System-Wide Protective Relay Setting and Coordination in Large-Scale Transmission systems-A Review

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Abstract- This paper presents an extensive bibliography resulting from a detailed literature survey on the topic of System-wide protective relay setting and coordination in large scale transmission systems. Coordinating a system of directional relays is also very complicated due to the typical loop structure of the transmission system and also changing the setting parameters of one relay for obtaining coordination for all the relevant fault current pairs can disturb the proper coordination of the already checked relay pairs. Arbitrary starting relay locations and arbitrary consideration of relay sequence to set and coordinate relays will result in navigating loops many times, and usually result in futile attempts to achieve system-wide relay coordination. This paper lists out the various methods for determining the break point set to provide accurate directional relay coordination.

Index Terms: Break Point Set (BPS), Looped System, Relay Coordination, Relay settings.

1. INTRODUCTION

Modern societies are more and more dependent on electricity to fulfil the needs of industrial development and quality of life so that large interconnected power systems provide a very important service. Any power system is prone to 'faults', (also called short-circuits), due to external causes. In both high systems and low voltage systems of higher capacities, the sensing is done by more sophisticated devices called relays. Protective relaying is highly developed area and specialized field of protection engineering. With more complex systems, it is necessary to detect the point of fault precisely and trip only those sections affected by the fault while the rest of the system can continue to function normally. In the event of the nearest circuit breaker failing to operate, the next breaker in the upstream (feeding) side has to be tripped as a 'back up' measure. Another requirement is to minimize the time for which a fault remains in the circuit, this is necessary to reduce equipment damage and the danger to operating personnel. The term "Coordination of protective relays" means determining the parameters of the relays, so that the relays operate correctly both as primary and backup. Relays detect such faults and are able to give a tripping order to circuit breakers. The operation of these relays must be coordinated in the sense that if a fault occurs, faulted component is isolated. This requires that, given a fault, only its primary relays operate. The corresponding back up relays should only operate if one of those primary ones fails to trip. Setting of overcurrent relays required two parameters: time dial setting (TDS) and pick up current setting (I_p).

2. PROTECTIVE RELAY COORDINATION PROBLEM

The process of relay coordination gets more difficult as the network's structure is more complex and more reduced operating times are required in order to increase the system availability and stability. Difficulty in setting relays appears when one sets the last relay in a sequence which closes a loop, it must coordinate with the one set initially in that loop otherwise must go for re-coordinating relays in sequence.

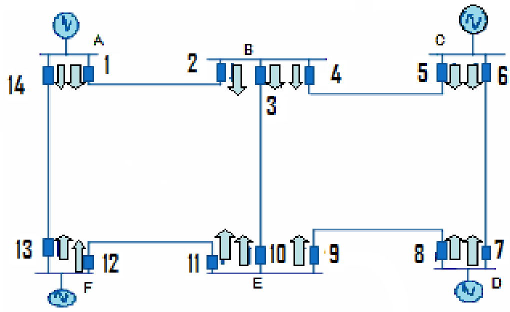

Figure 1: 6-Bus Test System

As an illustration of the coordination problem, let us consider the 6-bus test system shown in Fig. 1. Let us start with Relay 13 for backup coordination process. Relay 13 is initially set as a backup to coordinate with relay 1. Then, Relay 11 is set as a backup to coordinate with Relay 13. Next, Relay 3 is set as a backup to coordinate with Relays 11 and 9. And finally, relay 1 is set as backup to coordinate with Relays 3 and 4, thereby closing the loop. This newly changed setting value of relay 1 necessitates recomputing the already set values of our initial relay 13. This new setting value of relay 13 is then to be propagated to all other relays in that loop for proper coordination of the relays in this loop. Further, the coordination process is also affected by relays in the adjacent loops and therefore, we can conclude that this traversal of loops for coordination is a highly iterative and complex process. To overcome this problem and identify efficient ways of addressing this problem, one of the major approaches suggested is the concept of **Break Point Relays**, which are a minimum set of relays which will break all the loops in the system in both directions. Then, an efficient sequence all other relays will be determined to reduce the number of iterations and accelerate the convergence of the coordination process. Published work in this area is reported in our paper.

Major difficulties and problems in coordinating relays in large-scale looped transmission system usually arise due to:

- One would have to cope with large quantities of data.
- Lots of calculations have to be done.
- During the process lots of settings have to be changed and their values have to be recalculated.
- Changes in the settings of one relay propagate changes to several other relays.

All these aspects suggest the use of computational procedures for obtaining properly coordinated settings. We summarise below an extensive list of publications which describes various such computational procedures and algorithms for efficiently and correctly coordinate directional relays in large transmission system

The idea of BPS to reduce the complexity in relay coordination was first introduced by Knable in [1]. These relays are first set and the other relays are coordinated. As looped circuits are normally protected by directional overcurrent relays located at both ends, the looped formed in the clockwise and anti –clockwise directions are considered for determining the break point relays. Dwarakanath and Nowitz suggested a systematic approach for determining the relative sequence setting of the relays in a Multiloop network by using a linear graph theory approach which provided a directional loop matrix. A minimal set of break point relays spanning all loops of the system graph were obtained from this matrix. Then, an efficient sequence of all other relays will be determined to reduce the number of iterations and accelerate the convergence of the coordination process. The sequence for setting the relays is displayed by a relative sequence matrix (RSM) by Damborg et al in [3]. For setting a relay, it is necessary to know which relays are going to be back up by this relay. The set of all primary and back up relays sorted by the backup relays is the set of sequential pairs (SSP) by Damborg et al in [3]. Ramaswami et al in [4] proposed an algorithm employing a sparsity techniques and data structures for coordinating directional overcurrent and distance relays on transmission network where the problem of memory requirements have been solved. Ramaswami in [5] describes about the computer-aided-engineering (CAE) tool developed for setting and coordinating directional overcurrent and distance relays of a transmission system for subsystems and full-systems.Finding a break point relays in a small network with limited number of buses and loops is not much complex. However, with the increase of the number of buses and loops in the system, the problem of finding the suitable BPS is practically complicated [6]. Rao in [6] used the notion of loop matrix L_D, the MBPS problem was mapped to find the minimum cover of relays such that their span is the whole set of directed loops. Ramaswami et al. in [8] developed a new subsystem coordination algorithm which will efficiently compute the relay setting for a part of the system in response to changes in system condition has been developed. This procedure automatically identifies the subsystem which is affected by the system change and carries out the coordination process to ensure correct relay operation under the new system conditions. The breath first search can enhance the efficiency of finding all of the loops by the authors in [9]. Prasad et al in [10] developed a methodology which does not require the generation of all the directed loops. Jenkin et al. in [11] applied the concept of functional dependency to the topological analysis of the graph which does not require the computation of all the loops and also the exponential time but settled for the suboptimal solutions. This approach was extended by Madani and Rijato in [18] and [19]. Madani and Rijato in [20], approach with improve algorithm by using the concept of partitioning graphs into forest. K Kawahara et al. in [21], present about the rule based system for solving the coordination problem of directional overcurrent relays. In order to efficiently determine the setting values in a looped system, the system involved finding a BPS by using the heuristic knowledge. Sastry in [30] has tried heuristic approach where a bus with the highest degree of relays is chosen and all the relays on that bus are removed. The process is carried till no more loops are left out in the system which does not provide efficient solutions. The author in [31] developed a heuristic approach by recognizing the problem as NP hard problem which consumes lots of time. Determining the BPS in polynomial time has been approach in [36] by Yue et al. But ended with suboptimal results. Their method is in order to reduce the CPU time and complexity of calculating minimum break point set (MBPS), a new concept named as protection relay dependency dimension (PRDD) is presented in this paper. By comparison of PRDD in a multiloop network, the MBPS can be determined, and the process of comparisons will not stop until the MBPS of the multiloop networks is discovered. The approach in [36] is a greedy approach. Hossein et al. in [37], a powerful approach based on expert system is applied. The rules of the expert system include network configuration, protection systems, fault levels, etc.Shateri and. Jamali in [38], presents an improved functional dependency based method to determine the break point. A reduction method is presented to reduce the network, which leads to decrease in the problem dimension and computational burden. This method has the capability of considering the three-end branches such as three terminal transmission lines and three-winding transformers.A novel based on two dynamic matrixes of node-relay matrix (NRM) and relay incidence matrix (RIM) was introduced by the authors in [39] to find MBPS.

3. DIFFERENT APPROACHES TO FIND BREAK POINT RELAYS

Zero-One (0-1) Integer Programming, Genetic Algorithm, Particle swarm optimization, Functional Dependency and graph theory etc are some of the techniques for solving the set covering problem which are explained briefly in below.

3.1GRAPH THEORY:

Initiated the system-wide coordination in a scientific way. Graph theory is used to analyze network graph. Need to find fundamental loops, l= e-v+1 where e is the no. of the edges (branches/lines) and v is the no of the vertices (nodes/bus) .The total no. of the loops, $L_T= 2*(2^l-1)$ .Need to BREAK all of L_T. Utilizing the network structure they analyze the information about minimum break points set, sequence for setting the relays and all primary/back up relays. An approach to identify and analyze all simple loops of the network in both directions was presented [17]. The determination of break point set is a problem in graph theory known as feedback vertex set (FVS). To illustrate this method, coordinating the 6 bus test system (Fig 1) is considered. The primary and backup relationships of this test system is shown in fig 3 as a dependency- diagram (directed graph), D1. In dependency-diagram each vertex (node) represents a relay, and each arc (directed branch) indicates the primary-backup relation between two relays [12].

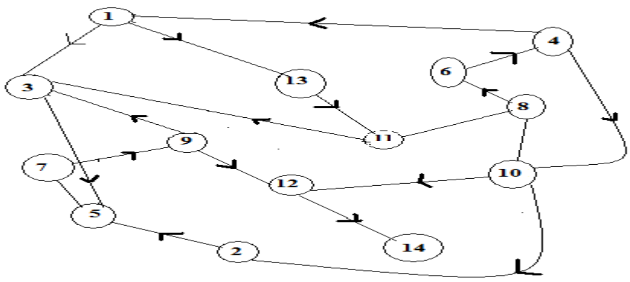

Fig 3: A Dependency- diagram (directed graph), D1

3.2 FUNCTIONAL DEPEDENCY:

Functional dependency is a concept which has been applied to database systems. A functional dependency occurs when one attribute in a relation uniquely determines another attribute. This can be written A -> B which would be the same as stating "B is functionally dependent upon A". It has been utilize for topological analysis of the power systems. Constraints on relay settings were expressed through a set of functional dependencies. Coordinating a system having a large number of relays required a large amount of time but these have been overcome by functional dependency. The functional dependency relationships are generated from primary-back-up pairs. For example, if relay R1 is going to back up the relays R3 and R4 as shown in fig 2 then the setting of R1 is determined on the basis of R3 and R4. The relay R1 is said to be functionally dependent on relays R3 and R4 [11, 24, 25].

3.3 ZERO-ONE (0-1) INTEGER PROGRAMMING:

The zero-one programming technique has been successfully applied to solve a project selection problem in which projects are mutually exclusive and/or technologically interdependent. It is a term used in a special case of integer programming where all the decision variables are integers and can assume values of either zero or one. Integer linear programming problems are the special class of linear programming problems where all or some of the variables in the optimal solution are restricted to non-negative integer values. Here the problem for finding the break point relays is formulated as 0-1 integer programming problem. Each directed loop should have at least one break point relay which break the loop, the relay will take the value of 1 if it is breakpoint and 0 if it is not. 0-1 integer programming provides an efficient approach to the computation of optimal BPS [21].

3.4 GENETIC ALGORITHM:

It is an optimization tool for engineering problems. It is a directed search algorithms based on the mechanics of biological evolution. It was developed by John Holland, University of Michigan (1970's). In general, the genetic algorithm is a probabilistic search algorithm that iteratively transforms a set (called a population) of mathematical objects (typically fixed-length binary character strings), each with an associated fitness value, into a new population of offspring objects using the Darwinian principle of natural selection and using operations that are patterned after naturally occurring genetic operations, such as crossover and mutation. Genetic algorithm is chosen over other traditional optimization techniques because of the lower probability of trapping in local minimum. Larger number of generations and population size produce better results [15, 23].

3.5 BINARY PARTICLE SWARM OPTIMIZATION (BPSO):

It was introduced by Russel Ebenhart (an Electrical Engineer) and James Kennedy (a Social Psychologist) in 1995. It belongs to the categories of Swarm Intelligence techniques and Evolutionary Algorithms for optimization. It is inspired by the social behavior of birds, which was studied by Craig Reynolds (a biologist) in late 80s and early 90s. Basic mathematical equations in PSO:

$$\begin{cases} v_{t+1} = c_1 v_t + c_2 \left(p_{i,t} - x_t \right) + c_3 \left(p_{g,t} - x_t \right) \\ x_{t+1} = x_t + v_{t+1} \end{cases}$$

Where,

v_t = velocity at time step t

x_t = position at time step t

p_{it} = best previous at time step t

p_{gt} = best neighbour's previous best, at time step t

The original version of PSO operates on real values. However, determining a break point set is a discrete optimization problem with 0–1 decision variables representing on/off status of relays, which determines the relay is break point if it is 1 and o if not. So it must extend the real-valued PSO to handle discrete space of the break point set. A clever technique for creating a discrete binary version of the PSO introduced by Kennedy and Eberhart (1997) in 1997 uses the concept of velocity as a probability that a bit takes on a one or a zero. Binary PSO can be used to solve the break point set.

All these aspects suggest the use of computational procedures for obtaining properly coordinated settings.

4. FUTURE WORK SUGGESTED

Based on the knowledge gained by conducting this extensive literature survey and from the previous work done by us in this area, we are looking into significantly improved new algorithms like 0-1 integer programming problem, genetic algorithm and particle optimization for the determination of Minimum Break Points and further systematic ways of coordinating directional relays in large scale power transmission systems. We will report the results of this new research study in future publications.

5. CONCLUSION

We have done an extensive and very detailed literature search and survey on the subject of "System-wide protective relay setting and coordination in large-scale transmission systems" especially for dealing with systems with tightly coupled loop or mesh structures. The major concept of Break Point Relays, a concept which was pioneered by the primary author of this paper is paid special attention in conducting this survey. Suitable and brief annotations have been provided with all the cited publications. Our future plans of research in this area are also briefly included in this paper. It is anticipated that the extensive work presented here will encourage other researchers to pursue this very important problem of large scale relay coordination and suggest new and improved approaches for solving this very difficult and important problem.

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