Gravitational Search Algorithm for the optimal coordination of an overcurrent relay

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Abstract : The overcurrent relays are the major protection devices in a distribution system. This paper presents Gravitational Search Algorithm (GSA) method for coordination of overcurrent relays. Modern distribution systems consist of various distributed generators (DG) to make reliable power system. Penetration of distributed generation in a distribution system changes the fault current and unidirectional nature of power flow. This leads to loss of coordination between various relays present in the system. Nowadays, various programming optimization techniques are frequently used to find optimal relay settings of overcurrent relays. The OC relay coordination in ring fed distribution networks is a highly constrained optimization problem. The purpose is to find an optimum relay setting to minimize the time of operation of relays and at the same time, to avoid the mal-operation of relays. This paper presents Gravitational Search Algorithm for the coordination of overcurrent relay for a system containing DG. A proper combination of primary and backup relay is selected to avoid mal operation of relays and unwanted outages when DG is penetrated. A four bus radial system is simulated in MATLAB SIMULINK platform and programming is done using MATLAB software.

***IndexTerms* - Distributed generation, Gravitational Search Al- gorithm (GSA), overcurrent (OC) relay, relay coordination.**

I. INTRODUCTION

The most obvious effect of a shunt fault is a sudden built up of current. So it is natural that the magnitude of current be utilized as positive indication of existence of a fault. Therefore the over-current protection is the most widely used form of protection. Overcurrent (OC) relay is usually employed as backup protection. But in some situations it may be the only protection provided.

A relay must get sufficient chance to protect the zone under its primary protection. Only if the primary protection does not clear the fault, the back-up protection should initiate tripping. A typical power system may consist of hundreds of equipment and even more protection relays to protect the system. Each relay in the system needs to be coordinated with the relay protecting the adjacent equipment. If backup protections are not well coordinated, mal-operation can occur and, therefore, OC relay coordination is a major concern of power system protection. Each protection relay in the power system needs to be coordinated with the relays protecting the adjacent equipment. The overall protection coordination is thus very complicated.

In a system where there is a source at more than one of the line terminals, fault and load current can flow in either direction. Relays protecting the lines are, therefore, subject to fault currents flowing in both the directions. If non directional OC relays were used in such system, they would have to be coordinated with, not only the relays at the remote end of the line, but also with relays behind them. Since directional relays operate only when the fault current flows in the specified tripping direction, they avoid coordination with the relays behind them.

The main function of the power system protective devices is to detect and remove the faulty parts as fast as possible. Modern distribution systems consist of various Distributed Generators (DG) to make power system operation reliable. With the addition of DG, distribution system experiences change in the short circuit level of the system and thus earlier relay settings causes mal operation of relays. This leads to loss of coordination between various relays present in the system.

II. COORDINATION OF OC RELAY

As soon as the fault takes place it is sensed by both primary and backup protection. The primary protection is the first to operate as its operating time being less that that of the backup relay.

Primary and backup are the two protection schemes incorporated in the radial system [11]. Sensitivity and selectivity are two attributes of a relay that are of utmost importance for reli- ability and stability of any power system. With the inception of fault both primary and backup relay sees the fault current but primary relay is the first to issue the trip signal as it has been made more selective than backup relay.

The coordination time interval (CTI) between the backup and the primary relay depends on various parameters such as operating time of primary relay, operating time of circuit breaker associated with the primary relay, overshoot time of backup relay, and signal travelling time.

In a radial system, power flow is unidirectional. But when the DG is penetrated in the system the power flow becomes bidirectional. Moreover, when a fault occurs, the directional feature of over current relay comes into picture.

III. DESIGN ISSUES

The relay coordination problem of OC relays can be formulated as constrained optimization problem. The objective function of the problem is total operating time of all the relays present in the system. The function is to be minimized so that each relay operates in minimum time and reliability of the system is maintained. The formulated objective function which is denoted as 'S' here is

$$\min s = \sum_{i=1}^{n} t_{i,k} \quad (3.1)$$

where n is the number of relays, $t_{i,k}$ is operating time of i[th] relay for fault in k[th] zone. The constraints to solve this optimization problem are divided in three sections.

A. Coordination criteria

$$t_{bi,k} - t_{i,k} \geq \Delta t \quad (3.2)$$

where, $t_{i,k}$ is the operating time of primary relay at i for fault in zone k and $t_{bi,k}$ is the operating time of backup relay for fault in same zone and Δt is the coordination time interval (CTI)

B. Bounds on relay operating time

$$t_{i,kmin} \leq t_{i,k} \leq t_{i,kmax} \quad (3.3)$$

where, $t_{i,k\,min}$ is the minimum operating time of relay at i for fault in zone k and $t_{i,k}$ max is the maximum operating time of relay at i for fault in zone k. So bound on time multiplier settings (TMS) will be

$$TMS_{i,k\,min} \leq TMS_{i,k} \leq TMS_{i,k\,max} \quad (3.4)$$

C. Bounds on Pickup current

The minimum value of pickup current is determined by maximum load current seen by each relay. The maximum pickup current is determined by minimum fault current seen by each relay. This will impose bound on relay plug setting (PS) also which is given below as:

$$I_{p\,min} \leq I_p \leq I_{p\,max}$$
$$PS_{\,min} \leq PS \leq PS_{max} \quad (3.5)$$

D. Relay characteristics

All relays are identical and assumed to have IDMT characteristic as [3], [4]:

$$t_{op} = \frac{\lambda(TMS)}{(PSM)^{\gamma} - 1} \quad (3.6)$$

$$t_{op} = \frac{\lambda(TMS)}{(I_{relay}/PS*CT_{sec\,rated})^{\gamma} - 1} \quad (3.7)$$

Where, top is relay operating time, PS is plug setting. TMS is time multiplier setting, PSM is plug multiplier setting, I_{relay} is fault current seen by relay and CT sec rated is rated current of CT secondary. For normal IDMT characteristic relay, γ is 0.02 and λ is 0.14. Hence we have two parameters, TMS and PS to be determined using GSA.

Gravitational Search Algorithm (GSA):

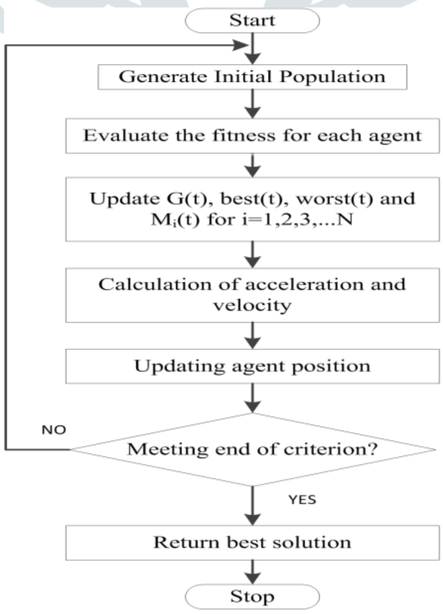

Fig. 1

Gravitational Search Algorithm is a population based heuristic algorithm based on gravitational and Newton's law of motion. Agents are regarded to be bodies having variable masses. Gravitational force between masses guides the movement of the agents.

Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of distance between them. Four parameters quantify each body in GSA: Position of the mass in d-th dimension, inertia mass, active gravitational mass, passive gravitational mass. The velocity of a body in a dimension is controlled by the gravitational and inertial masses. Moreover, the fitness value obtained through the application of this algorithm gives the value of these parameters. The basic flowchart of GSA is given in Fig.1.

IV. RESULTS

A 4 bus radial system is taken, in which the grid is of 25 MVA and standard line data's are taken. Two cases are taken here, utility only mode, grid connected mode with 20 % penetration of DG. In all cases GSA technique is applied to find the optimum value of TMS and PS of six relays present in each feeder. This optimization is achieved in MATLAB platform. The complete problem formulation of case I is described here. Similar process is adopted for other cases.

Case I: Without DG- A 4 bus radial distribution system is modelled in MATLAB platform as given in Fig.2. The grid rating is 25 MVA, 161 kV and the transformer step downs the voltage to 11 kV. This system consists of six relays. The CT ratios of each relays are given in Table I. Faults are created at near end of each relays. Fault inception time is 1s and it is a sustained fault for 2s as shown in Fig.3.The objective function is derived using the equations given in section III.

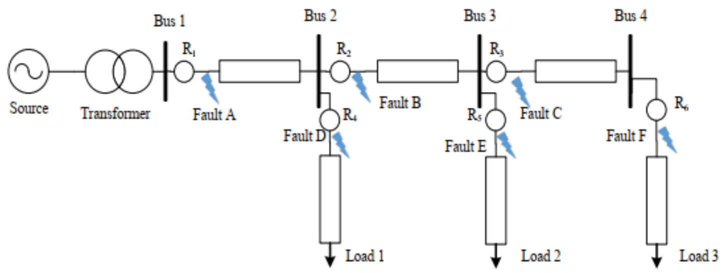

Fig. 2. Single source 4 bus radial system

TABLE I.

C.T RATIOS OF EACH RELAYS (CASE I)

Relay No.	CT Ratio
1	1000/1
2	800/1
3	600/1
4	600/1
5	600/1
6	600/1

In this case twelve variables are there, six TMS and six PS of each relays. There are five constraints due to coordination time interval between primary and backup relays. The CTI is set as 0.3s. First six variables, x_1-x_6 represents the TMS and x_7-x_{12} represents PS.

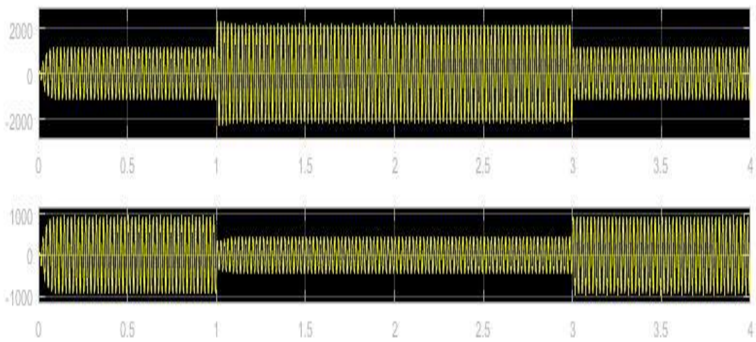

Fig. 3 Fault current for relay 1 and 2 at fault point A

A comparison bar graph for both TMS and PS is drawn in

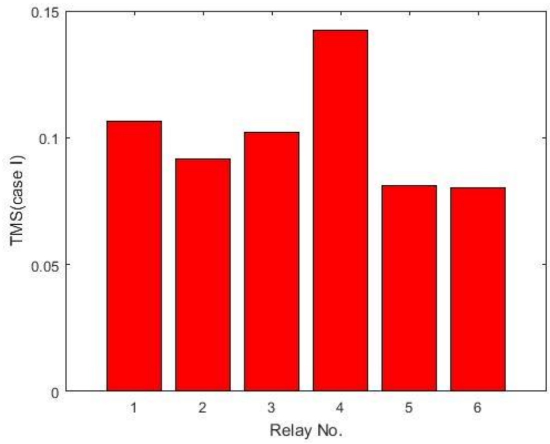

Fig. 4 TMS

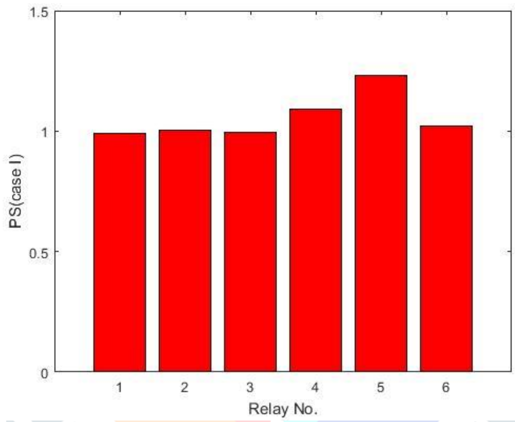

Fig. 5 PS

The convergence graph is given in Fig.6. The values of TMS and PS obtained by GSA ensure that relay will operate in minimum possible time for fault at any location and coordination will be achieved.

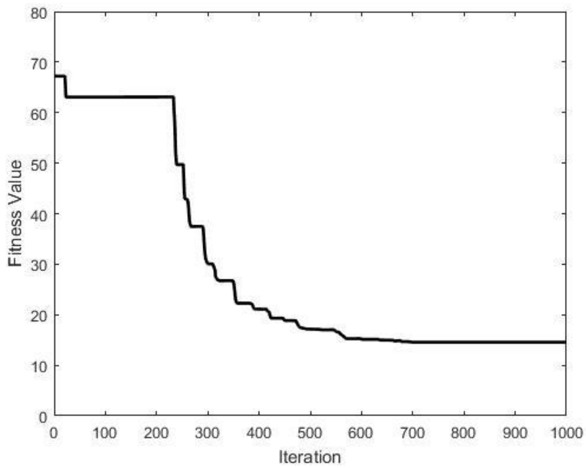

Fig. 6 Convergence graph for GSA

V. Conclusion

The optimization technique used in this paper in order to find the optimal time multiplier setting (TMS) and Plug setting (PS) of six relays so that their total operating time can be minimized. The simulated fault current retrieved in MATLAB-SIMULINK is subsequently processed in MATLAB. The objective function is framed for two cases i.e. with and without DG. Further, it is minimized by maintaining the range of TMS of each relay as 0.08 to 1 and coordination time interval as 0.3s.The range of PS, determined for each relay is based on maximum load current and minimum fault current. Coordination is achieved in every case. The mal operation of relays due to presence of DG is thoroughly discussed and a comparative assessment of results is done. This represents that GSA is a potential optimization technique which can be applied for relay coordination task. Once the relays are set as per settings given by GSA it will work for all types of asymmetrical faults that occur frequently in a system.

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