

- $w$  : Inertia weight of the particle
- $v_i^k$  : The velocity of  $i^{th}$  particle at  $k^{th}$  iteration
- $c_1, c_2$  : Positive constants having values between [0, 2.5]
- $r_1, r_2$  : Randomly generated numbers between [0, 1]
- $p_{best}$  : The best position of the  $i^{th}$  particle obtained based upon its own experience
- $g_{best}$  : Global best position of the particle in the population
- $x_i^{k+1}$  : The position of  $i^{th}$  particle at  $(k + 1)^{th}$  iteration
- $x_i^k$  : The position of  $i^{th}$  particle at  $k^{th}$  iteration
- $\omega$  : Constriction factor. It may help insure convergence.
- Suitable selection of inertia weight  $\omega$  provides good balance between global and local explorations.

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (9)$$

Where,  $w_{max}$  is the value of inertia weight at the beginning of iterations,  $w_{min}$  is the value of inertia weight at the end of iterations, the value of  $w_{max}$  and  $w_{min}$  are taken to be equal to 0.9 and 0.5 respectively,  $iter$  is the current iteration number and  $iter_{max}$  is the maximum number of iterations.

### 5. IMPLEMENTATION OF PROPOSED PROGRAM

Conventionally, objective function in coordination studies is constituted as the summation of operating times of all primary relays. Specific to directional over-current relays, the optimal coordination problem determines two parameters, that is, the pickup current setting  $I_p$  and the time dial setting TDS. The objective function represented by  $J$ , is given by:

$$J = \min \sum_{i=1}^N t_i \quad (10)$$

where  $J$  is the objective function to be,  $t_i$  is the operating time of the  $i$ th relay, and  $N$  is the total DOCRs in the system.

The two variables in the objective function are the TDS and  $I_p$ . By minimizing both the TDS and  $I_p$ , we can able to minimize the operating time of the primary relays and satisfying the coordination between the primary and backup relays. The set of the constraints are also framed as per the constraints conditions mentioned above. The range of TDS's is from 0.01 to 1.0 and for  $I_p$  from 0.5 to 2.5. The CTR is set to a desired value of 0.3 sec.

The various steps involved in the implementation of PSO to the DOCRs problem with 64 decision variables are:

- Step 1.** Input the data of 33 IEEE distribution test system to calculate the power flow and current.
- Step 2.** Define population size (100), no. of iteration (500), assume suitable values of PSO parameters.
- Step 3.** Initial searching points and velocities are randomly generated within their limits.  $P^{best}$  is set to each initial searching point. The best-evaluated values among  $P^{best}$  is set to  $g^{best}$ .
- Step 4.** New velocities are calculated using the equation (7).
- Step 5.** Evaluate the fitness values for new searching point. If evaluated values of each agent is better than previous  $P^{best}$  then set to  $P^{best}$ . If the best  $P^{best}$  is better than best  $g^{best}$  then set to  $g^{best}$ .
- Step 6.** If the maximum iteration is reached then the process otherwise go to step3.

### 6. CASE STUDIES

A developed Matlab program is implemented to a modified 33-bus (IEEE 12.46 kV, 100 MVA) [10] in order to calculate the optimal coordination of DOCRs using PSO under system changes. This change is the varying mode of the TCSC. The program is implemented for different firing angle alpha of the TCSC and two angles for each mode are selected. Three phase faults are generated on each bus. The calculation of fault current seen by each primary and backup relays is carried out, however no backup relay exists for relays R3.

Directional over-current relays are used in the system to protect the feeder in case of three phase faults. The single line diagram of the IEEE 33-bus system is shown in Figure 3.

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