# CHAPTER I

# INTRODUCTION

## 1.1 General Introduction

At present, the electrical network is being rapidly expanded to meet energy demand, which is increasing at an average rate of over 4 percent per year. Therefore, it is critically important to focus on maintaining the system’s Voltage Stability (VS) to prevent Voltage Instability (VI), which can lead to severe system disturbances. Today's systems are extremely complicated, with widespread usage of renewable energy sources such as wind and solar power. Most renewable energy sources function in tandem with distribution electrical systems, influencing system parameters such as Voltage Profile (VP) and Voltage Deviation (VD). As a result, VS is a key element contributing to VI, must be considered because it has an impact on the system.

Voltage Stability is an important tool for considering electrical systems because it can indicate how the system operates or other design aspects. As a result, VI can cause system failure or power outages. For example, in 1978, Thailand experienced a huge blackout due to generator failures caused by VI, affecting the people statewide for several hours and badly damaging the economy. Thus, considering VS contributes to the system's efficiency.

To assess and improve VS, system operators and researchers utilize analytical tools such as Voltage Stability Indices (VSIs). From several VSIs, the L-index is one of the methods used to determine the weakest bus that causes the system's Voltage Collapse (VC). The L-index is calculated from power flow analysis and the system's admittance matrix (Y-bus), with values ranging from 0 to 1. A value approaching 1 indicates a high risk of voltage instability. By identifying and reinforcing these weak buses, it is possible to prevent VC and improve the resilience of the overall system.

In addition to analytical methods, technological solutions like Battery Energy Storage Systems (BESS) are another useful instrument for current electrical systems in resolving voltage stability issues. BESS operates to supply or receive active power at the weakest bus identified through L-index analysis, allowing it to address a variety of difficulties such as Voltage Profile and Voltage Drop. Furthermore, BESS improves the stability of the electrical system by collaborating with Renewable Energy, which has intermittent energy systems. Integrating BESS at strategically critical places is thus a promising strategy for reducing voltage instability and ensuring a consistent and dependable power supply.

## 1.2 Problem Statement

Voltage instability poses serious threats to the stability of power systems around the world. Maintaining voltage stability has become an increasingly difficult task. Conventional solutions for dealing with voltage instability usually rely on system improvements or actual power adjustment techniques, which may be insufficiently successful. Precise identification of important spots in the electrical grid is critical. The L-index has been shown to be an effective technique for measuring voltage stability, identifying the most sensitive buses to voltage collapse. Despite its usefulness, the L-index's practical applications in operations are restricted.

Battery Energy Storage Systems are an appealing alternative because of their quick response times and diverse operational properties. BESS can provide rapid voltage assistance by absorbing or injecting actual power. However, studies on BESS have investigated a variety of topics, including establishing appropriate installation sites in power systems to reduce losses and reducing dependency on older devices such as load tap-changing transformers and capacitor banks. In this study, BESS is used to increase voltage stability specifically VP and VD via battery management techniques. Among the strategies investigated, adaptive droop voltage control, which is an adaptation of droop frequency control, is used. The advantage of this technology is that it considers the battery's State of Charge (SoC) to avoid saturation, hence increasing the efficiency of BESS utilization. Furthermore, optimization procedures are used to accomplish the most efficient process.

This study seeks to provide a technique that combines the analytical precision of the L-index with the practical advantages of BESS implementation. VD are optimized, and the system's VP further improved, by selecting the most suitable buses for battery installation using the L-index and then managing the batteries with adaptive droop voltage control while taking the SoC into account. This strategy helps to strengthen the stability of the power system.

## 1.3 Research Objectives

The main objective of this research is to enhance voltage stability in power systems by integrating BESS at critical bus points identified by the L-index. The specific objectives of the research include:

1.3.1 To apply the method to identify critical buses that lead to voltage collapse using L-index.

1.3.2 To apply the method for BESS management using particle swarm optimization (PSO) to minimize voltage deviation and enhance voltage profile.

1.3.3 To manage BESS with adaptive droop voltage control while maintaining SoC at an appropriate level.

Achieving these objectives will provide a systematic approach for improving voltage stability through the use of BESS at critical points in power systems.

## 1.4 Scope and Limitations

1.4.1 In the IEEE 33-bus system, BESS are installed at four locations: 4.25 MW at bus 18, 1.75 MW at bus 22, 3.5 MW at bus 25, and 3.5 MW at bus 33. In the IEEE 69-bus system, BESS units are installed at eight locations: 1.75 MW at bus 27, 0.5 MW at bus 35, 0.75 MW at bus 46, 2.75 MW at bus 50, 0.25 MW at bus 52, 5.75 MW at bus 65, 0.25 MW at bus 67, and 0.25 MW at bus 69.

1.4.2 The IEEE 33-bus and IEEE 69-bus distribution system is employed for testing and analysis purposes. Including four cases as follows:

- case I: IEEE 33-bus base case,
- case II: modified IEEE 33-bus with PV and wind power penetration,
- case III: modified IEEE 33-bus with PV and wind power penetration and BESS and
- case IV: modified IEEE 33-bus and IEEE 69-bus with PV and wind power penetration and BESS considering SoC restoration

1.4.3 Economic considerations related to BESS, including battery costs and investment expenses, are not considered in this study.

1.4.4 The study does not cover dynamic or transient stability analysis, focusing solely on steady-state conditions.

## 1.5 Conception

This study originated from the need to enhance the stability of electrical systems, particularly voltage stability. Consequently, various relevant methodologies were investigated. It was discovered that weak buses may lead to VC. Therefore, the L-index, which can identify weak buses, was employed for calculation and assessment to determine optimal locations for BESS installation. This research hypothesizes that installing BESS at weak buses will significantly improve the stability and reliability of the electrical system. Furthermore, it is posited that incorporating BESS management through optimization techniques will yield even greater improvements in system stability. Fig. 1.1 shows the concept of the study.

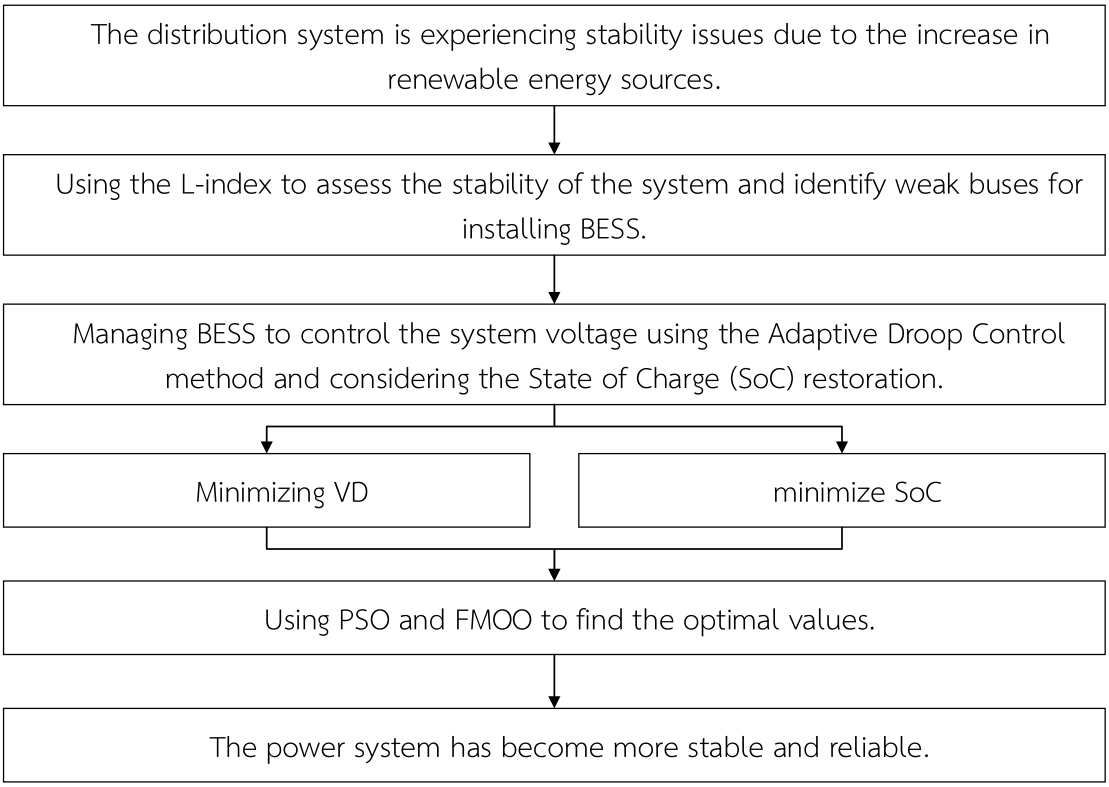


**Figure 1.1** The concept of study

## 1.6 Research Benefits

The L-index can effectively identify vulnerable buses within an electrical system, thereby enabling the assessment and prevention of system stability issues before they manifest. Furthermore, it facilitates the optimal placement of BESS on appropriate buses. The efficient management of BESS through PSO and Fuzzy Multi-objective contributes to the enhancement of VP and the reduction of VD. These parameters contribute to the heightened stability of the electrical system.

## 1.7 Organization of Proposal

This Proposal is organized as follows:

Chapter 2 involves presenting an overview of studies related to the research. In sections 2.2 to 2.11, a literature review is conducted on topics related to VS, VSI, Conventional Methods of Voltage Control, and BESS.

Chapter 3 examines the use of the L-index to identify weak buses in the power system. Section 3.2 presents the formula and calculation method for the L-index, and in Section 3.5, the experimental results are analyzed to identify weak buses in the power system.

Chapter 4 introduces methods for voltage control in power systems using BESS in systems with renewable energy. Section 4.2 proposes a method for managing BESS with VDC to ensure efficient operation, and Section 4.3 applies optimization to find optimal values for BESS management. Finally, Section 4.5 presents the results from BESS management.

Chapter 5 proposes a method for SoC restoration of BESS. Sections 5.2 to 5.3 demonstrate the calculation methods and optimization processes using Multi-objective Fuzzy Logic. Finally, Section 5.6 presents the results.

Chapter 6 summarizes all the work conducted in this study.