Moving Towards a New Era of Intelligent Protection Through Digital Relaying in Power Systems

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Abstract. This paper presents an intelligent approach for digital relaying design. Due to a powerful search scheme of the selected intelligent method, digital relays are well discriminated to satisfy a large number of constraints, which are so complicated over the ability of the conventional relay setting. Also, the proposed scheme is demonstrated through a small 5-bus power system, in which six digital relays are situated to be smartly discriminated.

1 Introduction

Short-circuit conditions can occur unexpectedly in any part of a power system at any time due to various physical problems. Such situations cause a large amount of fault current flowing through some power system apparatus. The occurrence of the fault is harmful and must be isolated promptly by a set of protective devices. Over several decades, protective relaying has become the brain of power system protection [1]. Its basic function is to monitor abnormal operations as a "fault sensor" and the relay will open a contractor to separate a faulty part from the other parts of the network if there exists a fault event. To date, power transmission and distribution systems are bulky and complicated. These lead to the need for a large number of protective relays cooperating with one another to assure the secure and reliable operation of a whole. Therefore, each protective device is designed to perform its action dependent upon a so-called "zone of protection" [2]. From this principle, no protective relay is operated by any fault outside the zone if the system is well designed. As widely known that old fashion analogue relays are inaccurate and difficult to establish the discrimination among protective relays. The relay setting is thus conducted based on the experience of an expert or only a simple heuristic algorithm. However, with the advancement of digital technologies, a modern digital protective relay is more efficient and flexible to enable the fine adjustment of the time-dial setting different to that of the electromagnetic one [3].

This paper proposes a new discrimination method based on some efficient search algorithm, called the Adaptive Tabu Search (ATS) [4], for digital relaying, in which the time-dial setting is appropriately adjusted in order to minimise operating time while discriminated relays are still reliable. In this paper, the discrimination of digital relaying systems is explained in Section 2 in such a way that the ATS method is employed to achieve the system objective. A case study of a 5-bus power system protection, where six digital over-current relays are discriminated, is discussed in Section 3. The last section provides the conclusions and future work.

2 Intelligent Discrimination for Digital Relaying

At present, working with relay parameter setting is wearisome and spends too much time. Although there exist a special computer software to help power engineers set up key parameters of relays, it cannot guarantee that the system under consideration has an optimal operating time [5-6]. This leads to the need for an alternative approach, which is able to provide the ability to search for an optimal solution of relay's parameter setting through a complicated search space. This setting is intrinsically an off-line parameter tuning, so the artificial intelligent search method can be a potential candidate where the time is not involved. In this paper, the ATS method is used to find an optimal time-dial setting of digital relays. This method has fast convergence and is verified by some intensive works [4,7], thus it is suitable to be an optimiser for this adjustment. The framework of the intelligent discrimination is summarised as follows.

Given that there is a set of digital relays to be discriminated in the considered power system. Therefore,

1) Perform steady-state power flow calculation at the maximum load condition for CT-ratio selection of all the relays.
2) Calculate all fault conditions and select some cases or even all the cases for design depended upon the design engineer. Note that the worst-case scenarios must be included.
3) Assign the operating curve to all involved digital relays.
4) Set the pick-up current for the relays with the account of maximum load and minimum fault current consideration.
5) Apply an efficient intelligent search method, which is the ATS method, to find the optimal time-dial setting for the digital relays.

2.1 Review of the ATS method

Adaptive Tabu Search (ATS) Method [4] is a modified form of the original Tabu search proposed by Glover [8] in 1986 especially for combinatorial optimisation problems. The modified version was developed according to the need for a powerful search method to solve non-linear continuous optimisation problems. The essence of this method, which distinguishes itself from the original is that 1) a continuous search space must be discretised and 2) back-tracking and adaptive radius features are employed to enhance the overall performance of the search process. Its effectiveness has been proved and verified by some intensive works [4,7-8]. The ATS algorithm is briefly presented by the flow diagram with appendix. In this paper, it is employed to be an efficient optimiser for the optimal adjustment of relay discrimination problems.

3 Case Study, Results and Discussions

A 5-bus power system is situated for test as shown in figure 1. The test requires the pre-calculation from a power flow solver and a fault calculator. The power flow calculation is employed to obtain the normal operating condition under the maximum load for CT's ratio setting as shown in figure 1, whereas the fault calculation is used to evaluate the fault current distributed in the power network. Although there are many possible fault locations and types, in this demonstration only two fault conditions are situated and their results are graphically presented in figures 2 and 3. These two fault cases are therefore used to form the objective function for relay discrimination, which is explained in the last part of this section.

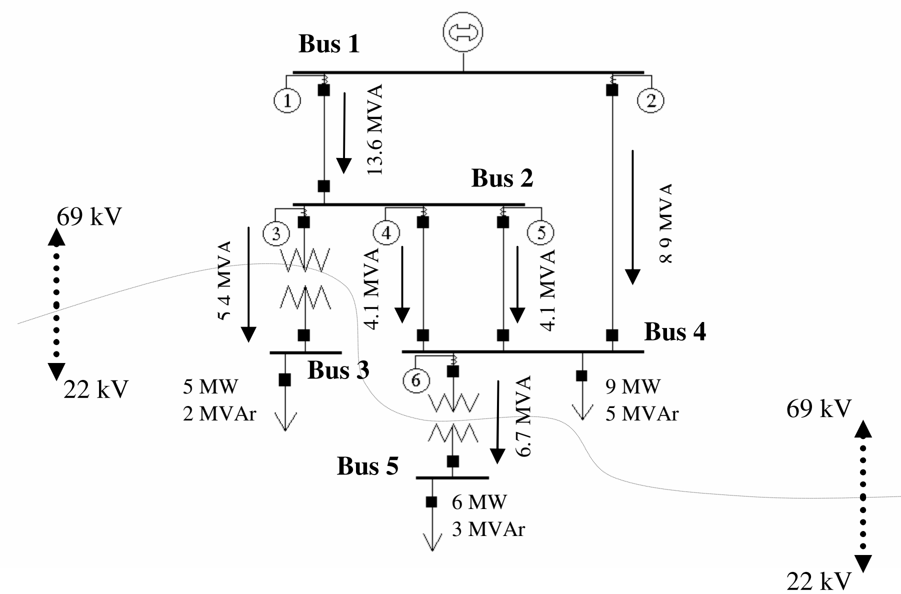

Fig. 1. Power flow solution for the maximum load operation

To achieve the optimum time relay grading, the system objective must be formed carefully, in which all necessary constraints are taken into account. In this paper, the addition of the operating time of all considered relays is set as the objective function, while the time grading margins between pairs of associated upstream and downstream relays are inequality constraints as in equations 1.

$$\textit{minimize} \qquad F_{obj} = \sum_{k=1}^{m}\left(\sum_{i=1}^{n}\frac{\alpha_i \times TDS_i}{\left(\dfrac{I_{i,k}}{I_{S,i}}\right)^{\gamma_i} - 1}\right) \tag{1}$$

$$\textit{Subject to} \qquad t_{u,j} - t_{d,j} > T_{gm} \;\; ; \;\; j = 1,2,...,J,$$

where

F_{obj} is the system objective function,
α_i are γ_i are arbitrary constants of relay i,
TDS_i is the time-dial setting of relay i,
$I_{S,i}$ is the pick-up current of relay i,
$I_{i,k}$ is the fault current seen by relay i for case k,
T_{gm} is the time-grading margin allowance,
T_{uj} ,$T_{d,j}$ are the operating time of upstream and downstream relays of pair j,
n, m and J are the total number of designed relays, fault cases and relay pairs.

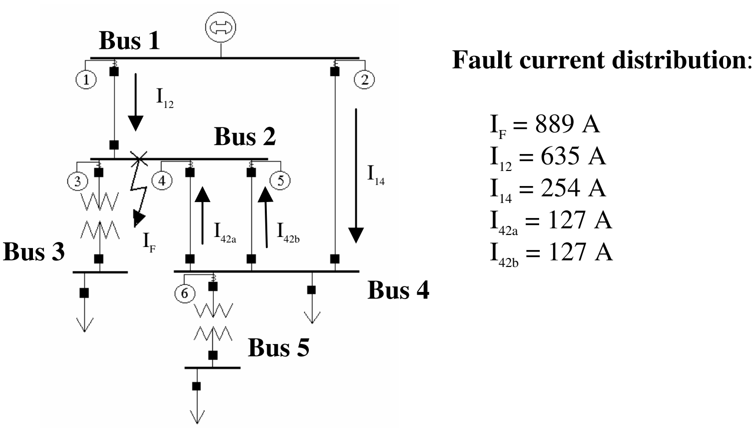

Fig. 2. Fault current distribution for the occurrence of fault at bus 2

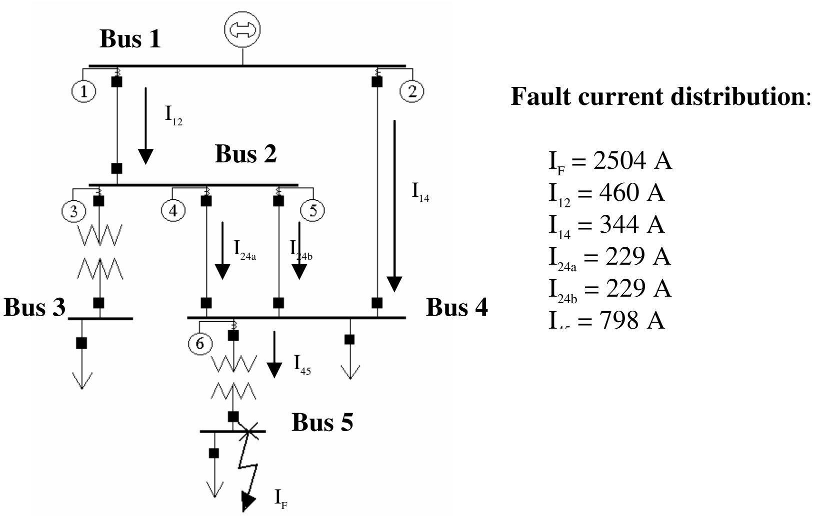

Fig. 3. Fault current distribution for the occurrence of fault at bus 5

In this case study, all the digital relays are characterised by α = 0.14 and γ = 0.02 (standard inverse) [9] and 100% pick-up current setting. Also, all selected CT ratios are shown in Table 1. To minimise the objective function, the search space of the problem is given by [0.05, 1.00] for the time-dial setting. Optimising the objective function by using the ATS method, the obtained optimal solution (TDS) is shown in Table 1 together with the operating time of the two fault cases. In addition, the grading graph interpreted from the obtained optimal solution is shown in figure 4. Moreover, the convergence of the search process is presented in figure 5.

Table 1. Optimal solution resulting from the ATS method for digital relay discrimination

Relay number	TDS	CT's ratio	Operating time (s)	
			Fault at bus 2	Fault at bus 5
1	0.15	150/5	0.71	0.93
2	0.17	100/5	1.27	0.95
4	0.12	50/5	0.86	0.52
5	0.12	50/5	0.86	0.52
6	0.05	50/5	not operate	0.12

Note: relay 3 is not involved for these two fault cases

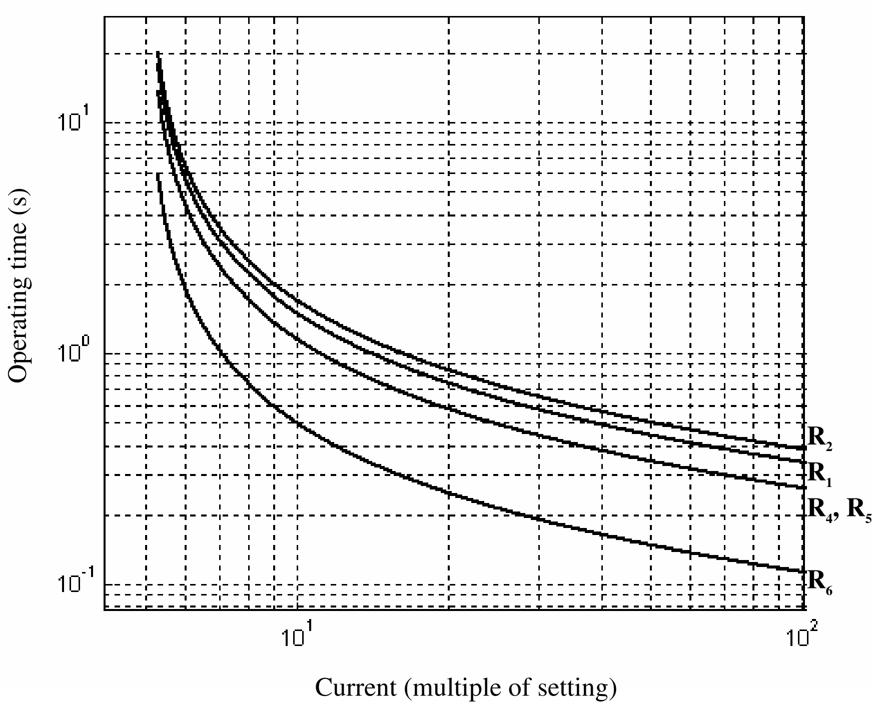

Fig. 4. Grading graph of the discriminated digital relay system

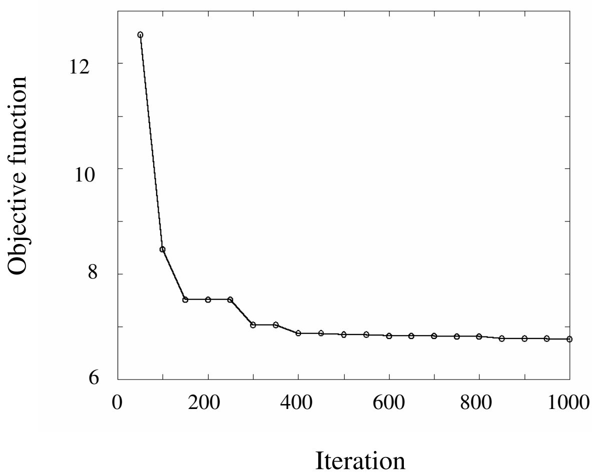

Fig. 5. Convergence of the search process

4 Conclusions

This paper discusses a new method of discrimination for digital over-current relaying based on an intelligent search method. The result from this proposed setting scheme gives the minimum relay operating time in which the relaying system is still reliable and well discriminated. The parameter setting design is simple and consumes less time. In addition, this method is applicable to a bulk and complicated power system, having a large number of constraints for taking into account. Although its formulation of this scheme is rather complicated, a design engineer is required to set up only the objective function. After the objective function is created, a whole process will be done by a digital computer. This may leads to the improvement of the relaying discrimination with fast operating time and still working in a secure and reliable operating region.

Acknowledgement

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Appendix

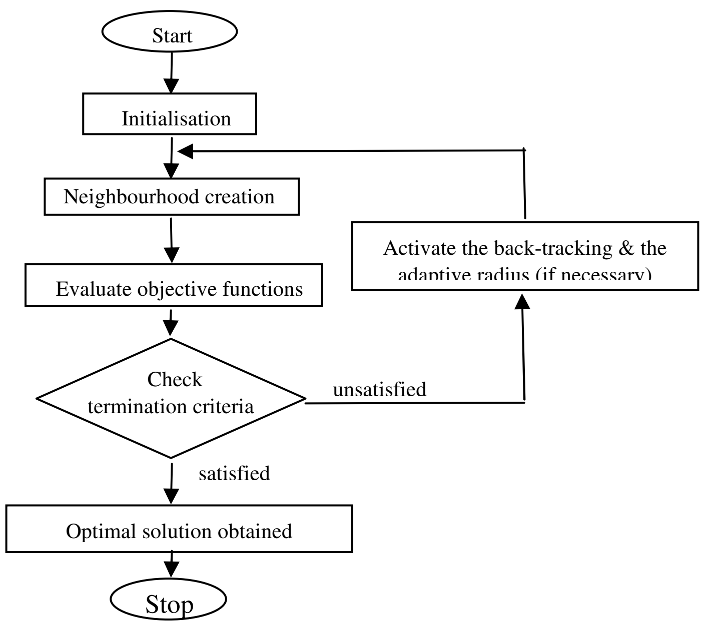

Fig. 6. Flow diagram for the ATS method