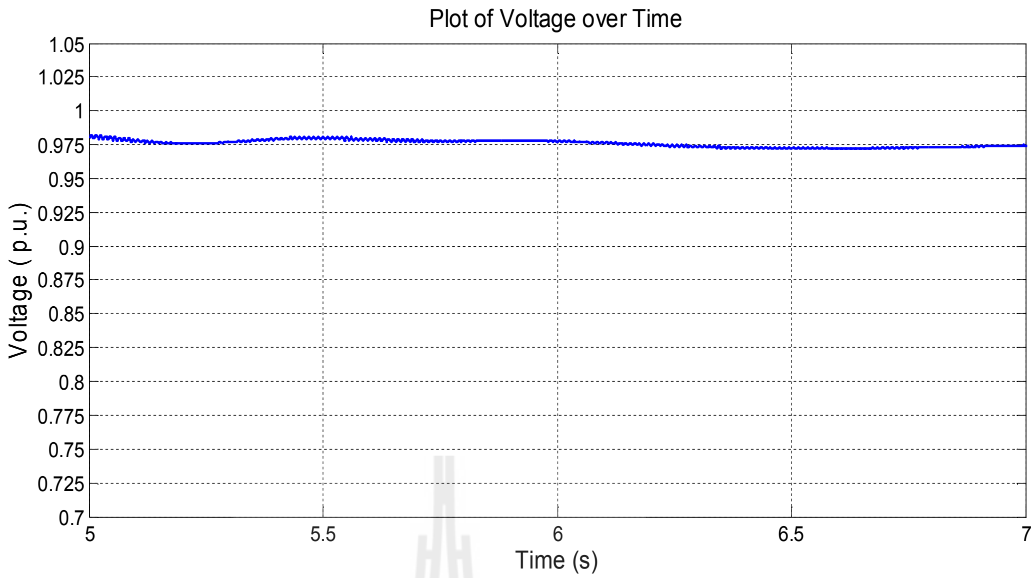


Figure 6.88 Voltages at buses after load shedding by Conventional scheme.

- The voltage plot shows an improvement as well after fluctuations for a while. The final voltage at the buses has improved due to the appropriate amount of shedding. Scheme shed 39 loads.

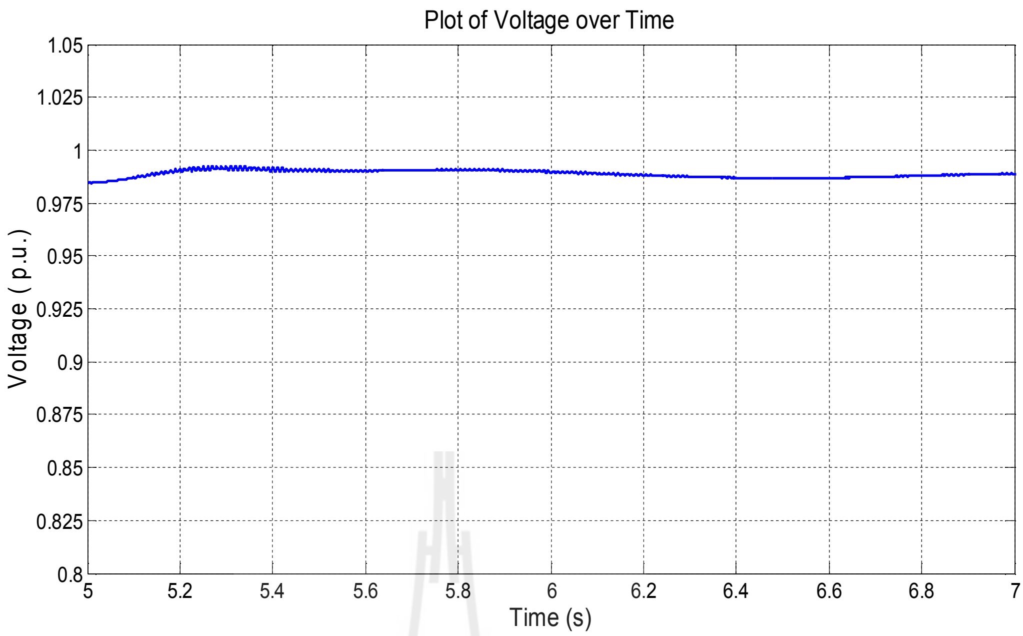


Figure 6.89 Voltages at buses after load shedding by Scheme based on reactive power demand.

- The voltage plot shows an improvement as well after fluctuations for a while. The final voltage at the buses has improved due to the appropriate amount of shedding. Scheme shed 39 loads.

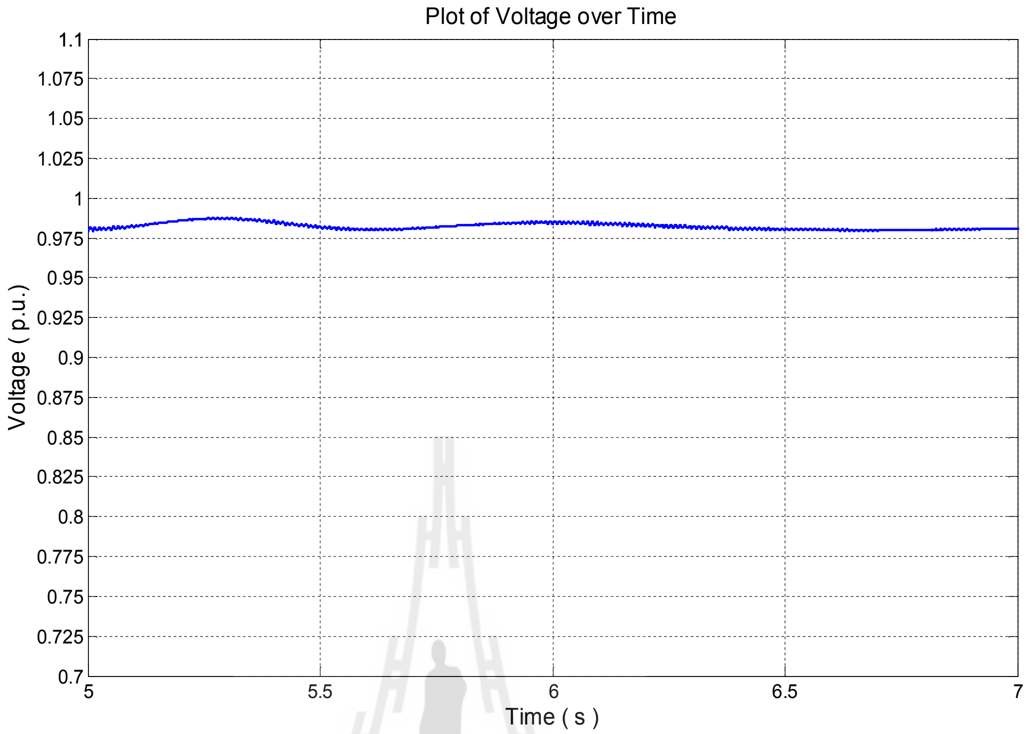


Figure 6.90 Voltages at buses after applying Load shedding scheme based on reactive power demand and priority.

- The voltage plot shows an improvement as well. Voltage at the buses shown in figure 98 has improved due to the appropriate amount of shedding. Scheme shed 14 loads based on the reactive power demand of the loads. This shows the advantage of shedding loads based on the reactive power demand as the number of loads shed is small.

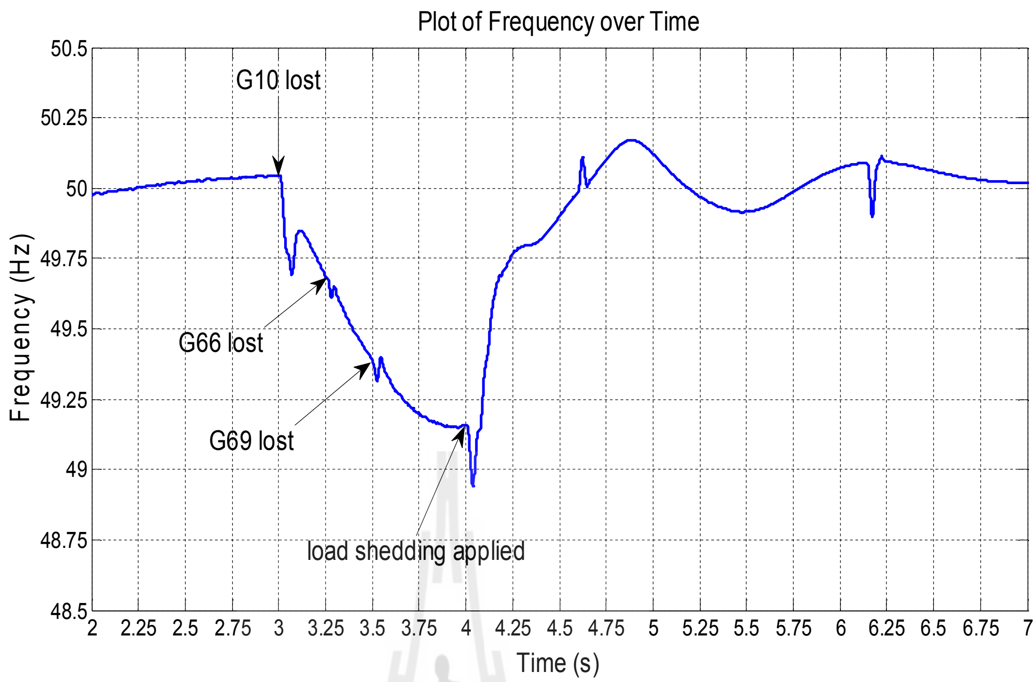


Figure 6.91 Frequency of the system before and after load shedding by Conventional scheme.

- Loss of the first generator at Time=3s caused frequency to decline to just below 49.75 Hz with some fluctuations. Another generator was lost at Time=3.25s which decreased the frequency to just above 49.2625 Hz at Time=3.5s and a third generator was lost at that time which dropped the frequency further to above 49.125 Hz at Time=4s when load shedding was applied which restored the frequency up to its rated value of 50 Hz.

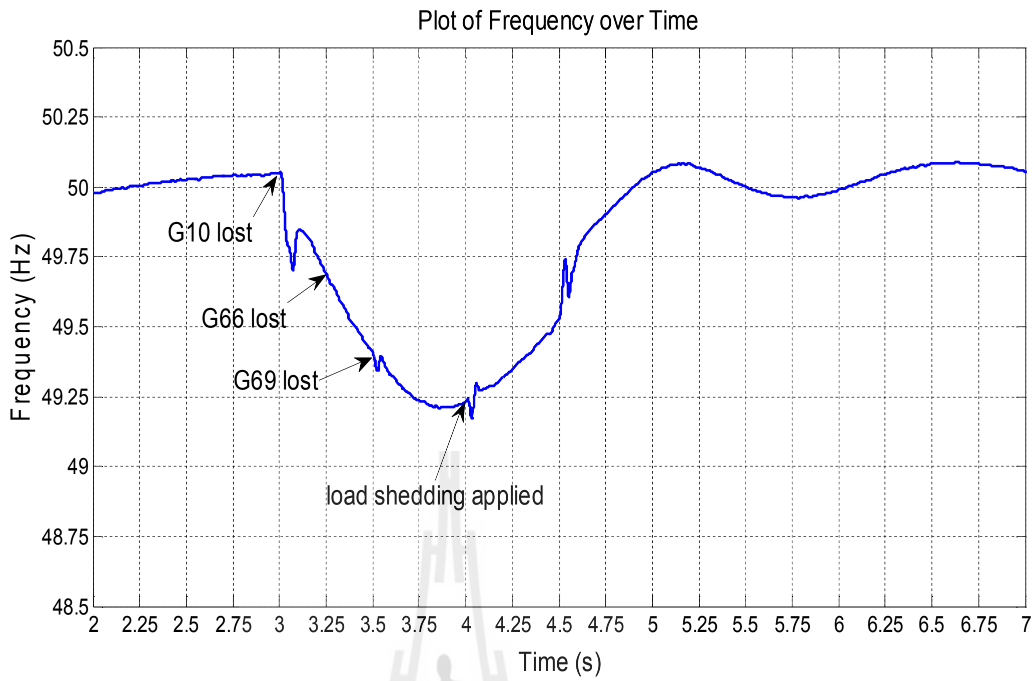


Figure 6.92 Frequency of the system before and after load shedding by Scheme based on reactive power demand.

- Loss of the first generator at Time=3s caused frequency to decline to just below 49.75 Hz with some fluctuations. Another generator was lost at Time=3.25s which decreased the frequency to just above 49.2625 Hz at Time=3.5s and a third generator was lost at that time which dropped the frequency further to above 49.125 Hz at Time=4s when load shedding was applied which restored system frequency to within its rated value of 50 Hz.

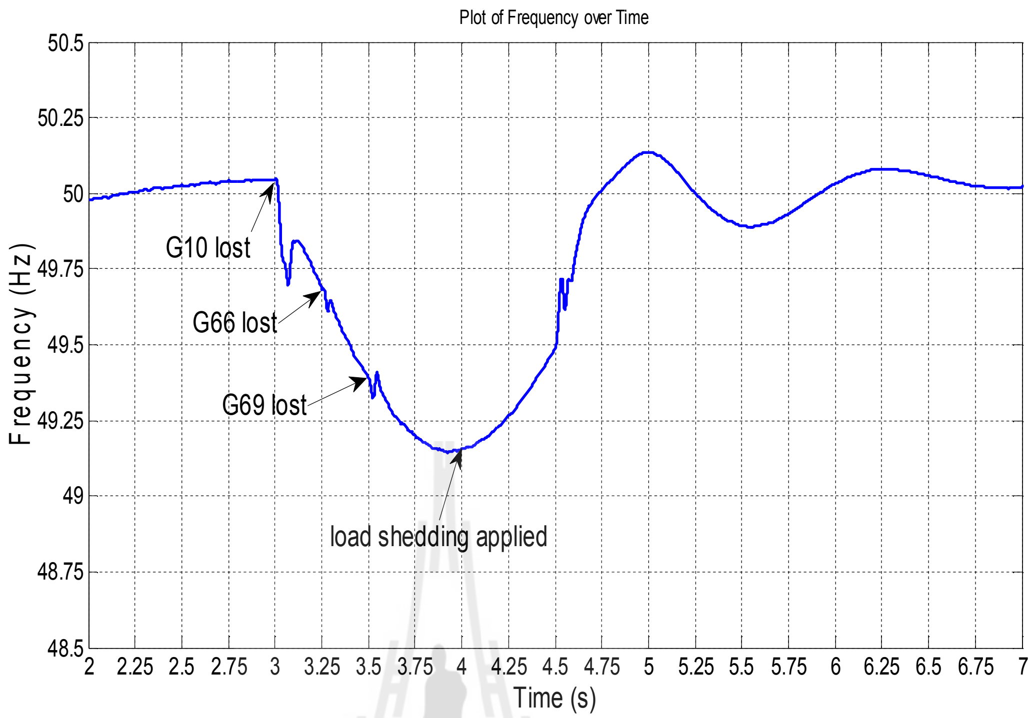


Figure 6.93 Frequency of the system before and after applying Load shedding scheme based on reactive power demand and priority.

- Loss of the first generator at Time=3s caused frequency to decline to just below 49.75 Hz with some fluctuations. Another generator was lost at Time=3.25s which decreased the frequency to just above 49.2625 Hz at Time=3.5s and a third generator was lost at that time which dropped the frequency further to above 49.125 Hz at Time=4s when load shedding was applied which restored it to 50 Hz.

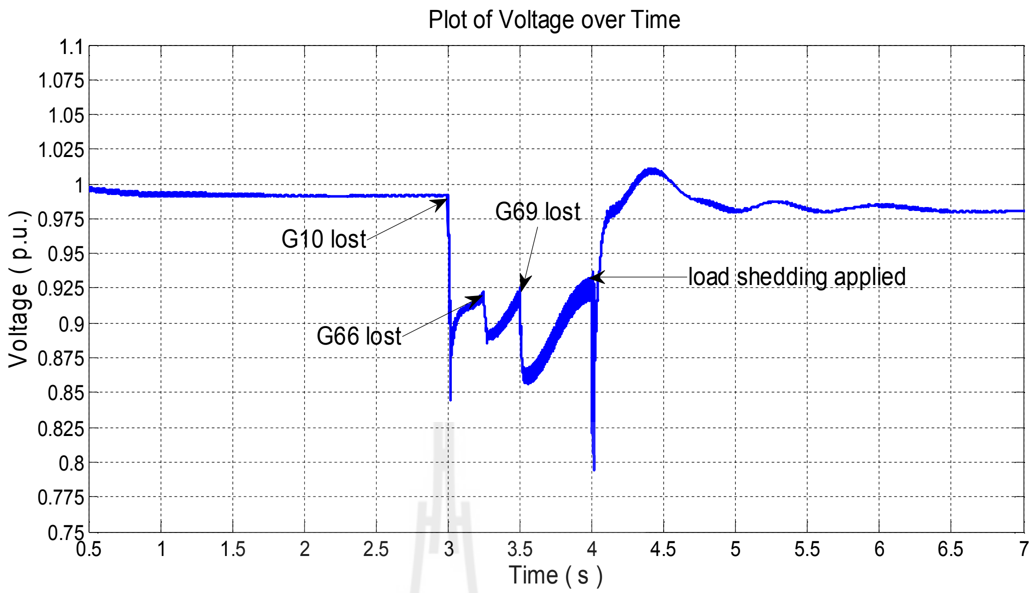


Figure 6.94 Voltage before and after load shedding by Conventional scheme.

- Voltage was 0.99375 p.u. until at Time=3s when the first generator was lost which caused voltage to drop to just below 0.85 p.u. and increased to near 0.925 p.u. at Time=3.25s when the second generator was lost. This decreased the voltage to 0.8875 p.u. and increased to 0.925 p.u. at Time= 3.5s with fluctuations. At this time occurred the loss of the third generator which decreased the voltage to 0.9167 p.u. Another generator was lost at Time=3.5s which decreased the voltage just below 0.86 p.u. and increased again to within 0.93 p.u. at Time=4s but very unstable. At that time load shedding was applied which improved the voltage to just above 0.975 p.u. at Time=5s and remained within that value up to the end of the simulation.

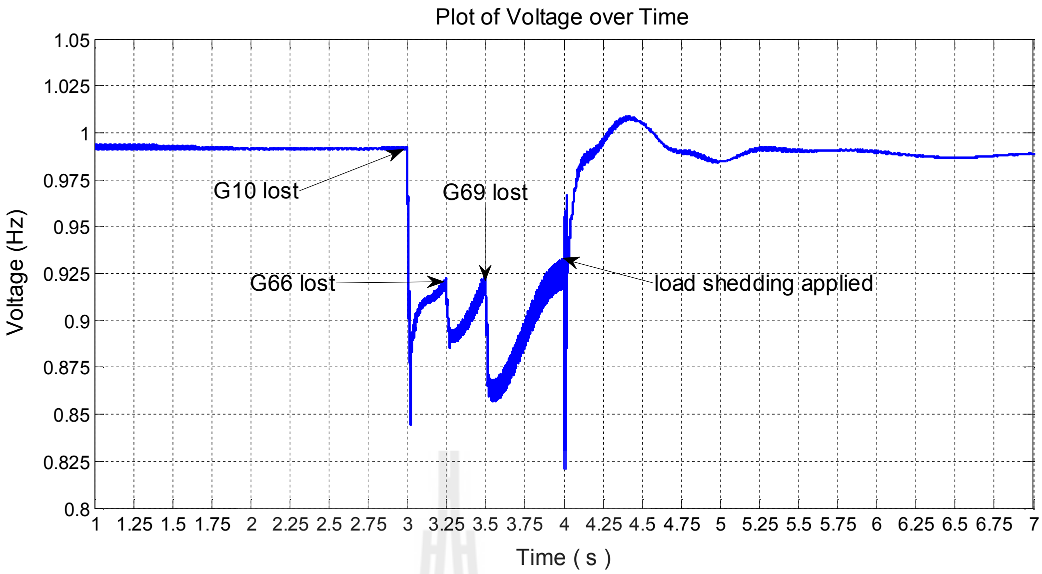


Figure 6.95 Voltage before and after load shedding by Scheme based on reactive power demand.

- Voltage was 0.99375 p.u. until at Time=3s when the first generator was lost which caused voltage to drop to just below 0.85 p.u. and increased to near 0.925 p.u. at Time=3.25s when the second generator was lost. This decreased the voltage to 0.8875 p.u. and increased to 0.925 p.u. at Time= 3.5s with fluctuations. At this time occurred the loss of the third generator which decreased the voltage to 0.9167 p.u. Another generator was lost at Time=3.5s which decreased the voltage just below 0.86 p.u. and increased again to within 0.93 p.u. at Time=4s but very unstable. At that time load shedding was applied which improved the voltage to near 0.99 p.u. at Time=5.25s and remained within that value up to the end of simulation although there are slight fluctuations.

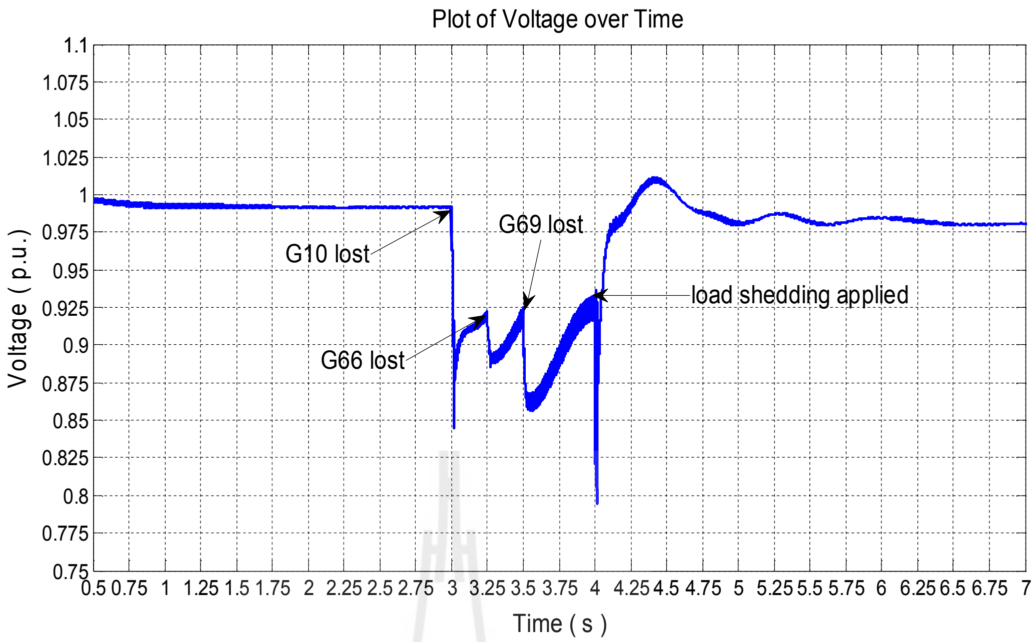


Figure 6.96 Voltage before and after applying Load shedding by scheme based on reactive power demand and priority.

- Voltage was 0.99375 p.u. until at Time=3s when the first generator was lost which caused voltage to drop to just below 0.85 p.u. and increased to near 0.925 p.u. at Time=3.25s when the second generator was lost. This decreased the voltage to 0.8875 p.u. and increased to 0.925 p.u. at Time= 3.5s with fluctuations. At this time occurred the loss of the third generator which decreased the voltage to 0.9167 p.u. Another generator was lost at Time=3.5s which decreased the voltage just below 0.86 p.u. and increased again to within 0.93 p.u. at Time=4s but very unstable. At that time load shedding was applied which improved the voltage to just above 0.975 p.u. at Time=5.25s up to the end of simulation.

6.8 Power flow solutions of IEEE 57-bus and IEEE 118-bus

The benefit in voltage improvement in underfrequency load shedding scheme that shed loads based on the reactive power demand of the loads over conventional method can also be realized by power flow solutions of IEEE 57-bus and IEEE 118-bus power systems.

Step 1:

Power flow solution of IEEE 57-bus and IEEE 118-bus power systems was run under normal condition.

Step 2:

Power imbalance was created in the systems by shutting down some generations at buses number 1 and 2 for IEEE 57- bus and buses number (12,28,29,78) for IEEE 118-bus. Power flow solution of the systems was run under abnormal operating conditions.

Step 3:

In the first case, high priority loads were positioned at the bottom of bus data to avoid shedding them and then loads were shed regardless of the reactive power demand of loads until power deficit became equal or just below 321.9 (IEE 57-bus) and 518 (IEEE 118-bus). Power flow solutions were run to observe voltages at the buses after load shedding. Results showed improvement in voltages at the buses. The scheme needed to shed 8 loads (IEEE 57 bus) and 25 loads (IEEE 118-bus).

Step 5:

In another case, bus data were sort with regard to the reactive power demand of loads. Then high priority loads were positioned at the bottom of bus data to avoid shedding them. Loads were shed with regard to the reactive power demand of loads. Power flow solutions were run to observe voltages at the buses after load shedding. Results showed improvement in voltages at the buses. The scheme needed to shed 3 loads (IEEE 57 bus) and 12 loads (IEEE 118-bus).

Results are shown in Appendix A.

6.9 Chapter summary

This chapter has presented simulations results of Conventional load shedding scheme and developed load shedding schemes when they were applied to test systems shown in chapter 5. In IEEE 9-bus two schemes were applied in which both schemes shed one load to restore balance in the system. Frequency and voltage plots of both schemes are the same because both schemes shed the same load to restore balance in the system..

In IEEE 14-bus, after the loss of two generators, Conventional scheme and Scheme based on reactive power demand and priority shed three loads to restore frequency and improve voltage while Scheme based on reactive power demand shed two loads. Both frequency and voltage plots of Scheme based on reactive power demand show fast restoration of system frequency and voltage and gives higher values of those parameters at the end of the simulations. Frequency and voltage plots also show that Load shedding scheme based on reactive power demand has given better results than Conventional load shedding scheme .

For IEEE 30-bus, after the loss of two generators, Conventional scheme shed 6 loads, Scheme based on reactive power demand and priority shed 3 loads but Scheme based on reactive power demand shed 2 loads. Both frequency and voltage plots of Scheme based on reactive power demand show fast restoration of frequency and voltage and gives higher values of those parameters at the end of the simulations followed by Scheme based on reactive power demand and priority.

Simulations of IEEE 57-bus load shedding after the loss of three generators has shown that both schemes that is Conventional scheme and Scheme based on reactive power demand and priority shed 9 loads. When Scheme based on reactive power demand was applied only 4 load shedding was enough to resore balance in the system. Both frequency and voltage plots of Scheme based on reactive power demand show fast restoration of frequency and voltage and gives higher values of those parameters at the end of the simulations. For voltage, plot of scheme based on reactive power demand and priority is the second best but for frequency it is the plot of Conventional scheme that is the second best.

In 80-bus power system, after the loss of three generators Conventional scheme shed 18 loads as compared to 8 loads shed by Scheme based on reactive power demand and priority and Scheme based on reactive power demand. In this case frequency and voltage plots of Scheme based on reactive power demand show fast restoration of frequency and voltage and gives higher values of those parameters at the end of the simulations. Voltage plot of scheme based on reactive power demand and priority is better than Conventional scheme plot.

For the case of IEEE 118-bus this chapter has shown that, Conventional scheme shed 32 loads, Scheme based on reactive power demand and priority shed 14 loads and Scheme based on reactive power demand shed 13 loads to restore declining system frequency and improve voltages. Both frequency and voltage plots of Scheme based on reactive power demand and priority show fast restoration of frequency and voltage and gives higher values of those parameters at the end of the simulations. Voltage plot of scheme based on reactive power demand is better than Conventional scheme plot. Simulations results have shown that Load shedding scheme based on reactive power demand shed few number of loads compared to Load shedding scheme based on reactive power demand and priority.

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

A load shedding scheme, when implemented, sheds selected nonpriority loads from the distribution system to reduce the demand to within the capacity of online generators in response to imbalance in the system which can cause underfrequency, voltage instability, generation overload, etc. These conditions can occur when there is a large or sudden disturbance or system fault(s) leading to a reduction in generation capacity. If such conditions are not cleared adequately, can lead to a total system collapse. In a large utility system, under frequency load shedding and under voltage load shedding are well developed and widely used to deal with overloads.

This thesis presented an adaptive underfrequency load shedding scheme based on reactive power demand, an adaptive underfrequency load shedding scheme based on reactive power demand and priority and a computational intelligency technique load shedding scheme based on Harmony Search Algorithm which have given better results in dealing with the load shedding requirement than a Conventional scheme.

These schemes were applied to IEEE 9-bus, IEEE 14-bus, IEEE 30-bus, IEEE 57-bus, 80-bus and IEEE 118-bus power systems.

Simulations of test systems show that loss of a single generator has huge effect in system frequency of a small power system as compared to a large system. In IEEE 9-bus power system loss of one generator was enough to create a severe decline of system frequency while in IEEE 14-bus and IEEE 30-bus a loss of one generator could not drop frequency to the extent of need of load shedding action. It was after the loss of two generators that frequency dropped below its rated value of 50 Hz and did not come back to normal until after the application of load shedding. In IEEE 57-bus, 80-bus and IEEE 118-bus it was the loss of three generators that caused severe frequency decline that needed load shedding. This is because, loss of generated power, system inertia and spinning reserve provided by a generator lost can be easily shared by a large number of generating units in large systems than a small number of generators in small systems. Another thing learnt is that, when frequency is allowed to drop to a very small value it becomes more difficult to restore it than when it is restored as soon as it starts to decline. Therefore there is a need for a utility company to have a scheme that is fast in response.

In addition, most of voltage plots obtained from simulations show that voltage improvement is better with load shedding scheme based on reactive power demand and Load shedding scheme based on reactive power demand and priority that shed loads based on reactive power demands of the loads than when shedding is done by Conventional scheme. This can been seen in most of voltage plots of simulations results of the test systems used.

Load shedding scheme based on reactive power demand and Load shedding scheme based on reactive power demand and priority which shed loads based on the rective power demand not only have better voltage improvement but also can shed few number of loads to restore balance in the system as compared to Conventional scheme. In 80 bus power system simulations, more loads, 18 were shed by Conventional scheme than Load shedding scheme based on reactive power demand

and Load shedding scheme based on reactive power demand and priority, 8, which shed loads based on the reactive power demand. In the case of IEEE 118-bus power system, Load shedding scheme based on reactive power demand shed 14 loads and Load shedding scheme based on reactive power demand and priority shed 13 loads compared to 32 loads that were shed by Conventional scheme to restore declining system frequency.

Results show that Load shedding scheme based on reactive power demand and Load shedding scheme based on reactive power demand and priority which shed loads based on the reactive power demand are more advantageous as the the size of the system increases. In the test systems used Load shedding scheme based on reactive power demand and priority and Conventional scheme both shed 1 load to restore balance in IEEE 9-bus and 3 loads in IEEE 14-bus. Simulations of IEEE 30-bus show that Conventional scheme shed 6 while Load shedding scheme based on reactive power demand and priority shed 3. For the case of IEEE 57-bus the number of loads shed is the same 9, but for 80-bus power system there is a very big difference in the number of loads shed to 18 for Conventional scheme and 8 for both Load shedding scheme based on reactive power demand and Load shedding scheme based on reactive power demand and priority. It further increases again in IEEE 118-bus where Conventional scheme shed 32 loads while Load shedding scheme based on reactive power demand and priority shed 14 loads and Load shedding scheme based on reactive power demand shed 13 loads.

Simulations results have shown that, Load shedding scheme based on reactive power demand shed few number of loads as compared to Load shedding scheme based on reactive power demand and priority. This is seen in the load shedding of IEEE 14-bus, IEEE 30-bus, IEEE 57-bus and IEEE 118-bus.

Furthermore, Load shedding scheme based on Harmony Search has also shown better performance than all the other schemes by shedding optimal amount of load at each bus within a single step to restore balance in the system, hence improving frequency as well as voltage fast due to its accuracy in finding amount of load to shed at each bus.

Finally, power flow solutions of all the two cases showed significant improvement in voltages at the buses but 16 loads were shed using Conventional scheme compared to 3 loads shed by Load shedding scheme based on reactive power demand and priority in IEEE 57-bus power system power flow solution. Twenty five (25) loads were shed using Conventional scheme compared to twelve (12) loads shed using Load shedding scheme based on reactive power demand and priority in IEEE 118-bus power system power flow solution. Reduction of loads shed is very helpful as the effect of blackout is felt in small part of the power system. Based on the simulink simulations and power flow solutions, Load shedding scheme based on reactive power demand and priority and Load shedding scheme based on Harmony Search are better than Conventional scheme.

7.2 Future work

A power system is subject to disturbances and faults for all its operating life. These are the main causes of unexpected outages in the equipment and imbalance in the system, thus degrading the electrical service. Severe disturbances take the system to an emergency status, making it necessary to implement control actions to prevent cascading outages in the equipment that would bring the collapse and disintegration of the system. Disturbances cause two types of emergencies called stability and viability crises.

The likelihood of having a generation deficit is very high and its effects are very severe. As generators are the most important and most costly equipment in the system, they are equipped with protection devices that automatically act upon the presences of a disturbance endangering the system. Thus, a power generation deficit is produced.

There are two options to face generation deficit:

i. Generation redispatch: the deficit is covered by the remaining generators, redispatching generation. This only applicable in a system with enough spinning reserve.

ii. Load shedding: the deficit is balanced through load shedding in some buses of the system, setting frequency steps to shed load blocks in specific buses. Less important loads are shed when the system's frequency drops to a determined level according to a previously assigned priority list. This option can be applied when facing a viability crisis.

When designing a load shedding scheme, the common practice is to determinine the load to be shed by means of transient stability studies. This shedding can be excessive or not enough if the optimization of the shed load is not considered.

Computational intelligency techniques are very efficient in dealing with these problems. In this research three techniques that is genetic algorithm, particle swarm and harmony search are used to find optimal load to shed in an underfrequency load shedding scheme. Their results are tested with the scheme to find which technique gives the most optimal load to be shed.

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APPENDIX A

POWER FLOW SOLUTIONS

Power flow solution of IEEE57-bus under normal operating condition

MATPOWER Version 4.1, 14-Dec-2011 -- AC Power Flow (Newton)

Newton's method power flow converged in 3 iterations.

Converged in 0.02 seconds

System Summary

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========How many? How much? P (MW) Q (MVAr)

How many?		How much?	P (MW)	Q (MVAr)
Buses	57	Total Gen Capacity	1975.9	-468.0 to 699.0
Generators	7	On-line Capacity	1975.9	-468.0 to 699.0
Committed Gens	7	Generation (actual)	1278.7	321.1
Loads	42	Load	1250.8	336.4
Fixed	42	Fixed	1250.8	336.4
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	3	Shunt (inj)	-0.0	21.6
Branches	80	Losses (I^2 * Z)	27.86	121.67
Transformers	17	Branch Charging (inj)	-	115.3
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	0.936 p.u. @ bus 31	1.060 p.u. @ bus 46
Voltage Angle	-19.38 deg @ bus 31	0.00 deg @ bus 1
P Losses (I^2*R)	-	3.90 MW @ line 1-15
Q Losses (I^2*X)	-	19.96 MVAr @ line 1-15

| Bus Data |
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Bus #	Voltage Mag(pu)	Voltage Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
1	1.040	0.000*	478.66	128.85	55.00	17.00
2	1.010	-1.188	0.00	-0.75	3.00	88.00
3	0.985	-5.988	40.00	-0.90	41.00	21.00
4	0.981	-7.337	-	-	-	-

5	0.976	-8.546	-	-	13.00	4.00
6	0.980	-8.674	0.00	0.87	75.00	2.00
7	0.984	-7.601	-	-	-	-
8	1.005	-4.478	450.00	62.10	150.00	22.00
9	0.980	-9.585	0.00	2.29	121.00	26.00
10	0.986	-11.450	-	-	5.00	2.00
11	0.974	-10.193	-	-	-	-
12	1.015	-10.471	310.00	128.63	377.00	24.00
13	0.979	-9.804	-	-	18.00	2.30
14	0.970	-9.350	-	-	10.50	5.30
15	0.988	-7.190	-	-	22.00	5.00
16	1.013	-8.859	-	-	43.00	3.00
17	1.017	-5.396	-	-	42.00	8.00
18	1.001	-11.730	-	-	27.20	9.80
19	0.970	-13.227	-	-	3.30	0.60
20	0.964	-13.444	-	-	2.30	1.00
21	1.008	-12.929	-	-	-	-
22	1.010	-12.874	-	-	-	-
23	1.008	-12.940	-	-	6.30	2.10
24	0.999	-13.292	-	-	-	-
25	0.983	-18.173	-	-	6.30	3.20
26	0.959	-12.981	-	-	-	-
27	0.982	-11.514	-	-	9.30	0.50
28	0.997	-10.482	-	-	4.60	2.30
29	1.010	-9.772	-	-	17.00	2.60
30	0.963	-18.720	-	-	3.60	1.80
31	0.936	-19.384	-	-	5.80	2.90
32	0.950	-18.512	-	-	1.60	0.80
33	0.948	-18.552	-	-	3.80	1.90
34	0.959	-14.149	-	-	-	-
35	0.966	-13.906	-	-	6.00	3.00
36	0.976	-13.635	-	-	-	-
37	0.985	-13.446	-	-	-	-
38	1.013	-12.735	-	-	14.00	7.00
39	0.983	-13.491	-	-	-	-
40	0.973	-13.658	-	-	-	-
41	0.996	-14.077	-	-	6.30	3.00
42	0.967	-15.533	-	-	7.10	4.40
43	1.010	-11.354	-	-	2.00	1.00
44	1.017	-11.856	-	-	12.00	1.80
45	1.036	-9.270	-	-	-	-
46	1.060	-11.116	-	-	-	-
47	1.033	-12.512	-	-	29.70	11.60
48	1.027	-12.611	-	-	-	-
49	1.036	-12.936	-	-	18.00	8.50
50	1.023	-13.413	-	-	21.00	10.50
51	1.052	-12.533	-	-	18.00	5.30

52	0.980	-11.498	-	-	4.90	2.20
53	0.971	-12.253	-	-	20.00	10.00
54	0.996	-11.710	-	-	4.10	1.40
55	1.031	-10.801	-	-	6.80	3.40
56	0.968	-16.065	-	-	7.60	2.20
57	0.965	-16.584	-	-	6.70	2.00
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	Total:		1278.66	321.08	1250.80	336.40

Power flow solution of IEEE57-bus under abnormal operating condition. Buses where their voltages dropped due to loss of some generations are highlighted.

MATPOWER Version 4.1, 14-Dec-2011 -- AC Power Flow (Newton)

Newton's method power flow converged in 4 iterations.

Converged in 0.01 seconds
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| System Summary |
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How many?		How much?	P (MW)	Q (MVAr)
Buses	57	Total Gen Capacity	1975.9	-468.0 to 699.0
Generators	7	On-line Capacity	1975.9	-468.0 to 699.0
Committed Gens	7	Generation (actual)	1380.0	699.0
Loads	42	Load	1250.8	336.4
Fixed	42	Fixed	1250.8	336.4
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	3	Shunt (inj)	-0.0	21.1
Branches	80	Losses (I^2 * Z)	129.24	498.13
Transformers	17	Branch Charging (inj)	-	114.4
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	0.914 p.u. @ bus 31	1.047 p.u. @ bus 46
Voltage Angle	-38.72 deg @ bus 53	0.00 deg @ bus 1
P Losses (I^2*R)	-	21.42 MW @ line 1-15
Q Losses (I^2*X)	-	109.53 MVAr @ line 1-15

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| Bus Data |

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Bus #	Voltage Mag(pu)	Voltage Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
1	1.040	0.000*	1030.04	126.78	55.00	17.00
2	1.010	-3.992	0.00	27.11	3.00	88.00
3	0.985	-17.563	40.00	81.99	41.00	21.00
4	0.976	-22.690	-	-	-	-
5	0.971	-29.967	-	-	13.00	4.00
6	0.980	-33.012	0.00	53.59	75.00	2.00
7	0.981	-36.166	-	-	-	-
8	1.005	-37.106	0.00	148.84	150.00	22.00
9	0.980	-33.794	0.00	54.44	121.00	26.00
10	0.980	-29.349	-	-	5.00	2.00
11	0.965	-29.517	-	-	-	-
12	1.015	-24.453	310.00	206.26	377.00	24.00
13	0.968	-25.056	-	-	18.00	2.30
14	0.956	-22.865	-	-	10.50	5.30
15	0.975	-18.000	-	-	22.00	5.00
16	0.998	-18.917	-	-	43.00	3.00
17	0.999	-10.588	-	-	42.00	8.00
18	0.994	-27.160	-	-	27.20	9.80
19	0.961	-28.676	-	-	3.30	0.60
20	0.952	-28.897	-	-	2.30	1.00
21	0.994	-28.452	-	-	-	-
22	0.995	-28.396	-	-	-	-
23	0.993	-28.698	-	-	6.30	2.10
24	0.980	-33.087	-	-	-	-
25	0.958	-37.507	-	-	6.30	3.20
26	0.947	-33.399	-	-	-	-
27	0.969	-36.508	-	-	9.30	0.50
28	0.984	-37.114	-	-	4.60	2.30
29	0.997	-37.411	-	-	17.00	2.60
30	0.939	-37.788	-	-	3.60	1.80
31	0.914	-37.731	-	-	5.80	2.90
32	0.933	-35.664	-	-	1.60	0.80
33	0.931	-35.705	-	-	3.80	1.90
34	0.939	-29.984	-	-	-	-
35	0.947	-29.628	-	-	6.00	3.00
36	0.958	-29.275	-	-	-	-
37	0.968	-28.963	-	-	-	-
38	0.999	-27.798	-	-	14.00	7.00
39	0.966	-29.062	-	-	-	-

40	0.954	-29.385	-	-	-	-
41	0.982	-32.665	-	-	6.30	3.00
42	0.955	-33.614	-	-	7.10	4.40
43	0.999	-30.481	-	-	2.00	1.00
44	1.004	-25.994	-	-	12.00	1.80
45	1.028	-21.482	-	-	-	-
46	1.047	-25.160	-	-	-	-
47	1.021	-27.116	-	-	29.70	11.60
48	1.015	-27.438	-	-	-	-
49	1.023	-28.326	-	-	18.00	8.50
50	1.011	-29.645	-	-	21.00	10.50
51	1.042	-30.150	-	-	18.00	5.30
52	0.971	-38.385	-	-	4.90	2.20
53	0.963	-38.722	-	-	20.00	10.00
54	0.993	-37.177	-	-	4.10	1.40
55	1.033	-35.372	-	-	6.80	3.40
56	0.960	-33.595	-	-	7.60	2.20
57	0.957	-33.737	-	-	6.70	2.00
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		Total:	1380.04	699.02	1250.80	336.40

Load shedding by conventional scheme shed 13 loads to improve voltages at the buses as shown below. Loads which were shed are highlighted.

Bus no.	Bus type	Pd	Qd	Gs	Bs	Area	Vm	Va
1.0000	3.0000	0	0	0	0	1.0000	1.0400	0
2.0000	2.0000	0	0	0	0	1.0000	1.0100	-1.1800
3.0000	2.0000	0	0	0	0	1.0000	0.9850	-5.9700
4.0000	1.0000	0	0	0	0	1.0000	0.9810	-7.3200
5.0000	1.0000	0	0	0	0	1.0000	0.9760	-8.5200
6.0000	2.0000	0	0	0	0	1.0000	0.9800	-8.6500
7.0000	1.0000	0	0	0	0	1.0000	0.9840	-7.5800
9.0000	2.0000	0	0	0	0	1.0000	0.9800	-9.5600
10.0000	1.0000	0	0	0	0	1.0000	0.9860	-11.4300
11.0000	1.0000	0	0	0	0	1.0000	0.9740	-10.1700
13.0000	1.0000	0	0	0	0	1.0000	0.9790	-9.7900
14.0000	1.0000	0	0	0	0	1.0000	0.9700	-9.3300
15.0000	1.0000	0	0	0	0	1.0000	0.9880	-7.1800
16.0000	1.0000	0	0	0	0	1.0000	1.0130	-8.8500
17.0000	1.0000	0	0	0	0	1.0000	1.0170	-5.3900
18.0000	1.0000	0	0	0	10.0000	1.0000	1.0010	-11.7100
19.0000	1.0000	3.3000	0.6000	0	0	1.0000	0.9700	-13.2000

20.0000	1.0000	2.3000	1.0000	0	0	1.0000	0.9640	-13.4100
21.0000	1.0000	0	0	0	0	1.0000	1.0080	-12.8900
22.0000	1.0000	0	0	0	0	1.0000	1.0100	-12.8400
23.0000	1.0000	6.3000	2.1000	0	0	1.0000	1.0080	-12.9100
24.0000	1.0000	0	0	0	0	1.0000	0.9990	-13.2500
25.0000	1.0000	6.3000	3.2000	0	5.9000	1.0000	0.9820	-18.1300
26.0000	1.0000	0	0	0	0	1.0000	0.9590	-12.9500
27.0000	1.0000	9.3000	0.5000	0	0	1.0000	0.9820	-11.4800
28.0000	1.0000	4.6000	2.3000	0	0	1.0000	0.9970	-10.4500
29.0000	1.0000	17.0000	2.6000	0	0	1.0000	1.0100	-9.7500
30.0000	1.0000	3.6000	1.8000	0	0	1.0000	0.9620	-18.6800

Load shedding by Proposed scheme shed three loads to improve voltages at the buses as shown below. Loads that were shed are highlighted.

Bus no.	Bus type	Pd	Qd	Gs	Bs	Area	Vm	Va
2.0000	2.0000	0	0	0	0	1.0000	1.0100	-1.1800
9.0000	2.0000	0	0	0	0	1.0000	0.9800	-9.5600
12.0000	2.0000	0	0	0	0	1.0000	1.0150	-10.4600
8.0000	2.0000	150.0000	22.0000	0	0	1.0000	1.0050	-4.4500
3.0000	2.0000	41.0000	21.0000	0	0	1.0000	0.9850	-5.9700
1.0000	3.0000	55.0000	17.0000	0	0	1.0000	1.0400	0
47.0000	1.0000	29.7000	11.6000	0	0	1.0000	1.0330	-12.4900
53.0000	1.0000	20.0000	10.0000	0	6.3000	1.0000	0.9710	-12.2300
18.0000	1.0000	27.2000	9.8000	0	10.0000	1.0000	1.0010	-11.7100
49.0000	1.0000	18.0000	8.5000	0	0	1.0000	1.0360	-12.9200
38.0000	1.0000	14.0000	7.0000	0	0	1.0000	1.0130	-12.7100
14.0000	1.0000	10.5000	5.3000	0	0	1.0000	0.9700	-9.3300
51.0000	1.0000	18.0000	5.3000	0	0	1.0000	1.0520	-12.5200
15.0000	1.0000	22.0000	5.0000	0	0	1.0000	0.9880	-7.1800
42.0000	1.0000	7.1000	4.4000	0	0	1.0000	0.9660	-15.5000
5.0000	1.0000	13.0000	4.0000	0	0	1.0000	0.9760	-8.5200
55.0000	1.0000	6.8000	3.4000	0	0	1.0000	1.0310	-10.7800
25.0000	1.0000	6.3000	3.2000	0	5.9000	1.0000	0.9820	-18.1300
16.0000	1.0000	43.0000	3.0000	0	0	1.0000	1.0130	-8.8500
35.0000	1.0000	6.0000	3.0000	0	0	1.0000	0.9660	-13.8600
41.0000	1.0000	6.3000	3.0000	0	0	1.0000	0.9960	-14.0500
31.0000	1.0000	5.8000	2.9000	0	0	1.0000	0.9360	-19.3400
29.0000	1.0000	17.0000	2.6000	0	0	1.0000	1.0100	-9.7500
13.0000	1.0000	18.0000	2.3000	0	0	1.0000	0.9790	-9.7900
28.0000	1.0000	4.6000	2.3000	0	0	1.0000	0.9970	-10.4500
52.0000	1.0000	4.9000	2.2000	0	0	1.0000	0.9800	-11.4700

56.0000	1.0000	7.6000	2.2000	0	0	1.0000	0.9680	-16.0400
23.0000	1.0000	6.3000	2.1000	0	0	1.0000	1.0080	-12.9100
6.0000	2.0000	75.0000	2.0000	0	0	1.0000	0.9800	-8.6500
10.0000	1.0000	5.0000	2.0000	0	0	1.0000	0.9860	-11.4300
57.0000	1.0000	6.7000	2.0000	0	0	1.0000	0.9650	-16.5600
33.0000	1.0000	3.8000	1.9000	0	0	1.0000	0.9470	-18.5000
30.0000	1.0000	3.6000	1.8000	0	0	1.0000	0.9620	-18.6800
44.0000	1.0000	12.0000	1.8000	0	0	1.0000	1.0170	-11.8600
54.0000	1.0000	4.1000	1.4000	0	0	1.0000	0.9960	-11.6900
20.0000	1.0000	2.3000	1.0000	0	0	1.0000	0.9640	-13.4100

Power flow solution of IEEE57-bus after load shedding

MATPOWER Version 4.1, 14-Dec-2011 -- AC Power Flow (Newton)

Newton's method power flow converged in 4 iterations.

Converged in 0.01 seconds
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| System Summary |
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How many?		How much?	P (MW)	Q (MVAr)
Buses	57	Total Gen Capacity	1975.9	-468.0 to 699.0
Generators	7	On-line Capacity	1975.9	-468.0 to 699.0
Committed Gens	7	Generation (actual)	795.0	233.9
Loads	39	Load	749.8	198.4
Fixed	39	Fixed	749.8	198.4
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	3	Shunt (inj)	-0.0	21.4
Branches	80	Losses (I^2 * Z)	45.24	172.05
Transformers	17	Branch Charging (inj)	-	115.2
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	0.927 p.u. @ bus 31	1.059 p.u. @ bus 46
Voltage Angle	-22.84 deg @ bus 31	0.00 deg @ bus 1
P Losses (I^2*R)	-	5.41 MW @ line 2-3
Q Losses (I^2*X)	-	23.62 MVAr @ line 1-15

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| Bus Data |

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Bus #	Voltage Mag(pu)	Voltage Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
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1	1.040	0.000*	445.04	125.28	55.00	17.00
2	1.010	-1.774	0.00	-86.51	-	-
3	0.985	-8.602	40.00	14.93	41.00	21.00
4	0.979	-12.055	-	-	-	-
5	0.975	-16.714	-	-	13.00	4.00
6	0.980	-18.510	0.00	24.76	75.00	2.00
7	0.982	-19.758	-	-	-	-
8	1.005	-19.441	0.00	150.48	150.00	22.00
9	0.980	-14.300	0.00	-18.39	-	-
10	0.984	-9.845	-	-	5.00	2.00
11	0.971	-11.989	-	-	-	-
12	1.015	-3.802	310.00	23.33	-	-
13	0.976	-9.098	-	-	18.00	2.30
14	0.968	-9.376	-	-	10.50	5.30
15	0.987	-7.903	-	-	22.00	5.00
16	1.016	-4.097	-	-	43.00	3.00
17	1.021	-2.918	-	-	42.00	8.00
18	0.997	-16.168	-	-	27.20	9.80
19	0.971	-16.565	-	-	3.30	0.60
20	0.966	-16.066	-	-	2.30	1.00
21	1.004	-14.539	-	-	-	-
22	1.006	-14.309	-	-	-	-
23	1.004	-14.562	-	-	6.30	2.10
24	0.990	-18.127	-	-	-	-
25	0.970	-22.505	-	-	6.30	3.20
26	0.955	-18.335	-	-	-	-
27	0.973	-20.562	-	-	9.30	0.50
28	0.987	-20.859	-	-	4.60	2.30
29	0.999	-20.962	-	-	17.00	2.60
30	0.951	-22.813	-	-	3.60	1.80
31	0.927	-22.844	-	-	5.80	2.90
32	0.946	-20.967	-	-	1.60	0.80
33	0.944	-21.007	-	-	3.80	1.90
34	0.953	-15.548	-	-	-	-
35	0.961	-15.213	-	-	6.00	3.00
36	0.971	-14.878	-	-	-	-
37	0.981	-14.635	-	-	-	-
38	1.010	-13.762	-	-	14.00	7.00

39	0.978	-14.689	-	-	-	-
40	0.968	-14.915	-	-	-	-
41	0.993	-15.769	-	-	6.30	3.00
42	0.963	-17.148	-	-	7.10	4.40
43	1.007	-13.123	-	-	2.00	1.00
44	1.014	-12.818	-	-	12.00	1.80
45	1.035	-10.094	-	-	-	-
46	1.059	-11.380	-	-	-	-
47	1.032	-13.027	-	-	29.70	11.60
48	1.026	-13.228	-	-	-	-
49	1.036	-13.019	-	-	18.00	8.50
50	1.023	-12.950	-	-	21.00	10.50
51	1.052	-11.142	-	-	18.00	5.30
52	0.972	-21.234	-	-	4.90	2.20
53	0.964	-21.188	-	-	20.00	10.00
54	0.995	-18.749	-	-	4.10	1.40
55	1.036	-16.153	-	-	6.80	3.40
56	0.965	-17.594	-	-	7.60	2.20
57	0.962	-18.052	-	-	6.70	2.00
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		Total:	795.04	233.86	749.80	198.40

Power flow solution of IEEE 118-bus system under normal operating condition.

MATPOWER Version 4.1, 14-Dec-2011 -- AC Power Flow (Newton)

Newton's method power flow converged in 4 iterations.

Converged in 0.01 seconds

| System Summary |
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How many?		How much?	P (MW)	Q (MVAr)
Buses	118	Total Gen Capacity	7904.0	-6688.0 to 10977.0
Generators	54	On-line Capacity	7904.0	-6688.0 to 10977.0
Committed Gens	54	Generation (actual)	2363.5	-322.7
Loads	73	Load	2286.	634.0
Fixed	73	Fixed	2286.0	634.0
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	14	Shunt (inj)	-0.0	87.1
Branches	186	Losses (I^2 * Z)	77.46	477.64

Transformers	9	Branch Charging (inj)	-	1347.2
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	0.943 p.u. @ bus 76	1.052 p.u. @ bus 9
Voltage Angle	21.18 deg @ bus 112	49.54 deg @ bus 26
P Losses (I^2*R)	-	4.83 MW @ line 23-25
Q Losses (I^2*X)	-	54.19 MVAr @ line 65-68

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Bus Data
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Bus #	Voltage Mag(pu)	Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
1	0.955	31.543	0.00	-44.50	-	-
2	0.971	31.434	-	-	20.00	9.00
3	0.967	31.247	-	-	39.00	10.00
4	0.998	32.316	0.00	-1.98	39.00	12.00
5	1.001	32.508	-	-	-	-
6	0.990	32.141	0.00	-16.72	-	-
7	0.989	31.955	-	-	19.00	2.00
8	1.015	34.006	0.00	-22.76	28.00	0.00
9	1.052	33.840	-	-	-	-
10	1.050	33.848	0.00	-73.43	-	-
11	0.991	32.106	-	-	-	-
12	0.990	32.024	85.00	65.19	47.00	10.00
13	0.972	31.789	-	-	34.00	16.00
14	0.983	32.406	-	-	14.00	1.00
15	0.970	35.207	0.00	-47.95	-	-
16	0.983	32.495	-	-	25.00	10.00
17	0.993	35.973	-	-	11.00	3.00
18	0.973	35.841	0.00	-18.24	-	-
19	0.962	35.573	0.00	-52.93	-	-
20	0.959	35.162	-	-	18.00	3.00
21	0.961	35.806	-	-	14.00	8.00
22	0.973	37.289	-	-	10.00	5.00
23	1.001	40.522	-	-	7.00	3.00
24	0.992	37.923	0.00	1.01	13.00	0.00
25	1.050	48.055	220.00	47.00	-	-

26	1.015	49.543	314.00	7.50	-	-
27	0.968	38.122	0.00	-0.46	71.00	13.00
28	0.962	36.960	-	-	17.00	7.00
29	0.963	36.595	-	-	24.00	4.00
30	0.989	37.900	-	-	-	-
31	0.967	36.935	7.00	-6.40	-	-
32	0.963	38.101	0.00	-60.72	-	-
33	0.971	34.500	-	-	23.00	9.00
34	0.984	35.383	0.00	-62.75	-	-
35	0.980	34.783	-	-	33.00	9.00
36	0.980	34.821	0.00	9.38	31.00	17.00
37	0.990	35.517	-	-	-	-
38	0.969	37.508	-	-	-	-
39	0.970	35.070	-	-	27.00	11.00
40	0.970	35.704	0.00	-18.46	-	-
41	0.967	35.540	-	-	37.00	10.00
42	0.985	37.908	0.00	-16.57	-	-
43	0.987	35.226	-	-	18.00	7.00
44	1.009	37.472	-	-	16.00	8.00
45	1.016	39.160	-	-	-	-
46	1.005	39.697	19.00	-27.70	28.00	10.00
47	1.016	39.267	-	-	34.00	0.00
48	1.021	41.334	-	-	20.00	11.00
49	1.025	42.389	204.00	25.72	-	-
50	1.002	41.782	-	-	17.00	4.00
51	0.969	41.037	-	-	17.00	8.00
52	0.960	40.608	-	-	18.00	5.00
53	0.947	41.074	-	-	23.00	11.00
54	0.955	43.053	48.00	-62.93	-	-
55	0.952	43.047	0.00	-36.64	-	-
56	0.954	42.775	0.00	-8.24	84.00	18.00
57	0.971	41.942	-	-	12.00	3.00
58	0.960	41.474	-	-	12.00	3.00
59	0.985	45.569	155.00	-74.69	-	-
60	0.993	44.085	-	-	78.00	3.00
61	0.995	44.663	160.00	-37.98	-	-
62	0.998	43.655	0.00	-0.40	77.00	14.00
63	0.974	44.504	-	-	-	-
64	0.987	43.862	-	-	-	-
65	1.005	42.014	391.00	80.21	-	-
66	1.050	45.300	392.00	25.43	39.00	18.00
67	1.020	43.749	-	-	28.00	7.00
68	1.001	36.678	-	-	-	-
69	1.035	30.000*	-440.54	73.57	-	-
70	0.984	29.419	0.00	-3.93	66.00	20.00
71	0.987	29.862	-	-	-	-
72	0.980	33.119	0.00	-8.50	12.00	0.00

73	0.991	29.648	0.00	9.95	6.00	0.00
74	0.958	29.602	0.00	-58.34	-	-
75	0.969	29.316	-	-	47.00	11.00
76	0.943	30.451	0.00	-54.87	-	-
77	1.006	31.798	0.00	-41.99	61.00	28.00
78	1.007	31.778	-	-	71.00	26.00
79	1.019	32.639	-	-	-	-
80	1.040	35.234	477.00	15.44	-	-
81	0.994	36.150	-	-	-	-
82	1.008	28.215	-	-	-	-
83	1.000	26.348	-	-	20.00	10.00
84	0.985	23.967	-	-	11.00	7.00
85	0.985	23.119	0.00	-6.24	24.00	15.00
86	0.987	21.749	-	-	21.00	10.00
87	1.015	22.008	4.00	11.02	-	-
88	0.989	22.038	-	-	48.00	10.00
89	1.005	23.207	0.00	88.97	-	-
90	0.985	23.483	0.00	-33.07	-	-
91	0.980	23.558	0.00	-13.07	10.00	0.00
92	0.990	24.184	0.00	-30.26	65.00	10.00
93	0.993	25.729	-	-	12.00	7.00
94	1.002	27.489	-	-	30.00	16.00
95	1.006	28.143	-	-	-	-
96	1.009	28.976	-	-	38.00	15.00
97	1.018	31.724	-	-	15.00	9.00
98	1.022	31.735	-	-	34.00	8.00
99	1.010	29.570	0.00	-15.51	42.00	0.00
100	1.017	29.076	252.00	68.77	37.00	18.00
101	0.992	26.140	-	-	22.00	15.00
102	0.990	24.731	-	-	5.00	3.00
103	1.010	27.324	40.00	66.05	23.00	16.00
104	0.971	26.341	0.00	-34.94	-	-
105	0.965	25.381	0.00	-55.01	-	-
106	0.962	24.458	-	-	43.00	16.00
107	0.952	21.998	0.00	6.10	50.00	12.00
108	0.966	24.743	-	-	2.00	1.00
109	0.967	24.519	-	-	8.00	3.00
110	0.973	24.275	0.00	-42.57	-	-
111	0.980	25.920	36.00	-1.84	-	-
112	0.975	21.176	0.00	41.51	68.00	13.00
113	0.993	36.075	0.00	12.99	6.00	0.00
114	0.960	37.546	-	-	8.00	3.00
115	0.960	37.501	-	-	22.00	7.00
116	1.005	36.230	0.00	114.14	184.00	0.00
117	0.974	30.483	-	-	20.00	8.00
118	0.950	29.377	-	-	33.00	15.00
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Total: 2363.46 -322.65 2286.00 634.00

Power flow solution of IEEE 118-bus system under abnormal operating condition. Buses that have been highlighted their voltages dropped due to loss of some generations.

MATPOWER Version 4.1, 14-Dec-2011 -- AC Power Flow (Newton)

Newton's method power flow converged in 4 iterations.

Converged in 0.02 seconds

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| System Summary |
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How many?		How much?	P (MW)	Q (MVAr)
Buses	118	Total Gen Capacity	9966.2	-7345.0 to 11777.0
Generators	54	On-line Capacity	9966.2	-7345.0 to 11777.0
Committed Gens	54	Generation (actual)	4512.3	1714.9
Loads	99	Load	4242.0	1438.0
Fixed	99	Fixed	4242.0	1438.0
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	14	Shunt (inj)	-0.0	84.2
Branches	186	Losses (I^2 * Z)	270.30	1700.74
Transformers	9	Branch Charging (inj)	-	1339.7
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	0.943 p.u. @ bus 76	1.050 p.u. @ bus 25
Voltage Angle	-24.08 deg @ bus 1	30.00 deg @ bus 69
P Losses (I^2*R)	-	34.93 MW @ line 69-77
Q Losses (I^2*X)	-	354.12 MVAr @ line 68-69

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| Bus Data |

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Bus #	Voltage Mag(pu)	Voltage Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
1	0.955	-24.079	0.00	-3.08	51.00	27.00
2	0.971	-23.514	-	-	20.00	9.00
3	0.968	-23.206	-	-	39.00	10.00
4	0.998	-19.537	0.00	-14.55	39.00	12.00
5	1.002	-19.101	-	-	-	-
6	0.990	-21.775	0.00	15.92	52.00	22.00
7	0.989	-22.199	-	-	19.00	2.00
8	1.015	-14.180	0.00	58.49	28.00	0.00
9	1.043	-6.926	-	-	-	-
10	1.050	0.655	450.00	-51.04	-	-
11	0.985	-22.021	-	-	70.00	23.00
12	0.990	-22.523	85.00	91.04	47.00	10.00
13	0.968	-23.259	-	-	34.00	16.00
14	0.984	-23.085	-	-	14.00	1.00
15	0.970	-22.944	0.00	6.49	90.00	30.00
16	0.984	-22.816	-	-	25.00	10.00
17	0.995	-20.991	-	-	11.00	3.00
18	0.973	-22.824	0.00	27.25	60.00	34.00
19	0.962	-22.916	0.00	-12.33	45.00	25.00
20	0.956	-22.039	-	-	18.00	3.00
21	0.957	-20.450	-	-	14.00	8.00
22	0.968	-17.890	-	-	10.00	5.00
23	0.997	-12.957	-	-	7.00	3.00
24	0.992	-8.690	0.00	-7.01	13.00	0.00
25	1.050	-11.683	220.00	67.45	-	-
26	1.015	-13.066	0.00	2.44	-	-
27	0.968	-21.009	0.00	-0.85	71.00	13.00
28	0.962	-22.377	-	-	17.00	7.00
29	0.963	-22.972	-	-	24.00	4.00
30	0.987	-16.388	-	-	-	-
31	0.967	-22.714	7.00	32.77	43.00	27.00
32	0.963	-20.707	0.00	-11.73	59.00	23.00
33	0.970	-21.988	-	-	23.00	9.00
34	0.984	-19.589	0.00	-7.88	59.00	26.00
35	0.980	-20.041	-	-	33.00	9.00
36	0.980	-20.044	0.00	9.35	31.00	17.00
37	0.990	-19.116	-	-	-	-
38	0.956	-14.194	-	-	-	-
39	0.970	-21.445	-	-	27.00	11.00

40	0.970	-21.907	0.00	27.87	66.00	23.00
41	0.967	-21.861	-	-	37.00	10.00
42	0.985	-18.921	0.00	48.44	96.00	23.00
43	0.973	-17.536	-	-	18.00	7.00
44	0.978	-11.928	-	-	16.00	8.00
45	0.982	-8.956	-	-	53.00	22.00
46	1.005	-4.754	19.00	15.49	28.00	10.00
47	0.999	-0.216	-	-	34.00	0.00
48	1.021	-4.119	-	-	20.00	11.00
49	1.025	-3.330	204.00	215.97	87.00	30.00
50	1.001	-5.435	-	-	17.00	4.00
51	0.967	-8.139	-	-	17.00	8.00
52	0.957	-9.115	-	-	18.00	5.00
53	0.946	-10.150	-	-	23.00	11.00
54	0.955	-9.283	48.00	4.24	113.00	32.00
55	0.952	-9.594	0.00	4.67	63.00	22.00
56	0.954	-9.395	0.00	-2.24	84.00	18.00
57	0.970	-8.095	-	-	12.00	3.00
58	0.959	-8.969	-	-	12.00	3.00
59	0.985	-5.426	155.00	76.81	277.00	113.00
60	0.993	-2.071	-	-	78.00	3.00
61	0.995	-1.108	160.00	-43.96	-	-
62	0.998	-2.257	0.00	-0.21	77.00	14.00
63	0.968	-1.995	-	-	-	-
64	0.983	-0.198	-	-	-	-
65	1.005	3.470	0.00	247.94	-	-
66	1.050	-0.542	0.00	28.39	39.00	18.00
67	1.020	-2.124	-	-	28.00	7.00
68	0.999	10.266	-	-	-	-
69	1.035	30.000*	2225.30	88.03	-	-
70	0.984	11.707	0.00	87.57	66.00	20.00
71	0.985	9.621	-	-	-	-
72	0.980	0.051	0.00	2.82	12.00	0.00
73	0.991	9.390	0.00	13.30	6.00	0.00
74	0.958	11.537	0.00	10.50	68.00	27.00
75	0.961	13.176	-	-	47.00	11.00
76	0.943	9.030	0.00	11.02	68.00	36.00
77	1.006	10.024	0.00	74.94	61.00	28.00
78	1.003	9.157	-	-	71.00	26.00
79	1.009	8.371	-	-	39.00	32.00
80	1.040	7.598	0.00	219.99	130.00	26.00
81	0.993	9.272	-	-	-	-
82	0.988	8.400	-	-	54.00	27.00
83	0.984	9.420	-	-	20.00	10.00
84	0.980	11.679	-	-	11.00	7.00
85	0.985	13.099	0.00	-5.20	24.00	15.00
86	0.987	11.729	-	-	21.00	10.00

87	1.015	11.989	4.00	11.02		-	-
88	0.988	16.003	-	-		48.00	10.00
89	1.005	19.903	607.00	-6.47		-	-
90	0.985	13.458	0.00	59.37		163.00	42.00
91	0.980	13.424	0.00	-13.10		10.00	0.00
92	0.990	13.884	0.00	-12.03		65.00	10.00
93	0.985	10.787	-	-		12.00	7.00
94	0.989	8.563	-	-	30.00	16.00	
95	0.980	7.661	-	-	42.00	31.00	
96	0.991	7.584	-	-	38.00	15.00	
97	1.011	7.243	-	-	15.00	9.00	
98	1.024	6.408	-	-	34.00	8.00	
99	1.010	6.379	0.00	-17.58	42.00	0.00	
100	1.017	7.655	252.00	97.89	37.00	18.00	
101	0.991	9.415	-	-	22.00	15.00	
102	0.989	12.290	-	-	5.00	3.00	
103	1.010	3.914	40.00	75.42	23.00	16.00	
104	0.971	1.344	0.00	2.39	38.00	25.00	
105	0.965	0.240	0.00	-18.33	31.00	26.00	
106	0.961	-0.020	-	-	43.00	16.00	
107	0.952	-2.821	0.00	6.56	50.00	12.00	
108	0.966	-0.960	-	-	2.00	1.00	
109	0.967	-1.413	-	-	8.00	3.00	
110	0.973	-2.259	0.00	0.28	39.00	30.00	
111	0.980	-0.614	36.00	-1.84	-	-	
112	0.975	-5.359	0.00	41.51	68.00	13.00	
113	0.993	-21.087	0.00	5.88	6.00	0.00	
114	0.960	-21.397	-	-	8.00	3.00	
115	0.960	-21.466	-	-	22.00	7.00	
116	1.005	9.809	0.00	154.84	184.00	0.00	
117	0.974	-24.064	-	-	20.00	8.00	
118	0.945	10.781	-	-	33.00	15.00	
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	Total:	4512.30	1714.92	4242.00	1438.00		

Load shedding by proposed scheme shed 12 loads to improve voltages at the buses as shown below. Loads that were shed are highlighted.

Bus no.	Bus type	Pd	Qd	Gs	Bs	Area	Vm	Va
59.0000	2.0000	0	0	0	0	1.0000	0.9850	19.3700
90.0000	2.0000	0	0	0	0	1.0000	0.9850	33.2900
76.0000	2.0000	0	0	0	0	1.0000	0.9430	21.7700
18.0000	2.0000	0	0	0	0	1.0000	0.9730	11.5300
54.0000	2.0000	0	0	0	0	1.0000	0.9550	15.2600
79.0000	1.0000	0	0	0	20.0000	1.0000	1.0090	26.7200
95.0000	1.0000	0	0	0	0	1.0000	0.9810	27.6700
15.0000	2.0000	0	0	0	0	1.0000	0.9700	11.2300
49.0000	2.0000	0	0	0	0	1.0000	1.0250	20.9400
110.0000	2.0000	0	0	0	6.0000	1.0000	0.9730	18.0900
77.0000	2.0000	0	0	0	0	1.0000	1.0060	26.7200
1.0000	2.0000	0	0	0	0	1.0000	0.9550	10.6700
31.0000	2.0000	43.0000	27.0000	0	0	1.0000	0.9670	12.7500
74.0000	2.0000	68.0000	27.0000	0	12.0000	1.0000	0.9580	21.6400
82.0000	1.0000	54.0000	27.0000	0	20.0000	1.0000	0.9890	27.2400
34.0000	2.0000	59.0000	26.0000	0	14.0000	1.0000	0.9860	11.3000
78.0000	1.0000	71.0000	26.0000	0	0	1.0000	1.0030	26.4200
80.0000	2.0000	130.0000	26.0000	0	0	1.0000	1.0400	28.9600
105.0000	2.0000	31.0000	26.0000	0	20.0000	1.0000	0.9650	20.5700
19.0000	2.0000	45.0000	25.0000	0	0	1.0000	0.9630	11.0500
11.0000	1.0000	70.0000	23.0000	0	0	1.0000	0.9850	12.7200
32.0000	2.0000	59.0000	23.0000	0	0	1.0000	0.9640	14.8000
40.0000	2.0000	66.0000	23.0000	0	0	1.0000	0.9700	7.3500
42.0000	2.0000	96.0000	23.0000	0	0	1.0000	0.9850	8.5300
6.0000	2.0000	52.0000	22.0000	0	0	1.0000	0.9900	13.0000
45.0000	1.0000	53.0000	22.0000	0	10.0000	1.0000	0.9870	15.6700
55.0000	2.0000	63.0000	22.0000	0	0	1.0000	0.9520	14.9700
70.0000	2.0000	66.0000	20.0000	0	0	1.0000	0.9840	22.5800
56.0000	2.0000	84.0000	18.0000	0	0	1.0000	0.9540	15.1600
66.0000	2.0000	39.0000	18.0000	0	0	1.0000	1.0500	27.4800
100.0000	2.0000	37.0000	18.0000	0	0	1.0000	1.0170	28.0300
36.0000	2.0000	31.0000	17.0000	0	0	1.0000	0.9800	10.8700
13.0000	1.0000	34.0000	16.0000	0	0	1.0000	0.9680	11.3500
103.0000	2.0000	23.0000	16.0000	0	0	1.0000	1.0010	24.4400
106.0000	1.0000	43.0000	16.0000	0	0	1.0000	0.9620	20.3200
85.0000	2.0000	24.0000	15.0000	0	0	1.0000	0.9850	32.5100

Load shedding by Conventional scheme shed 27 loads to improve voltages at the buses as shown below. Loads that were shed are highlighted.

Bus no.	Bus type	Pd	Qd	Gs	Bs	Area	Vm	Va
1.0000	2.0000	0	0	0	0	1.0000	0.9550	10.6700
2.0000	1.0000	0	0	0	0	1.0000	0.9710	11.2200
3.0000	1.0000	0	0	0	0	1.0000	0.9680	11.5600
4.0000	2.0000	0	0	0	0	1.0000	0.9980	15.2800
5.0000	1.0000	0	0	0	-40.0000	1.0000	1.0020	15.7300
6.0000	2.0000	0	0	0	0	1.0000	0.9900	13.0000
7.0000	1.0000	0	0	0	0	1.0000	0.9890	12.5600
8.0000	2.0000	0	0	0	0	1.0000	1.0150	20.7700
9.0000	1.0000	0	0	0	0	1.0000	1.0430	28.0200
10.0000	2.0000	0	0	0	0	1.0000	1.0500	35.6100
11.0000	1.0000	0	0	0	0	1.0000	0.9850	12.7200
12.0000	2.0000	0	0	0	0	1.0000	0.9900	12.2000
13.0000	1.0000	0	0	0	0	1.0000	0.9680	11.3500
14.0000	1.0000	0	0	0	0	1.0000	0.9840	11.5000
15.0000	2.0000	0	0	0	0	1.0000	0.9700	11.2300
16.0000	1.0000	0	0	0	0	1.0000	0.9840	11.9100
17.0000	1.0000	0	0	0	0	1.0000	0.9950	13.7400
18.0000	2.0000	0	0	0	0	1.0000	0.9730	11.5300
19.0000	2.0000	0	0	0	0	1.0000	0.9630	11.0500
20.0000	1.0000	0	0	0	0	1.0000	0.9580	11.9300
21.0000	1.0000	0	0	0	0	1.0000	0.9590	13.5200
22.0000	1.0000	0	0	0	0	1.0000	0.9700	16.0800
23.0000	1.0000	0	0	0	0	1.0000	1.0000	21.0000
24.0000	2.0000	0	0	0	0	1.0000	0.9920	20.8900
25.0000	2.0000	0	0	0	0	1.0000	1.0500	27.9300
26.0000	2.0000	0	0	0	0	1.0000	1.0150	29.7100
27.0000	2.0000	0	0	0	0	1.0000	0.9680	15.3500
28.0000	1.0000	0	0	0	0	1.0000	0.9620	13.6200
29.0000	1.0000	0	0	0	0	1.0000	0.9630	12.6300
31.0000	2.0000	0	0	0	0	1.0000	0.9670	12.7500
32.0000	2.0000	0	0	0	0	1.0000	0.9640	14.8000
34.0000	2.0000	0	0	0	14.0000	1.0000	0.9860	11.3000
35.0000	1.0000	33.0000	9.0000		0	1.0000	0.9810	10.8700
36.0000	2.0000	31.0000	17.0000		0	1.0000	0.9800	10.8700
37.0000	1.0000	0	0	0	-25.0000	1.0000	0.9920	11.7700
38.0000	1.0000	0	0	0	0	1.0000	0.9620	16.9100

Power flow solution of IEEE 118-bus system after load shedding.

MATPOWER Version 4.1, 14-Dec-2011 -- AC Power Flow (Newton)

Newton's method power flow converged in 4 iterations.

Converged in 0.01 seconds
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| System Summary |
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How many?		How much?	P (MW)	Q (MVAr)
Buses	118	Total Gen Capacity	9966.2	-7345.0 to 11777.0
Generators	54	On-line Capacity	9966.2	-7345.0 to 11777.0
Committed Gens	54	Generation (actual)	3457.2	525.8
Loads	90	Load	3303.0	1058.0
Fixed	90	Fixed	3303.0	1058.0
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	14	Shunt (inj)	-0.0	84.6
Branches	186	Losses (I^2 * Z)	154.16	895.27
Transformers	9	Branch Charging (inj)	-	1342.9
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	0.943 p.u. @ bus 76	1.050 p.u. @ bus 10
Voltage Angle	-2.86 deg @ bus 41	41.31 deg @ bus 89
P Losses (I^2*R)	-	8.40 MW @ line 69-75
Q Losses (I^2*X)	-	92.43 MVAr @ line 68-69

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| Bus Data |
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Bus Voltage Generation Load

#	Mag(pu)	Ang(deg)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	0.955	-2.698	0.00	-3.02	51.00	27.00
2	0.971	-2.072	-	-	20.00	9.00
3	0.968	-1.851	-	-	39.00	10.00
4	0.998	1.698	0.00	-13.33	39.00	12.00
5	1.002	2.112	-	-	-	-
6	0.990	-0.431	0.00	15.92	52.00	22.00
7	0.989	-0.804	-	-	19.00	2.00
8	1.015	6.791	0.00	51.10	28.00	0.00
9	1.043	14.045	-	-	-	-
10	1.050	21.626	450.00	-51.04	-	-
11	0.985	-0.582	-	-	70.00	23.00
12	0.990	-1.044	85.00	90.96	47.00	10.00
13	0.968	-1.499	-	-	34.00	16.00
14	0.984	-1.247	-	-	14.00	1.00
15	0.970	-0.095	0.00	-52.04	-	-
16	0.984	-1.271	-	-	25.00	10.00
17	0.995	0.696	-	-	11.00	3.00
18	0.973	0.197	0.00	-21.61	-	-
19	0.962	-0.466	0.00	-15.02	45.00	25.00
20	0.959	-0.780	-	-	18.00	3.00
21	0.961	-0.065	-	-	14.00	8.00
22	0.972	1.498	-	-	10.00	5.00
23	1.000	4.859	-	-	7.00	3.00
24	0.992	7.091	0.00	-20.66	13.00	0.00
25	1.050	7.365	220.00	59.22	-	-
26	1.015	6.396	0.00	-0.41	-	-
27	0.968	-1.422	0.00	-1.65	71.00	13.00
28	0.962	-2.531	-	-	17.00	7.00
29	0.963	-2.837	-	-	24.00	4.00
30	0.990	4.104	-	-	-	-
31	0.967	-2.476	7.00	33.41	43.00	27.00
32	0.963	-1.096	0.00	-16.70	59.00	23.00
33	0.971	-0.760	-	-	23.00	9.00
34	0.984	-0.087	0.00	-17.71	59.00	26.00
35	0.980	-0.573	-	-	33.00	9.00
36	0.980	-0.564	0.00	8.11	31.00	17.00
37	0.991	0.303	-	-	-	-
38	0.963	4.622	-	-	-	-
39	0.970	-2.228	-	-	27.00	11.00
40	0.970	-2.809	0.00	27.07	66.00	23.00
41	0.967	-2.862	-	-	37.00	10.00
42	0.985	-0.190	0.00	46.69	96.00	23.00
43	0.974	1.394	-	-	18.00	7.00

44	0.980	6.145	-	-	16.00	8.00
45	0.983	8.805	-	-	53.00	22.00
46	1.005	12.330	19.00	0.79	28.00	10.00
47	1.014	15.347	-	-	34.00	0.00
48	1.021	13.747	-	-	20.00	11.00
49	1.025	14.743	204.00	83.77	-	-
50	1.002	13.892	-	-	17.00	4.00
51	0.969	12.845	-	-	17.00	8.00
52	0.959	12.342	-	-	18.00	5.00
53	0.947	12.604	-	-	23.00	11.00
54	0.955	14.430	48.00	-62.69	-	-
55	0.952	13.937	0.00	4.31	63.00	22.00
56	0.954	14.075	0.00	-7.06	84.00	18.00
57	0.972	13.591	-	-	12.00	3.00
58	0.960	13.068	-	-	12.00	3.00
59	0.985	18.369	155.00	-80.64	-	-
60	0.993	17.191	-	-	78.00	3.00
61	0.995	17.903	160.00	-46.05	-	-
62	0.998	16.320	0.00	0.24	77.00	14.00
63	0.973	18.056	-	-	-	-
64	0.987	17.821	-	-	-	-
65	1.005	17.387	0.00	127.34	-	-
66	1.050	15.573	0.00	43.16	39.00	18.00
67	1.020	15.104	-	-	28.00	7.00
68	1.003	20.139	-	-	-	-
69	1.035	30.000*	1170.16	-73.15	-	-
70	0.984	18.421	0.00	37.65	66.00	20.00
71	0.986	17.148	-	-	-	-
72	0.980	11.686	0.00	-6.95	12.00	0.00
73	0.991	16.930	0.00	10.83	6.00	0.00
74	0.958	18.526	0.00	-2.61	68.00	27.00
75	0.966	20.142	-	-	47.00	11.00
76	0.943	20.367	0.00	-52.46	-	-
77	1.006	20.523	0.00	-5.98	61.00	28.00
78	1.007	19.931	-	-	71.00	26.00
79	1.019	19.701	-	-	-	-
80	1.040	19.250	0.00	195.59	130.00	26.00
81	0.996	19.824	-	-	-	-
82	0.988	22.716	-	-	54.00	27.00
83	0.982	24.975	-	-	20.00	10.00
84	0.978	29.229	-	-	11.00	7.00
85	0.985	31.611	0.00	0.03	24.00	15.00
86	0.987	30.242	-	-	21.00	10.00
87	1.015	30.501	4.00	11.02	-	-
88	0.986	36.229	-	-	48.00	10.00
89	1.005	41.306	607.00	8.70	-	-
90	0.985	39.636	0.00	-33.86	-	-

91	0.980	37.105	0.00	-10.77	10.00	0.00
92	0.990	33.836	0.00	4.07	65.00	10.00
93	0.986	29.036	-	-	12.00	7.00
94	0.994	25.357	-	-	30.00	16.00
95	0.994	24.091	-	-	-	-
96	0.995	22.505	-	-	38.00	15.00
97	1.012	20.538	-	-	15.00	9.00
98	1.023	19.771	-	-	34.00	8.00
99	1.010	21.312	0.00	-16.33	42.00	0.00
100	1.017	23.925	252.00	100.54	37.00	18.00
101	0.989	27.235	-	-	22.00	15.00
102	0.987	31.536	-	-	5.00	3.00
103	1.010	20.184	40.00	75.42	23.00	16.00
104	0.971	17.614	0.00	2.39	38.00	25.00
105	0.965	16.510	0.00	-18.33	31.00	26.00
106	0.961	16.250	-	-	43.00	16.00
107	0.952	13.449	0.00	6.56	50.00	12.00
108	0.966	15.310	-	-	2.00	1.00
109	0.967	14.857	-	-	8.00	3.00
110	0.973	14.011	0.00	0.28	39.00	30.00
111	0.980	15.656	36.00	-1.84	-	-
112	0.975	10.911	0.00	41.51	68.00	13.00
113	0.993	0.336	0.00	6.49	6.00	0.00
114	0.960	-1.796	-	-	8.00	3.00
115	0.960	-1.867	-	-	22.00	7.00
116	1.005	19.701	0.00	64.52	184.00	0.00
117	0.974	-2.585	-	-	20.00	8.00
118	0.949	19.781	-	-	33.00	15.00
			--------	--------	--------	-------
		Total:	3457.16	525.78	3303.00	1058.00

APPENDIX B

SOUCE CODES

Conventional load shedding scheme source code

```
ka=1;kb=1;kc=1;

R1=0.0000001;R5=0.0000001;R7=0.0000001;

Pd2=90;Qd2=30;Pd8=100;Qd8=35;Pd9=125;Qd9=50;
k(1)=1;k(2)=1;k(3)=1;
k1=k(1);k2=k(2);k3=k(3);

simopt =
simset('solver','ode23tb','SrcWorkspace','Current','DstWorkspace','Cu
rrent');  % Initialize sim options
[tout,xout,Data_out] = sim('BUS_9.mdl',linspace(0.00,10),simopt);

y1=f2(100);
disp(y1);

plot(t,f2);grid;
title('Plot of Frequency over Time');
ylabel('Frequency');xlabel('Time');

plot(t,v2);grid;
title('Plot of Voltage over Time');
ylabel('Voltage');xlabel('Time');

%creating power deficit in the system
R5=1e9;H2=0;kb=0;

%run simulations
simopt =
simset('solver','ode23tb','SrcWorkspace','Current','DstWorkspace','Cu
rrent');  % Initialize sim options
[tout,xout,Data_out] = sim('BUS_9.mdl',linspace(0.00,10),simopt);

y2=f2(100);
disp(y2);

plot(t,f2);grid;
title('Plot of Frequency over Time');
ylabel('Frequency');xlabel('Time');

plot(t,v2);grid;
title('Plot of Voltage over Time');
ylabel('Voltage');xlabel('Time');

% Shedding loads
i=0;
i=i+1;
while y2<49.7

      %shed loads
      k(1)=1;k(2)=1;k(3)=1;
      k(i)=0;
      k1=k(1);k2=k(2);k3=k(3);
```

```
        %run simulations
        simopt = 
simset('solver','ode23tb','SrcWorkspace','Current','DstWorkspace','Cu
rrent');  % Initialize sim options
        [tout,xout,Data_out] = 
sim('BUS_9.mdl',linspace(0.00,10),simopt);

        y3=f2(100);
        y2=y3;
        i=i+1;
end

y3=f2(100);
disp(y3);

plot(t,f2);grid;
title('Plot of Frequency over Time');
ylabel('Frequency');xlabel('Time');

plot(t,v2);grid;
title('Plot of Voltage over Time');
ylabel('Voltage');xlabel('Time');
```

Load shedding scheme based on reactive power demand and priority source code

```
ka=1;kb=1;kc=1;

R1=0.0000001;R5=0.0000001;R7=0.0000001;

Pd2=90;Qd2=30;Pd8=100;Qd8=35;Pd9=125;Qd9=50;
k(1)=1;k(2)=1;k(3)=1;
k1=k(1);k2=k(2);k3=k(3);
H1=23.64;H2=6.4;H3=3.01;

simopt = 
simset('solver','ode23tb','SrcWorkspace','Current','DstWorkspace','Cu
rrent');  % Initialize sim options
[tout,xout,Data_out] = sim('BUS_9.mdl',linspace(0.00,5),simopt);

for k=1:1:99
    df_dt(k+1) = (f2(k+1)-f2(1))/(t(k+1)-t(1));
    fprintf('ROCOF =  %10.2f MW \n',df_dt(k));
end

dfdt_total=sum(df_dt);
dfdt_final=dfdt_total/k;
H=H1+H2+H3;
Pdiff1=abs(dfdt_final*2*H/50);

y1=f2(100);
disp(y1);
disp(Pdiff1);
```

```
plot(t,f2);grid;
title('Plot of Frequency over Time');
ylabel('Frequency');xlabel('Time');

plot(t,v2);grid;
title('Plot of Voltage over Time');
ylabel('Voltage');xlabel('Time');

%creating power deficit in the system
R5=1e9;H2=0;kb=0;

simopt =
simset('solver','ode23tb','SrcWorkspace','Current','DstWorkspace','Cu
rrent');  % Initialize sim options
[tout,xout,Data_out] = sim('BUS_9.mdl',linspace(0.00,5),simopt);

for k=1:1:99
    df_dt(k+1) = (f2(k+1)-f2(1))/(t(k+1)-t(1));
    fprintf('ROCOF =  %10.2f MW \n',df_dt(k));
end

% Find power mismatch between generation and demand
dfdt_total=sum(df_dt);
dfdt_final=dfdt_total/k;
H=H1+H2+H3;
Pdiff2=abs(dfdt_final*2*H/50);

y2=f2(100);
disp(y2);
disp(Pdiff2);

plot(t,f2);grid;
title('Plot of Frequency over Time');
ylabel('Frequency');xlabel('Time');

plot(t,v2);grid;
title('Plot of Voltage over Time');
ylabel('Voltage');xlabel('Time');

% Shedding loads
i=0;
i=i+1;
while y2<49.7
      if (Qd2 > Qd8) && (Qd2 > Qd9)
          k1=0;
      elseif (Qd8 > Qd2) && (Qd8 > Qd9)
          k2=0;
      else
          k3=0;
      end

      simopt =
simset('solver','ode23tb','SrcWorkspace','Current','DstWorkspace','Cu
rrent');  % Initialize sim options
      [tout,xout,Data_out] =
sim('BUS_9.mdl',linspace(0.00,5),simopt);
```

```
        for k=1:1:99
            df_dt(k+1) = (f2(k+1)-f2(1))/(t(k+1)-t(1));
            fprintf('ROCOF =  %10.2f MW \n',df_dt(k));
        end

    dfdt_total=sum(df_dt);
    dfdt_final=dfdt_total/k;
    H=H1+H2+H3;
    Pdiff3=abs(dfdt_final*2*H/50);

    y3=f2(100);
    y2=y3;
    i=i+1;
end

y3=f2(100);
disp(y3);
disp(Pdiff2);

plot(t,f2);grid;
title('Plot of Frequency over Time');
ylabel('Frequency');xlabel('Time');

plot(t,v2);grid;
title('Plot of Voltage over Time');
ylabel('Voltage');xlabel('Time');
```

Load shedding scheme based Harmony Search source code for finding optimal load to shed in each bus IEEE 14-bus

```
function [BestGen,BestFitness,hx]=HarmonySearch14bus

% This code has been written with Matlab 7.0
% You can modify the simple constraint handling method using more
efficient
% methods. A good review of these methods can be found in:
% Carlos A. Coello Coello,"Theoretical and numerical constraint-
handling techniques used with evolutionary algorithms: a survey of
the state of the art"

clc
clear;
global NVAR NG NH MaxItr HMS HMCR PARmin PARmax bwmin bwmax;
global HM NCHV fitness PVB BW;
global BestIndex WorstIndex BestFit WorstFit currentIteration;
global rho
rho = 1e6;

NVAR=18;         %number of variables
NG=0;            %number of inequality constraints
NH=1;            %number of equality constraints
MaxItr=1000;     % maximum number of iterations
HMS=6;           % harmony memory size
```

```
HMCR=0.9;        % harmony consideration rate  0< HMCR <1
PARmin=0.4;      % minumum pitch adjusting rate
PARmax=0.9;      % maximum pitch adjusting rate
bwmin=0.0001;    % minumum bandwidth
bwmax=1.0;       % maxiumum bandwidth

PVB=[0 47.8;0 3.9;0 7.6;0 1.6;0 11.2;0 7.5;0 29.5;0 16.6;0 9;0 5.8;0
3.5;0 1.8;0 6.1;0 1.6;0 13.5;0 5.8;0 14.9;0 5];   % range of
variables

% /**** Initiate Matrix ****/
HM=zeros(HMS,NVAR);
NCHV=zeros(1,NVAR);
BestGen=zeros(1,NVAR);
fitness=zeros(1,HMS);
BW=zeros(1,NVAR);
hx=zeros(1,NH);

MainHarmony;

% /**********************************************/

    function sum =Fitness(sol)

             sum=abs(260-21.7-12.7-94.2-19-sol(1)-sol(2)-sol(3)-
sol(4)-sol(5)-sol(6)-sol(7)-sol(8)-sol(9)-sol(10)-sol(11)-sol(12)-
sol(13)-sol(14)-sol(15)-sol(16)-sol(17)-sol(18)-60.189863612);

    end

% /**********************************************/

    function initialize
        % randomly initialize the HM
        for i=1:HMS
            for j=1:NVAR
                HM(i,j)=randval(PVB(j,1),PVB(j,2));
            end
            fitness(i) = Fitness(HM(i,:));
        end
    end
%/*******************************************/


    function MainHarmony
        % global NVAR NG NH MaxItr HMS HMCR PARmin PARmax bwmin
bwmax;
        % global HM NCHV fitness PVB BW gx currentIteration;

        initialize;
        currentIteration  = 0;

        while(StopCondition(currentIteration))

            PAR=(PARmax-PARmin)/(MaxItr)*currentIteration+PARmin;
```

```
            coef=log(bwmin/bwmax)/MaxItr;
            for pp =1:NVAR
                BW(pp)=bwmax*exp(coef*currentIteration);
            end
            % improvise a new harmony vector
            for i =1:NVAR
                ran = rand(1);
                if( ran < HMCR ) % memory consideration
                    index = randint(1,HMS);
                    NCHV(i) = HM(index,i);
                    pvbRan = rand(1);
                    if( pvbRan < PAR) % pitch adjusting
                        pvbRan1 = rand(1);
                        result = NCHV(i);
                        if( pvbRan1 < 0.5)
                            result =result+  rand(1) * BW(i);
                            if( result < PVB(i,2))
                                NCHV(i) = result;
                            end
                        else
                            result =result- rand(1) * BW(i);
                            if( result > PVB(i,1))
                                NCHV(i) = result;
                            end
                        end
                    end
                else
                    NCHV(i) = randval( PVB(i,1), PVB(i,2) ); % random
selection
                end
            end
            newFitness = Fitness(NCHV);
            UpdateHM( newFitness );

            currentIteration=currentIteration+1;
        end
        BestFitness = min(fitness);
    end
% /**********************************************/

    function UpdateHM( NewFit )
        % global NVAR MaxItr HMS ;
        % global HM NCHV BestGen fitness ;
        % global BestIndex WorstIndex BestFit WorstFit
currentIteration;

        if(currentIteration==0)
            BestFit=fitness(1);
            for i = 1:HMS
                if( fitness(i) < BestFit )
                    BestFit = fitness(i);
                    BestIndex =i;
                end
            end

            WorstFit=fitness(1);
            for i = 1:HMS
```

```
                if( fitness(i) > WorstFit )
                    WorstFit = fitness(i);
                    WorstIndex =i;
                end
            end
        end
        if (NewFit< WorstFit)

            if( NewFit < BestFit )
                HM(WorstIndex,:)=NCHV;
                BestGen=NCHV;
                fitness(WorstIndex)=NewFit;
                BestIndex=WorstIndex;
            else
                HM(WorstIndex,:)=NCHV;
                fitness(WorstIndex)=NewFit;
            end


            WorstFit=fitness(1);
            WorstIndex =1;
            for i = 1:HMS
                if( fitness(i) > WorstFit )
                    WorstFit = fitness(i);
                    WorstIndex =i;
                end
            end

        end
    end % main if

end %function

% /******************************************/

function val1=randval(Maxv,Minv)
    val1=rand(1)*(Maxv-Minv)+Minv;
end

function val2=randint(Maxv,Minv)
    val2=round(rand(1)*(Maxv-Minv)+Minv);
end

% /*******************************************/

function val=StopCondition(Itr)
    global MaxItr;
    val=1;
    if(Itr>MaxItr)
        val=0;
    end

end
```

Load shedding scheme based Harmony Search source code for finding optimal load to shed in each bus IEEE 30-bus

```
function [BestGen,BestFitness,hx]=HarmonySearch30bus

% This code has been written with Matlab 7.0
% You can modify the simple constraint handling method using more
efficient
% methods. A good review of these methods can be found in:
% Carlos A. Coello Coello,"Theoretical and numerical constraint-
handling techniques used with evolutionary algorithms: a survey of
the state of the art"

clc
clear;
global NVAR NG NH MaxItr HMS HMCR PARmin PARmax bwmin bwmax;
global HM NCHV fitness PVB BW;
global BestIndex WorstIndex BestFit WorstFit currentIteration;
global rho
rho = 1e6;

NVAR=34;         %number of variables
NG=0;            %number of inequality constraints
NH=1;            %number of equality constraints
MaxItr=5000;     % maximum number of iterations
HMS=6;           % harmony memory size
HMCR=0.9;        % harmony consideration rate  0< HMCR <1
PARmin=0.4;      % minumum pitch adjusting rate
PARmax=0.9;      % maximum pitch adjusting rate
bwmin=0.0001;    % minumum bandwidth
bwmax=1.0;       % maxiumum bandwidth

PVB=[0 2.4;0 1.2;0 7.6;0 1.6;0 94.2;0 19;0 5.8;0 2;0 11.2;0 7.5;0
6.2;0 1.6;0 3.5;0 1.8;0 9;0 5.8;0 3.2;0 0.9;0 9.5;0 3.4;0 2.2;0 0.7;0
17.5;0 11.2;0 3.2;0 1.6;0 8.7;0 6.7;0 3.5;0 2.3;0 2.4;0 0.9;0 10.6;0
1.9];    % range of variables

% /**** Initiate Matrix ****/
HM=zeros(HMS,NVAR);
NCHV=zeros(1,NVAR);
BestGen=zeros(1,NVAR);
fitness=zeros(1,HMS);
BW=zeros(1,NVAR);
hx=zeros(1,NH);

MainHarmony;

% /**********************************************/

    function sum =Fitness(sol)

            sum=abs(230-21.7-12.7-22.8-10.9-0-30-8.2-2.5-sol(1)-
sol(2)-sol(3)-sol(4)-sol(5)-sol(6)-sol(7)-sol(8)-sol(9)-sol(10)-
```

```
sol(11)-sol(12)-sol(13)-sol(14)-sol(15)-sol(16)-sol(17)-sol(18)-
sol(19)-sol(20)-sol(21)-sol(22)-sol(23)-sol(24)-sol(25)-sol(26)-
sol(27)-sol(28)-sol(29)-sol(30)-sol(31)-sol(32)-sol(33)-sol(34)-
4.643131932);

    end

% /*********************************************/

    function initialize
        % randomly initialize the HM
        for i=1:HMS
            for j=1:NVAR
                HM(i,j)=randval(PVB(j,1),PVB(j,2));
            end
            fitness(i) = Fitness(HM(i,:));
        end
    end
%/*******************************************/


    function MainHarmony
        % global NVAR NG NH MaxItr HMS HMCR PARmin PARmax bwmin
bwmax;
        % global HM NCHV fitness PVB BW gx currentIteration;

        initialize;
        currentIteration  = 0;

        while(StopCondition(currentIteration))

            PAR=(PARmax-PARmin)/(MaxItr)*currentIteration+PARmin;
            coef=log(bwmin/bwmax)/MaxItr;
            for pp =1:NVAR
                BW(pp)=bwmax*exp(coef*currentIteration);
            end
            % improvise a new harmony vector
            for i =1:NVAR
                ran = rand(1);
                if( ran < HMCR ) % memory consideration
                    index = randint(1,HMS);
                    NCHV(i) = HM(index,i);
                    pvbRan = rand(1);
                    if( pvbRan < PAR) % pitch adjusting
                        pvbRan1 = rand(1);
                        result = NCHV(i);
                        if( pvbRan1 < 0.5)
                            result =result+  rand(1) * BW(i);
                            if( result < PVB(i,2))
                                NCHV(i) = result;
                            end
                        else
                            result =result- rand(1) * BW(i);
                            if( result > PVB(i,1))
                                NCHV(i) = result;
                            end
```

```
                        end
                    end
                else
                    NCHV(i) = randval( PVB(i,1), PVB(i,2) ); % random
selection
                end
            end
            newFitness = Fitness(NCHV);
            UpdateHM( newFitness );

            currentIteration=currentIteration+1;
        end
        BestFitness = min(fitness);
    end
% /****************************************/

    function UpdateHM( NewFit )
        % global NVAR MaxItr HMS ;
        % global HM NCHV BestGen fitness ;
        % global BestIndex WorstIndex BestFit WorstFit
currentIteration;

        if(currentIteration==0)
            BestFit=fitness(1);
            for i = 1:HMS
                if( fitness(i) < BestFit )
                    BestFit = fitness(i);
                    BestIndex =i;
                end
            end

            WorstFit=fitness(1);
            for i = 1:HMS
                if( fitness(i) > WorstFit )
                    WorstFit = fitness(i);
                    WorstIndex =i;
                end
            end
        end
        if (NewFit< WorstFit)

            if( NewFit < BestFit )
                HM(WorstIndex,:)=NCHV;
                BestGen=NCHV;
                fitness(WorstIndex)=NewFit;
                BestIndex=WorstIndex;
            else
                HM(WorstIndex,:)=NCHV;
                fitness(WorstIndex)=NewFit;
            end


            WorstFit=fitness(1);
            WorstIndex =1;
            for i = 1:HMS
                if( fitness(i) > WorstFit )
                    WorstFit = fitness(i);
```

```
                        WorstIndex =i;
                    end
                end

            end
        end % main if

    end %function

    % /*****************************************/

    function val1=randval(Maxv,Minv)
        val1=rand(1)*(Maxv-Minv)+Minv;
    end

    function val2=randint(Maxv,Minv)
        val2=round(rand(1)*(Maxv-Minv)+Minv);
    end

    % /*******************************************/

    function val=StopCondition(Itr)
        global MaxItr;
        val=1;
        if(Itr>MaxItr)
            val=0;
        end

    end
```

BIOGRAPHY

Mr. Oscar Andrew Zongo was born on May 18, 1975 in Pwani Region, Tanzania. He received his Bachelor’s Degree in Engineering (Electrical Engineering) from Dar-es-salaam Institute of Technology in 2008. He is currently a Master Degree student at School of Electrical Engineering, Suranaree University of Technology.