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A Review on Impact of Distributed Generation on Directional Overcurrent Relay Coordination

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Abstract: *Distributed generation (DG) is commonly used to supply the local loads. The penetration of distributed generation leads to violating the relay coordination in the distribution network. The interconnection of DG affects miscoordination of distribution system protection, because of the generator ability to contribute large fault currents to the fault point. The impact of DG on relay coordination affect the operating time of relay. The CTI associated with primary and backup relay pairs is getting violated due to changes in fault current level. Thus, coordination between primary and backup relays fails in the presence of distributed Generation. Hence, the interconnection of DG in the distribution system causes an adverse impact on protection. directional overcurrent relay (DOCR) which is the most implemented protection device in the electrical network also suffers performance degradation in presence of DG. Therefore, the paper proposes the mitigation of DG impact on DOCR coordination employing adaptive protection scheme (APS) using Genetic Algorithm (GA) .*

Keywords: *Distributed Generation, Relay coordination, Genetic Algorithm, MATLAB Toolbox, Inverse Definite Minimum Time relays, Adaptive protection scheme*

I. Introduction

Shunt faults in a power system give rise to sudden built up of current. This magnitude of fault current can be utilized forthe indication of fault existence. The over-current protection is most widely used for the protection of power system. Directional overcurrent relays (DOCR) are commonly used forthe protection of distribution systems and also as a secondary protection of the transmission system. In distribution feeders,they play a more prominent role and there it may be the onlyprotection provided. A relay must trip for a fault under itsprimary zone of protection. Only if, the primary relay fails toclear the fault, the back-up relay should take over tripping. If backup relays are not well coordinated, the relay may get maloperate.Therefore,relay coordination is a major concern for power system protection. Each relay in the power system must be coordinated with the other relays in the power system [1, 2]. Several heuristic-based optimization techniques were proposed for optimum coordination of OCRs [3]. The optimum settings for TMS and PS are obtained using different algorithms proposed by the researchers. In some cases, pickup currents are determined based on experience and only the value of TMS is optimized. Several non-linear programming (NLP) methods are used to optimize both TMS and PS. However, NLP methods are complex as well as time consuming. To avoid the complexity of the NLP methods, the OCR coordination to avoid the complexity of the NLP methods, the OCR coordination problem commonly formulated as a linear programming problem (LPP) [13]. Various LPP techniques are present by the researchers for OCR coordination [3-6]. In [7,8], optimum coordination is achieved by considering different network topologies. In [9], a genetic algorithm is proposed to find the optimum solution for relay settings. In [10], GA is used to find the optimum relay settings.

Injections of distributed generation (DG) in distribution system jeopardize the existing protection scheme. The impact depends on some DGs, size, type and location. Moreover, the position of DG in distribution network changes the configuration of the distribution system. The distribution system is radial in nature, and overcurrent based protection scheme are set for the uni-directional flow of current. But the injection of DG power causes meshed configuration of the distribution system and on few branches current flows in the both directional.[14-15]. In this paper, the problem of determining the optimum values of TMS and PS of OC Relay had been formulating. The Genetic algorithm optimization method with proposed algorithm is used to determine optimum values of TMS and PS. Two case studies with a 6-bus system with 10 OCR relays and 6-bus system with 10 OCR relays are presented to illustrate the proposed method.

II. Related work

The main function of the protective devices in the power system is to detect and clear the selected faulty parts as fast as possible. Directional over current relays are commonly used for the protection of interconnected sub-transmission systems, distribution system or as a secondary protection of transmission systems. For the systems having more than one source connected that is meshed or looped networks directional over current relay become the suitable choice for better selectivity since directional relays operate only when the fault current ows in the specific tripping direction desired. The most vital task when installing directional relays on the system is selecting their suitable current and time settings such that their fundamental protective functions are met the requirements of sensitivity, selectivity, reliability, and speed, etc.

A shunt fault in the power system brings about the sudden increase in current. Fault existence is indicated by the magnitude of fault current. Therefore, the overcurrent protection is most extensively used for the protection of power system [1]. An analytic representation of typical relay operating characteristic curve shapes of various relays e.g. Inverse Time overcurrent Relay, Inverse De_nite Minimum Time overcurrent Relay, Very Inverse Relays and Extremely Inverse Relay are presented in [2]. An advanced coordination method for an optimized protection time grading is based on a new non-standard tripping characteristic for over current protection relays. The intention is the highest possible reduction of tripping times for a selective fault clearing in distribution networks protected by overcurrent relays without communication links. The new non-standard tripping characteristic is described from its basic idea to its constraints of the optimization problem.

One of the most commonly used protective relays in power systems is the overcurrent relay. In the overcurrent coordination program two types of settings, i.e. current and time settings must be calculated. Plug setting (PS) for each relay is determined by two parameters the Minimum fault current and the maximum load current. For optimal coordination the following items are important:_ Optimal method.

- Network type (radial or interconnected network).
- Nonlinear or linear relay characteristic proportional to TSM or TDS.
- Continuous or discrete TSM or TDS [3].

The method to designate the constraints is provided an area called possible solution area (PSA) have introduced for each relay pair i.e. primary and backup relays. The PSA is a square which is bounded by the maximum and minimum values of the time multiplier setting (TMS) or time dial setting (TDS) for each primary and backup relays. A line on the two dimensional plane i.e. PSA is de_ned. It describes the relationship between the backup and primary relays operating time this is referred to as a constraint line. Based on the intersection of constraint lines and PSA, the constraint lines are divided into four categories among them only one is valid. Improvement of the feasibility is made by comparing the crossing points of valid constraint lines with the PSA [4]. The coordination problem of directional OCR in a ring fed distribution system can be stated as an optimization problem where the sum of the operating times of the relays of the system for di_erent fault points is to be minimized. In distribution system since the lines are short and are of approximately equal length equal weight is assigned to operating times of all the relays. The objective of minimizing the total operating time of relays is to be achieved under three sets of constraints, as discussed in the following sections. Fault is sensed by both primary as well as secondary relay simultaneously. To avoid mal-operation, primary relay fails to operate then backup relay should take over the tripping action. A linear programming problem is stated and solved for coordination of DOCR in terms the time dial settings [5] until a viable solution is reached.

The relay coordination problem was framed as mixed integer non-linear programming problem and solved in a proper manner using general algebraic modeling system (GAMS) [6]. In [7] all settings of DOCR using the nonlinear technique by Sequential Quadratic Programming method are presented. The optimum relay coordination problem is basically a highly constrained optimization problem. Formation of this problem as an LPP is explained in [8] and the optimum value of TMS of each relay is obtained using a big-M (Penalty) method. The relay coordination in an interconnected power system is an insipid task. To relieve the protection engineer from this task, it is designed to set and coordinate relays in an on-line manner. In an adaptive coordination, the relays should respond to the dynamic system conditions and adapt according to the new prevailing conditions.

An adaptive protection scheme for optimal coordination of DOCR in interconnected power networks by implementing a linear programming technique is investigated [9]. Some optimization techniques were base on the act of human searching. The coordination of DOCR's are formulated as a mixed-integer nonlinear programming problem and is then solved by a new seeker optimization technique [10]. DOCR mainly works as a backup protection in the distribution system. It acts as a defender

against the possible failure of main protection devices in power system protection [11,12]. The practically power system may be operated in different network typologies due to an outage of the transmission lines, transformers, and generating units. Protective system starts to operate without selectivity due to the changes in the network topology of a system.

DOCR coordination considering the _effects of the different network typologies in the optimization problem. The genetic algorithm is selected as a powerful tool for solving a complex optimization problem. Here, to improve convergence of GA, the latest hybrid method is introduced. The results show optimal solution can be obtained by implementing proposed hybrid GA [13].

A hybrid Genetic Algorithm Nonlinear programming (GA-NLP) method is in-[7]. Introduced for determination of optimum values of TMS & PSM of overcurrent relays and to overcome the drawback of GA and NLP method. Here detailed problem for obtaining optimum values of TMS & PSM is formulated as a constrained nonlinear optimization problem. Initial values of TMS & PS using GA technique are determined [14]. And optimal (global optimum) values are determined using nonlinear programming method. Thus, advantages of both methods are incorporated here. For optimal coordination of DOCR, different optimization techniques are employed. [15-17] deals with another way of optimal coordination using the artificial intelligent system such as the particle swarm optimization (PSO) algorithm.

A new method to select the settings of DOCR. A new selection criterion of pickup currents is adopted. It results in discrete pick-up current values, which mitigate the selectivity constraints select on the minimization of time multiplier settings. The selectivity constraint equations are divided into individual groups on backup relays. When solving these systems of equations, the initial time multiplier settings are obtained. The initial values are then increased gradually to find the final solution for all the constraints equations. The given method is tested on IEEE 3-bus system
and IEEE 9-bus system. Its performance is analyzed and compared with Informative Diferential Evolution Technique (IDA) [18].

A new optimization algorithm referred to the black hole phenomenon used for optimum coordination of digital overcurrent relays in the distribution network is proposed [25]. This black hole algorithm is used to a standard 33-bus radial distribution system for optimum coordination of overcurrent relays. MATLAB software is used to simulate the validation of the proposed algorithm and also used to compare with the Particle Swarm Optimization (PSO) Algorithm. The simulation results show that the Black Hole (BH) algorithm is quite faster and more accurate than Particle Swarm Optimization (PSO) Algorithm. DG impact on DOCR coordination employing adaptive protection scheme (APS) using differential evolution algorithm (DE). The impacts of DG prior and after the application of APS are presented and a new mitigation scheme is proposed [26]**.**

III. formulation of coordination problem

Relay Coordination problem can be formulated as constrained optimization and solved by different optimization methods. To achieve relay coordination, the sum of all primary relay operating times should be minimized using the optimal relay settings time multiple setting (TMS) and plug setting (PS)] [8-10]. This is present in equation 1.

$$\min \, Z = \sum_{i=1}^{N} t_i \qquad (1)$$

Where
z - The objective function in zone k,
i- Index,
t- Operating time of the ith primary relay for its near-end fault in k,
N - A total number of directional overcurrent relays. Depending upon relay characteristics the above optimization problem has following constraints.

A. Relay Setting

Each relay has time multiple setting (TMS) and plug setting(PS). PS limit has chosen based on the maximum load current and the minimum fault current seen by the relay, and the available relay setting. The TMS limits are based on the available relay current-time characteristics.

$$PS_{i\min} \le PS_i \le PS_{i\max} \qquad (2)$$

$$TMS_{i\min} \le TMS_i \le TMS_{i\max} \qquad (3)$$

Where

$PS_{i\min}$ minimum value of PS of relay R

$PS_{i\max}$ maximum value of PS of relay R

$TMS_{i\min}$ minimum value of TMS of relay R

$TMS_{i\max}$ maximum value of TMS of relay R

$PS_{i\max}$ and $TMS_{i\max}$ taken as 0.025 and 1.2, respectively.

B. Bounds on Relay Operating Time:

The relay needs a certain minimum amount of time to operate. Also, a relay should not be allowed to take too long time for its operation. Has been mathematically stated as.

$$t_{i\min} \le t_i \le t_{i\max}$$

Where,

$t_{i\min}$ Minimum operating time of the relay for the fault at anypoint in the zone k,

$t_{i\max}$ Maximum operating time of the relay for the fault at any point in the zone k,

C. Backup-Primary Relay Coordination Time Interval

The fault sensed by both primary as well as secondary relay simultaneously. The backup relay should take over the tripping action only after primary relay fails to operate, to avoid mal-operation. If Ri is the primary relay for fault at k, and R backup relay for the same fault, then the coordination constraint can be stated as.

$$t_{i,k} - t_{j,k} = \Delta \text{t} \qquad (5)$$

Where,
ti,k - Operating time of the primary relay R, for the fault at k,
tj,k - Operating time of the backup relay Rji , for the same fault at k,
∆t - Co-ordination time interval (CTI).

IV. Genetic Algorithm

A Genetic Algorithm Heuristic non-traditional optimization technique he has based on the, mimic the process of evolution, right. GA is advantages of converging to the global optimum. The genetic algorithm will be slow compared to conjugate gradient is disadvantages of GA. Distinguishing characteristics of GA compared to traditional methods are as follows: GA works with the coding of the parameter set, not the parameter themselves. GA's search for a population of the point, not a single point. GA uses the objective function information & not the derivatives & second derivatives.

A. Important terms in Genetic Algorithm:

- Chromosome: a set of generation, a chromosome contains the solution in a form of generations.
- Generation: a part of the chromosome, a generation contains a part of the solution. It determines the solution. e.g. 16743 is a chromosome and 1,6,7,4 and 3 are its generations.
- Individual: same as a chromosome.
- Population: number of individuals present with the same length of the chromosome.
- Fitness: the value assigned to an individual based on how far or close an individual is from the solution.
- Fitness function: a function that assigns fitness value to the individual. It is problem specific.
- Crossover: taking two fit individuals and then intermingling there chromosome to create new two individuals.
- Mutation: changing a random generation in anindividual.
- Selection: Selecting individuals for creating the next generation.

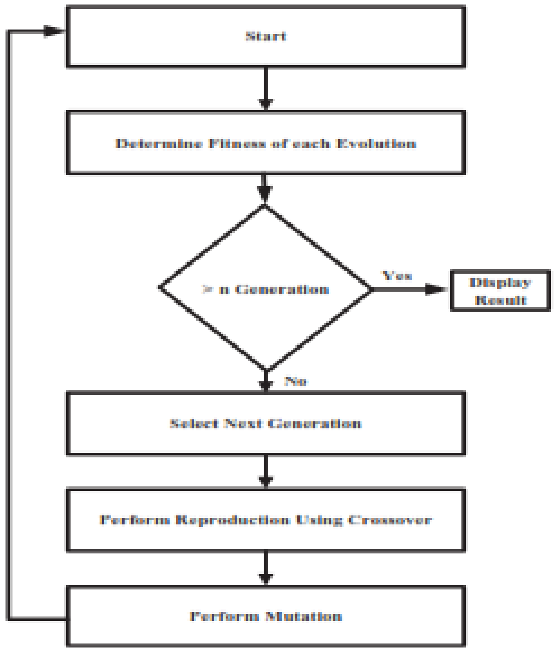

Fig 1. Flow chart of GA Algorithm

V. Description of Proposed Protective Scheme

A small interconnected 6 bus system was chosen to study the impacts of DGs on relay coordination. The impacts of DGs on the relays are the same in radial and interconnected systems But as the system under study becomes bigger, the impacts of DGs may not be clearly seen since the fault contribution of the system is several times greater than the contributions of DGs. The fault currents are calculated with the remote bus breaker opened. The system consists of 10 active phase relays and 16 coordination pairs. A DG farm of 10 MW and 20 MW will be connected on bus 6. base case (DOCRs are coordinated in this case including contingency analysis), the DG10 case (10MW DG inserted on bus 6 with Xd' 0.5 used for comparison purpose only, no coordination was carried out) and DG20 case (20MW DG inserted on bus 6 with Xd' 0.3 used for comparison purpose only, no coordination was carried out). The DG10 and DG20 cases run power flow and fault analysis including the penetration of DG on bus 6 without contingency analysis and without performing coordination. Then, the relay settings of base case are used to determine the new operation time of the relays (influenced by DG penetration) in order to evaluate the performance of the relays.

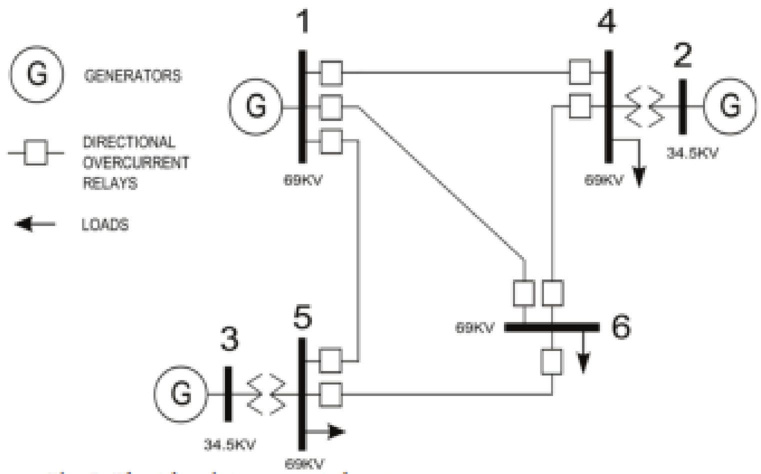

Fig – 6 bus system with 16 directional overcurrent relay

VI. Conclusion

In this paper, the interconnection of DG affects miscoordination of distribution system protection, because of the generator ability to contribute large fault currents to the fault point. Thus, coordination between primary and backup relays fails in the presence of distributed Generation. The CTI associated with primary and backup relay pairs is getting violated due to changes in fault current level. Hence, the interconnection of DG in the distribution system causes an adverse impact on protection co ordination. The optimum relay coordination problem is formulating as constrained optimization problem considering minimum operating time for each relay is considered as 0.2 (sec), and CTI is taking as 0.2(sec). The optimum values for TMS are obtained using GA.The algorithm was testing for various system configurations,including multi-loop systems, and was found to give satisfactory results in all cases. And to mitigate this problem an adaptive protective scheme are used .

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