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Automated Power system protection Scheme for Smart Grid Using Particle Swarm Optimization method

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Abstract
In this paper, the problem of coordinating directional over current relays in power systems is stated and solved in the framework of optimization theory. The proposed approach determines the "optimal" solution to this coordination problem in a cost effective and efficient way, by stating the problem as a parameter optimization problem, and solving it using efficient optimization techniques. Here the optimization of Time Dial Setting and minimized function got from Linear programming with Large-Scale: Interior Point in Matlab has been done by Particle swarm Optimization technique coded in MATLAB. It is pertinent to mention here that the Optimization methodology presented in this work can also be applied to the problem of optimal coordination of protective relays other than directional over current relays .The optimization approach and its particularization to the case of directional over current relays are based on PSO.

Keywords: Particle Swarm Optimization (PSO), Over current Relay, distributed generation source

1. Introduction:

Relay Coordination in a big distribution system with multiple meshes and bidirectional power feed becomes very Complex for protection engineers. Manual and graph theory based approaches were applied successfully in small power system. In a big distribution system linear and non-linear programming based optimizing techniques are applied for relay coordination. In this work optimization techniques are applied for optimal co-ordination of directional overcurrent relays. This thesis discusses the application of Particle Swarm Optimization (PSO) algorithm for optimal coordination of DOCR relays in a 8 bus power system. Combination of primary and backup relay is chosen by using far and near end vector of structure, to avoid mis-coordination of relays. Coordination of DOCR is tested for IEEE 8 bus systems using the PSO. Also, the objective function is modified to optimize the operating time between backup and primary relays. The results are compared with the optimized values of Time dial setting and Plug setting values obtained from popular conventional method. The proposed algorithm based on PSO gives optimal coordination margin and no mis-coordination between primary and backup pairs. Results are also verified using simulation developed on MATLAB software.
Producing energy should not threaten the environment. It should benefit the environment in one way or the other. Over the last five years non conventional resorces has become a leading renewable energy investment destination [1]. The government has incentivized initiatives aimed at addressing the challenges of energy demand, economic growth, the country's carbon footprint and climate changes. This is the reason why there are now an increased number of renewable energy resources being connected to the Eskom distribution network [1]. The two flowcharts in Figure 1 show the old and the new power system design. The arrows in the diagram show the direction of the electrical power flow and current. In the old design, as depicted on the left of Figure 1, conventional power stations are the main sources. During power system faults the main fault current contributors are synchronous machines used in the conventional power stations.

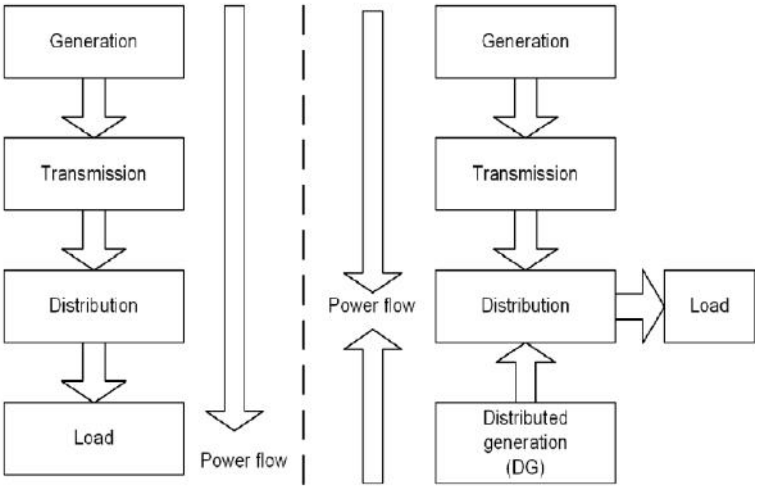

Figure 1: Radial (classical) and new design power system

The new paradigm in power system design is shown on the right of Figure 1. The flow of power and current is bi-directional. With this new design, during power system faults the distributed generation source (DG) has the capability to contribute to the fault. However, the main contributors to faults are synchronous machines in the conventional power stations. The benefits of connecting more DGs to the distribution network are threefold. Firstly, it increases
the existing power system capacity, thereby ensuring a higher probability that demand for electrical energy will be met even during peak periods. Secondly, construction of a single conventional coal power station takes longer than constructing a single DG substation. Thirdly, most of the DG sources are connected at the distribution side, therefore only a few additional transmission lines are needed in the transmission network. Thus, the source is brought closer to the load centre. As a result, technical losses and capital expenditure are reduced, while reliability and integrity of the network are enhanced [2],[3]. The impact of the DG depends mainly on the location, capacity and the technology of the DG used.

However, connection of DG sources to the distribution network introduces network conditions which were not encountered before. The new conditions include a change in the magnitude and direction of the power flow and the short circuit current [4],[5]. Secondly, during a transient fault in the power system, DGs (when connected) will continue operating, thereby sustaining the power system voltage and feeding the fault current. Consequently, this prevents the arc of a transient fault from being extinguished, and results in an unsuccessful auto-reclose operation of the device clearing the fault. Lastly, transient overvoltages may be experienced, which could damage the power system equipment and customers' equipment [4],[5]. These conditions have a significant impact on the operation and integrity of the power system [4],[5],[6]. Therefore, proper resolution of these challenges, and others as outlined in Chapter 4, determines whether the benefits of connecting more DG sources to the distribution network described above will be achieved.

When the number and capacity of the DG sources increases in the distribution network, the coordination of protective relays becomes more complex and challenging [6]. Coordination of overcurrent relays is the ability of the relay to discriminate and operate sequentially for faults in the protected zone in order to avoid unnecessary trips. There are various methods which can be used to calculate the settings of the overcurrent relays. The conventional method is used to calculate the overcurrent protection relay settings. The particle swarm optimization (PSO) algorithm is proposed to improve on the calculated overcurrent protection relay settings. The PSO algorithm is a relatively new stochastic search algorithm. PSO emulates the behaviour of swarms such as birds, fish and social insects.

Several system operating conditions arise when DGs are connected to power distribution systems:

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- All the DGs are connected and the system is operating in the normal operation mode.

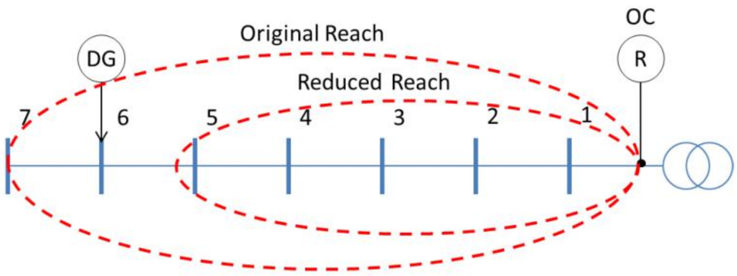

Figure 2: Relay reach with and without a DG.

- Part of the DGs is disconnected due to maintenance or due to a previously isolated fault.
- The main grid is disconnected, and the system is operating in island mode.
  The variations in the configuration of power distribution systems are not taken into account in conventional protection systems. Moreover, the introduction of DGs changes the system from being radial, and therefore the relays must detect the direction of the fault. This chapter discusses the importance of implementing protection systems in power distribution systems and the different types of protection systems used.

2. General model of the problem

An important characteristic of some types of protection in an electrical circuit is their capacity to determine the direction of the flow of power. Because of this feature they inhibit opening of the associated switch when the fault current flows in the direction opposite to the setting of the relays. Directional relays can tackle this situation when relays face fault currents in both directions because they operate only when fault current flows in specified tripping direction. Hence, directional over-current relays are used extensively for the protection of feeders having infeed from both the ends (e.g. loop systems and parallel feeders). A DOCR consists of two units: (i) an instantaneous unit and (ii) a time-delay unit.

The instantaneous unit operates with no intentional time delay when current is above a predefined threshold value, known as the instantaneous current setting. Time-delay unit is used for current, which is below the instantaneous current setting but exceeds the normal flow due to a fault. This unit operates at the occurrence of a fault with an intentional time-delay. Two settings are associated with the time-delay unit, which are as under

- time dial setting (TDS)
- plug setting (PS) (e.g. tap setting)

The TDS adjusts time-delay before a relay operates whenever the fault current reaches a value equal to or greater than the pickup current. Tap setting is a value that defines the pick-up current of the relay, and currents are expressed as multiple of this. These settings essentially specify the particular time–current characteristics from the family of available curves and the multiple of tap setting to be used to find the relay operating time for a given current flowing through the relay. ''Threshold'' or ''Pick-up current'' is the minimum current for which the relay operates and is determined by selecting one of the plug setting taps available on the relay.

The mathematical model of the problem followed in this paper is same as Thakur (2007)but DE and its modified versions are used to solve the given problem instead of GA.The operating time (T) of a DOCR is a non-linear function of the relay settings (time dial settings (TDS) and plug settings (PS) and the fault current (I) seen by the relay. Thus, relay operating time equation for a DOCR is given by

$$T = \frac{\alpha * TDS}{\left(\frac{1}{PS * CT_{pri\_rating}}\right)^{\beta} - \gamma} \qquad (1)$$

Only TDS and PS are unknown variables in above equation. These are the ''decision variables'' of the problem. Throughout this paper, the symbol ''n'' represents scalar multiplication. α, β *and* γ are the constants representing the behaviour of characteristic in a mathematical way, in which operating time of the DOCR varies and are given as 0.14, 0.02 and 1.0, respectively as per [IEEE std. (1997)]. Value of CTpri_rating depends upon the number of turns in the equipment current transformer (CT). CT is used to reduce the level of the current so that relay can withstand it. With each relay one ‘‘current transformer’’ is used and thus, CTpri_rating is known in the problem. Value of I (Fault current passing through the relay) is also known, as it is a system dependent parameter and continuously measured by measuring instruments. Number of constraints for systems of bigger sizes depends upon the number of lines in the system.

3. Results and Discussions

The network of this test case is shown in the figure given below, where the near-end 3ϕ fault is considered. Bus 4 is connected to an external grid that is modeled by 400 MVA short-circuit capacity. Some studies named this system as a 6-bus test system, because bus 7 and bus 8 are connected to the generating units and do not have any relay.

The available set of the discretized plug-setting (PS) is {0.5,0.6,0.8,1.0,1.5,2,2.5. Although this test case has small dimension, it has been noticed that it is very hard to get feasibly and optimal solution.The CT ratios (CTRs) and the 3ϕ short-circuit current for each P/B pair of relays are given below

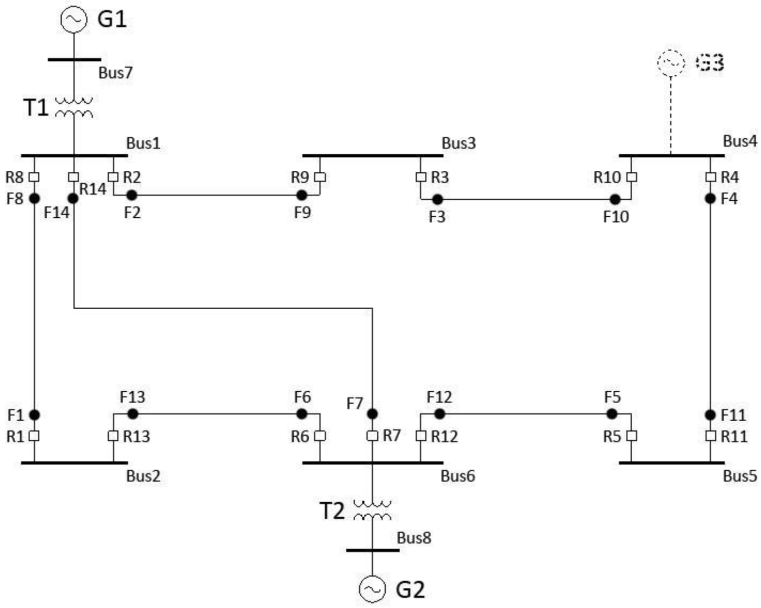

Figure 3: 8 Bus system

Table 1: Generator data of the 8-bus system

Gen.	S_n **(MVA)**	V_p **(kV)**	x **(%)**
G1	150	10	15
G2	150	10	15

Table 2: Transformer data of the 8-bus system

Trans.	S_n **(MVA)**	V_p **(kV)**	V_s **(kV)**	x **(%)**
T1	150	10	150	4
T2	150	10	150	4

Table 3: Line data of the 8-bus system

Nodes	R (Ω/km)	X (Ω/km)	Y (S/km)	Length (km)
1-2	0.004	0.05	0.0	100
1-3	0.0057	0.0714	0.0	70
3-4	0.005	0.0563	0.0	80
4-5	0.005	0.045	0.0	100
5-6	0.0045	0.0409	0.0	110
2-6	0.0044	0.05	0.0	90
1-6	0.005	0.05	0.0	100

Table 4: Load data of the 8-bus system

Node	P (MW)	Q (MVAr)
2	40.0	20.0
3	60.0	40.0
4	70.0	40.0
5	70.0	50.0

Characterstic Equation's constants :
CT Ratio : CTR=[240, 240, 160, 240, 240, 240, 160, 240, 160, 240, 240, 240, 240, 160]
Fault Current (A) seen by Primary Relays : FCpr=[3232, 5924, 3556, 3783, 2401, 6109, 5223, 6093, 2484, 3883, 3707, 5899, 2991, 5199]
Fault Current (A) seen by Backup Relays: FCbc=[996, 3556, 2244, 2401, 1197, 3232, 1890, 2991, 1165, 2484, 2344, 3707, 987, 1874
Primary relays' sequence :p=[1;2;2;3;4;5;6;6;7;7;8;8;9;10;11;12;12;13;14;14
Back-up relays' sequence :q=[6;1;7;2;3;4;5;14;5;13;7;9;10;11;12;13;14;8;1;9]
Coordinating Time Interval : CTI=0.3

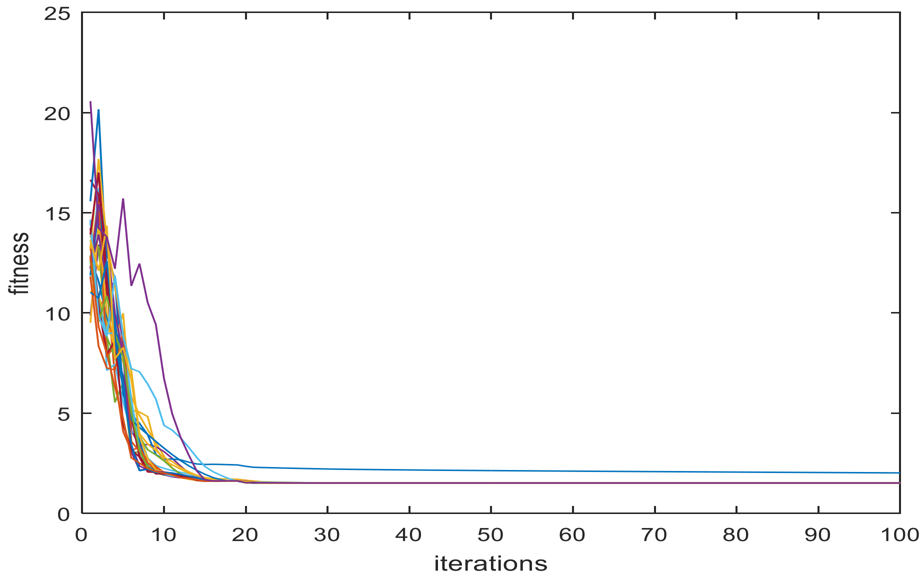

Figure 4 (a) : Convergence plot of PSO fitness cost function.

Primary R_i	Primary CTR	Fault Current (A)	Backup R_j	Fault Current (A)
R_1	1200:5	3232	R_6	3232
R_2	1200:5	5924	R_1	996
R_2	1200:5	5924	R_7	1890
R_3	800:5	3556	R_2	3556
R_4	1200:5	3783	R_3	2244
R_5	1200:5	2401	R_4	2401
R_6	1200:5	6109	R_5	1197
R_6	1200:5	6109	R_{14}	1874
R_7	800:5	5223	R_5	1197
R_7	800:5	5223	R_{13}	987
R_8	1200:5	6093	R_7	1890
R_8	1200:5	6093	R_9	1165
R_9	800:5	2484	R_{10}	2484
R_{10}	1200:5	3883	R_{11}	2344
R_{11}	1200:5	3707	R_{12}	3707
R_{12}	1200:5	5899	R_{13}	987
R_{12}	1200:5	5899	R_{14}	1874
R_{13}	1200:5	2991	R_8	2991
R_{14}	800:5	5199	R_1	996
R_{14}	800:5	5199	R_9	1165

The optimization process is run for 100 iterations and the final value of above mentioned fitness function is observed to be decreasing as shown in figure.

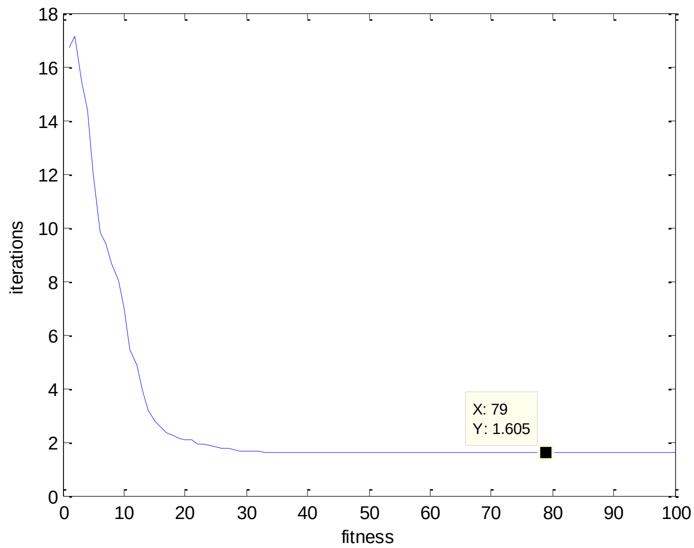

Figure 4(b) : Convergence plot of PSO average fitness cost function.

After the finish of optimization process the optimized solution in terms of TDS and PS are shown in figure5.

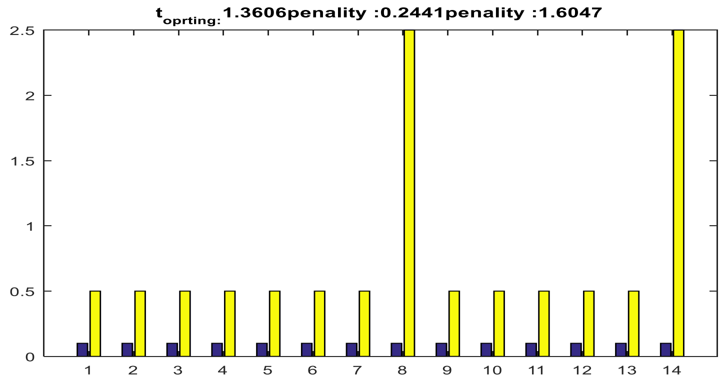

Figure 5: Penality time and plug setting value for all relays

The values of TDS and PS are also given in the table5.

Table 5 : Fitness Value for optimized solution

conventionally result	**Result Using PSO**
Fitness=14.3501	Fitness=1.5103

Table 6: Optimized opersting times of relay

Relay	Primary T operating time	Relay	Back up T operating time
1	0.20563	6	0.20563
2	0.17261	1	0.32382
2	0.17261	7	0.21443
3	0.17757	2	0.19964
4	0.19593	3	0.20304
5	0.2267	4	0.2267
6	0.17121	5	0.29739
6	0.17121	14	0.4463
7	0.16061	5	0.29739
7	0.16061	13	0.32525
8	0.17133	7	0.21443
8	0.17133	9	0.25441
9	0.19683	10	0.22408
10	0.19441	11	0.22859
11	0.19713	12	0.19713
12	0.17281	13	0.32525
12	0.17281	14	0.4463
13	0.21075	8	0.21075
14	0.26599	1	0.32382
14	0.26599	9	0.25441

4. Conclusion

The conventional relay protection coordination method is mainly used in the industry to calculate the protective overcurrent relay settings. The conventional method requires many inputs and does not produce the best relay coordination results. When there are multiple sources, the calculation process becomes even more complicated and cumbersome. In order to optimize the coordination results of the interconnected network with multiple sources, the particle swarm optimization algorithm is proposed in this research. Optimization algorithms have been applied to many engineering problems. However, few researchers have applied particle swarm optimization to the coordination problem especially in power systems with distributed generation sources. The objective of this research is to propose a particle swarm optimization algorithm to improve on then protection settings for a distribution network with distributed generation sources as calculated by the conventional method.
Coordination of directional over-current relay (DOCR) is a frequently arising problem in the field of electrical engineering, which can be formulated as an optimization problem. The mathematical model of the problem is highly complex and non- linear in nature, subject to various constraints, and requires sophisticated optimization techniques for its solution. In this work, an attempt is made to solve the IEEE 8-bus model with the help of optimization approach and with modified fitness equation version. Improved versions suggested here consider time and penalty constraints both and used to solve the above mentioned DOCR problem. Empirical analysis of numerical results obtained by PSO schemes and conventional algorithms show the competence of the proposed algorithms. Moreover PSO optimization schemes require only one control parameter i.e. the crossover rate, whereas most of the other techniques have more than one control parameters, which are to be fine tuned for the successful performance of an algorithm. Among the PSO, the algorithm design would require the use of fast convergence approach for solving the complex type of problems mentioned in the present study.

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