Efficient Reduction of Fault Current in Distribution Systems Connected With Multiple Distributed Generations

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ABSTRACT - *Connection of distributed generation (DG) to the network and the extension of transmission system with a specific end goal to meet the developing for power are affecting the extent and unpredictability of the system structure. This situation brings about an extensive number of short circuits in the systems, which may cause extreme damage to the system. Introducing Fault current limiters (FCLs) into the power system is a standout amongst the most cost effective approaches to lessen fault current ranges. Likewise islanding operations of DG typically happen when power supply from the fundamental utility is hindered because of a few reasons but the DG continues supplying power into the distribution systems. In this paper, we proposed a novel method for lessening of fault current in distributed system with DGs alongside islanding detection method. In the proposed method, the islanding conditions are detected in light of two parameters they are voltage unbalance and total harmonic distortion of current. Then we design an efficient FCL so as to minimize the impact of the DG on the distribution protection system. At last, so as to locate the optimal location for setting the FCLs in distributed system we formulated the objective function as optimization problem and it is solved by using particle swarm optimization (PSO). The proposed method is implemented on the IEEE bus system and the experimental results are analyzed.*

Keywords: Distributed generation (DG), Fault Current Limiter (FCL), Islanding, Particle Swarm Optimization (PSO), distribution system.

1. INTRODUCTION

The DG is in view of the renewable energy sources, for example, energy component, photovoltaic, and wind power, and additionally consolidated heat and power gas turbine, micro turbine, and so on. The number of DG systems is quickly expanding, and the majority of them are associated with a distribution system by supplying power into the system, and in addition neighborhood loads [1]. An islanding operation happens at the point when the DG keeps supplying power into the system after power from the principle utility is intruded [2-3]. In the event that the islanding operation happens, the distribution system gets to be out of the utility's control. It can in this way cause various negative effects on the system and DG itself, for example, the security risks to utility faculty and general society, the power quality issues, and genuine harm to the system and DG unless the fundamental utility power is restored accurately and rapidly. Moreover, the DG system must be detached from the system for its protection by the successful location strategy before the recloser begins to work taking after by the islanding operation [4].

Two types of islanding detection methods, which are the passive and active methods, have so far been developed. The active methods [5], for example, the system fault level checking system and the reactive export error detection technique. In spite of their viability in identifying island operation of DG, these active strategies need to ceaselessly fluctuate the DG output and may adversely influence the operations of the DG and the utility system [6]. Other detection routines can be called passive methods since they recognize islanding operation of DG by observing the system parameters: voltage magnitude, phase displacement, the rate of change in frequency, and impedance checking. Despite the fact that they are unrealistic to impact the working systems and administration of utility power system, if there are little changes in the DG loadings in the wake of islanding, these techniques experience issues in figuring out the islanding operation since the observing parameters don't change enough to recognize these islanding conditions [7].

Numerous DGs make utilization of power electronic inverters for energy conversion to match the grid voltage and recurrence. Nonetheless, such DGs are known to have an incredible effect on the security and protection of distribution system [8]. The inverter-based DGs (IBDGs) can influence system security when an electrical fault happens because of fault current detection issues [9-11]. This is on account of they don't create large amounts of fault current when a short circuit happens. Besides, small rated DGs additionally have lacking inactivity to persistently sustain the fault current dissimilar to the conventional expansive rotating machine generators. The IBDGs have their own particular internal protection to guarantee wellbeing of semiconductor devices against substantial over currents coursing through them [12]. Generally, this current is in the range of two to three times of the rated current [13]. The impact of such an internal protection needs to be considered in the general system protection plan subsequent to the inverter inward protection can't identify fault streams with levels lower than its settings. There are essentially two sorts of control plans that govern IBDGs, viz., voltage control and current control [14].

A few thoughts have been presented as would be prudent solutions [15-16]. These papers propose switchgears and protection coordination update in frameworks comprise of DG. Despite the fact that these arrangements might actually work, they are muddled and expensive. Along these lines, these arrangements are not useful for existing distribution frameworks [17]. Adaptive Relaying calculations were proposed in [18] and [19] to comprehend the detection issues of the IBDGs. In [20], considered the impact on fuse saving plans. While these plans showed promising results, but they are costly solutions obliging additional hardware to be introduced in the system. Besides, the greater part of the previously stated distributions did not examine the impacts on protection plan brought about by different sorts of controllers utilized in IBDGs. Then again, in the few papers that considered the impact of inverter controllers and gave arrangements that are constrained in extent of utilization.

The outline of the paper is organized as follows. Section 2 gives the related researches in impact of multiple DGs. The proposed methodology is given in section 3 and the simulation results and their discussions are given in section 4 followed by conclusion in section 5.

1.1 RELATED WORKS

Vahedi H ***et al.*** [21] have presented a new method for islanding detection of inverter-based distributed generation (DG). The main idea of paper was to change the dc-link voltage considering the PCC voltage changes during islanding condition. A simple islanding detection scheme has been designed based on this idea. The proposed method has been studied under multiple-DG operation modes and the UL 1741 islanding tests. The simulations results, carried out by MATLAB/Simulink, show that the proposed method has a small nondetection zone. Also, this method was capable of detecting islanding accurately within the minimum standard time.

Najy W.K.A ***et al.*** [22] have proposed a new passive islanding detection method for grid-connected inverter-based distributed-generation (DG) systems. A statistical signal-processing algorithm known as estimation of signal parameters via rotational invariance techniques was used to extract new features from measurements of the voltage and frequency at the point of common coupling as islanding indicators. The new features are defined based on a damped-sinusoid model for power system voltage and frequency waveforms, and include modal initial amplitudes, oscillation frequencies, damping factors, and initial phases. A set of training cases generated on the IEEE 34 bus system was used to train a naïve-Bayes classifier that discriminates islanding and nonislanding events. Cross-validation was used to evaluate the performance of the proposed islanding detection method. The results showed that by using the new features extracted from ESPRIT, the classifier was capable of discriminating islanding and nonislanding events with good accuracy.

Sinsukthavorn W ***et al.*** [23] have proposed a flexible control methodology of inverters as grid front end using an isochronous control function which is used by synchronous generators in conventional power systems to provide load sharing and control. The control tasks for voltage and frequency are done locally at the inverters to guarantee modularity and to minimize communication requirements. The simulation results illustrated the ability of the proposed concept of inverter control methodology for DG to supply high-quality power. The total load was distributed among the different inverters according to their capacity to guarantee flexibility.

Abdel-Khalik A.S ***et al.*** [24] have proposed a solution for IBDG in a medium voltage distribution network that allows active and adjustable IBDG fault current contribution without violating the nonoverload nature of the inverters. This was achieved by introducing a flywheel energy storage system based on a doubly-fed induction machine (DFIM) in parallel with the IBDG. Normally, the flywheel system was dedicated to power leveling; however, during faults, the flywheel DFIM storage system (FW-DFIM) has the ability to supply an exponentially decaying current to the grid. The parallel combination of the IBDG and FW-DFIM as a distributed generation (DG) unit was capable of providing a response similar to that of synchronous generators during a fault, but with additional control capability. The simulated system showed the effectiveness of the DG unit for downstream faults where it was capable of providing sufficient fault current to trigger the distribution network's protection devices when operating in island mode.

Rajaei N ***et al.*** [25] have proposed a novel fault current management technique using IBDGs. When a fault occurs, the function of the IBDGs was modified from that of PQ generators to that of FCM units by changing the IBDG current phase angle. To calculate the reference current phase angle for FCM operation with only one IBDG, a method that was a function of grid current and fault current phase angles was proposed. When multiple IBDGs are added to the system, the method can be easily extended to obtain the desired current phase angle. Current and voltage phasor information obtained from smart meters are utilized for calculating the fault current phase angle. The results of the case study simulations proved that IBDGs controlled the fault current magnitude effectively.

2. PROPOSED METHODOLOGY TO MITIGATE THE IMPACT OF MULTIPLE DISTRIBUTED GENERATIONS

This research work is intended to develop an efficient detection of islanding condition and reduction of fault current produced in distribution system when multiple distributed generations are introduced in the power system. In this work two parameters are used for detecting islanding conditions voltage unbalance and total harmonic distortion of current. Based on this parameters islanding conditions are detected. A fault current limiter is designed in order to minimize the impact of multiple DGs on the protection system in a distribution system during a fault occurrence. Finally, determining the optimal location and impedance of fault current limiter it is modeled as optimization problem with power loss and economical use as objective function. In this work, Particle Swarm Optimization (PSO) algorithm is used for determining the optimal location and impedance of fault current limiter. The outcome of the research produces efficient distribution systems with reduced fault current as well provide protection to the system by islanding detection. The process flow of the proposed system is shown in figure 1.

Figure 1: Process Flow of Proposed System

2.1 ISLANDING DETECTION METHOD

Islanding detection is a one among the most essential issues for the distributed generation (DG) associated with an electric power grid. Islanding condition cause negative effects on protection, operation, and administration of distribution systems; consequently, it is important to effectively distinguish the islanding conditions and quickly detach DG from distribution system. If there are vast changes in loading for DG after loss of the fundamental power supply, then islanding conditions are effortlessly identified by checking a few parameters. In this paper, for detection of islanding operation of DGs, we have used two parameters they are voltage unbalance and total harmonic distortion of the current.

A. Calculation of Voltage Unbalance:

For the most part, despite the fact that the loading for DG has minimal changes after the loss of main source, because of the changes of the systems and the load, the voltage unbalance fluctuates. Along these lines, on the off chance that we continue monitoring the unbalance of three phase output voltage of the DG, at that point it is conceivable to adequately recognize an islanding operation of DG. With a specific end goal to do this, we characterize the voltage unbalance at the observing time by using equation (1) which is given by

$$VU_t = \frac{NS_t}{PS_t} \times 100 \qquad (1)$$

Where PS_t and NS_t represents the magnitude of positive and negative sequence of voltage at time *t*, correspondingly. This characterizes the one sequence average of voltage unbalance which is given in equation (2), furthermore characterizes the voltage unbalance fluctuation which is given in equation (3), which measuring how much the observed voltage unbalance variations from the steady state and ordinary loading conditions.

$$VU_{avg,t} = \frac{1}{N}\sum_{i=0}^{N-1} VU_{t-i} \qquad (2)$$

$$\Delta VU_t = \frac{VU_{avg,s} - VU_{avg,t}}{VU_{avg,s}} \times 100 \qquad (3)$$

Where *N* indicates sampling number per cycle, *t* indicates monitoring time, and $VU_{avg,s}$ indicates reference value originally set for normal loading conditions. After $VU_{avg,s}$ is originally set, if ΔVU_t remains within -100% through +50% for per sequence, $VU_{avg,s}$ is updated by $VU_{avg,t}$ to receive the normal load variation.

B. Calculation of total harmonic distortion of current:

The changes in the loading for DG due to loss of main power source obviously result in variations on the harmonics of the current. The total harmonic distortion of current at observing time *t* is given by

$$THD_t = \frac{\sqrt{\sum_{h=2}^{H} I_h^2}}{I_1} \times 100 \quad (4)$$

Where I_h is RMS of the harmonic elements *h* and I_1 is RMS value of fundamental element. The average of THD_t per cycle is given in equation (5) and the variations for observed *THD* at time *t* from the normal condition is given by equation (6).

$$THD_{avg,t} = \frac{1}{N} \sum_{i=0}^{N-1} THD_{t-i} \quad (5)$$

$$\Delta THD_t = \frac{THD_{avg,s} - THD_{avg,t}}{THD_{avg,s}} \times 100 \quad (6)$$

Where *N* indicates sampling number per sequence $THD_{avg,s}$ indicates reference value for normal loading conditions. After $THD_{avg,s}$ is originally set, if ΔTHD_t remains within -100% through +75% for one cycle, $THD_{avg,s}$ is updated by $THD_{avg,t}$.

C. Detection of islanding condition:

After the calculation of changes in voltage unbalance and total harmonic distortion of current, now we formulate a condition for detection of islanding condition which is given below

$$RULE : \{(\Delta THD_t > +75\%) \; or \; (\Delta THD_t < -100\%)\}$$
$$\{(\Delta VU_t > +50\%) \; or \; (\Delta VU_t < -100\%)\}$$

If ΔTHD_t and ΔVU_t satisfies the above condition the proposed method detects as islanding condition. The flowchart for detection of islanding condition is shown in figure 2.

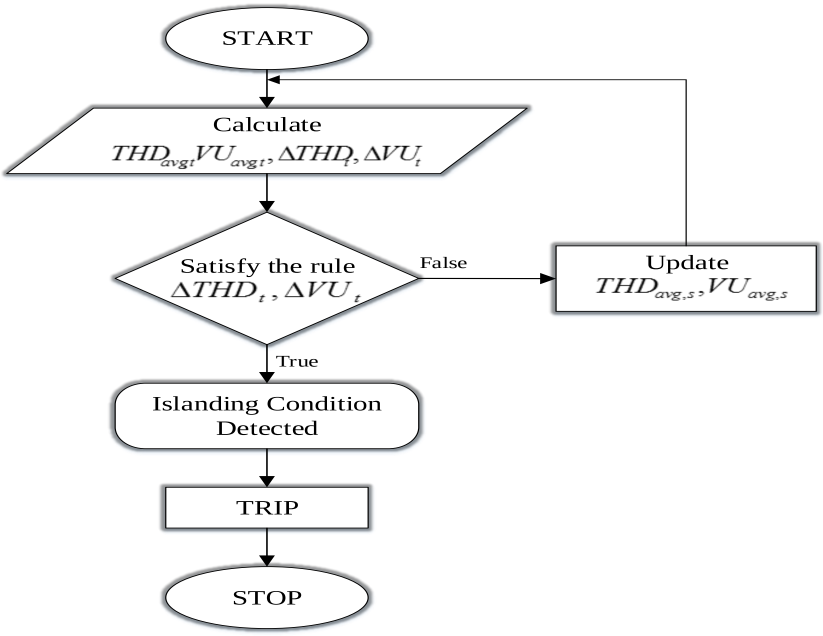

Figure 2: Flow Chart for Islanding Detection

From figure 2, we can see that how islanding condition detected by observing the parameters of voltage unbalance and harmonic distortion of current. Once the islanding mode is detected it gives trip signal and the system is isolated. If it is not detected then the system is analyzed during the occurrence of fault and fault current produced is limited by using fault current limiter which is described in the next section.

2.2 FAULT CURRENT LIMITER DESIGN

The most beneficial property of this setup is low steady state impedance, straightforwardness of structure and control, high impedance fault and quick response. The structure of fault current limiter is shown in figure 3. It comprises of a solid state switch, voltage limiting element, current limiting impedance, and series mechanical switch.

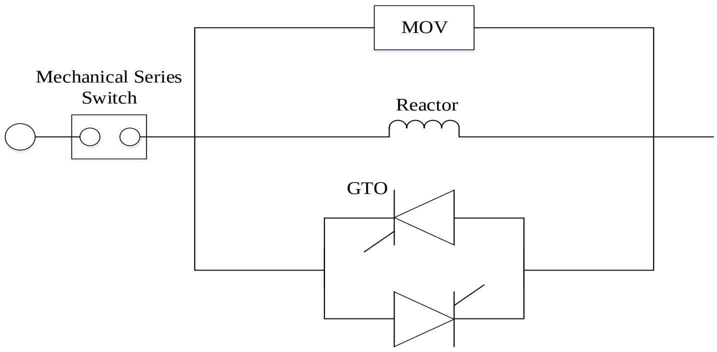

Figure 3: Fault Current Limiter

The GTO thyristors are utilized as the quick solid state switch and current limiting impedance is attached in parallel with thyristors. The GTO thyristors are utilized to interfere with a current immediately after getting a turn off signal and current limiter impedance is utilized as path for passing the fault current when the solid state switch intrude on a shortcoming current. Yet, a sudden intrusion of current is prone to bring about an overvoltage in the circuit, so voltage limiting component is utilized to keep this. The overcurrent detector with the control device detect fault and generate turn on and turn off signals for GTO thyristor.

Most of the system faults are unsymmetrical, balanced three-phase faults are frequently the worst and are utilized to define the Circuit breaker (CB) capacity. For a balanced three-phase fault at bus *i*, the short circuit current can be computed by

$$I_i^{sc} = \frac{E_i}{Z_{ii}} * I_b \tag{7}$$

Where I_i^{sc} denotes three phase short circuit current at bus *i*

E_i Denotes voltage before fault at bus *i* which can be set as 1 p.u

Z_{ii} denotes thevenin impedance at bus *i* and it is obtained from diagonal elements of impedance matrix Z_{bus}.

I_b denotes base current.

On adding line with impedance Z_b between buses *j* and *k*, original element Z_{xy} can be changed as given in below equation

$$Z_{xy}^{new} = Z_{xy} - \frac{(Z_{xj} - Z_{xk})(Z_{jy} - Z_{ky})}{Z_{jj} + Z_{kk} - 2Z_{jk} + Z_b} \tag{8}$$

Where Z_{xy}^{new} and Z_{xy}, correspondingly, are changed and original elements of Z_{bus}. Figure 4 gives the thevenin equivalent circuit of the system from two existing buses. If an FCL with impedance Z_{FCL} is connected on line between buses *k* and *j* and fired after faults, then thevenin equivalent circuit as shown in figure 5 can be demonstrated.

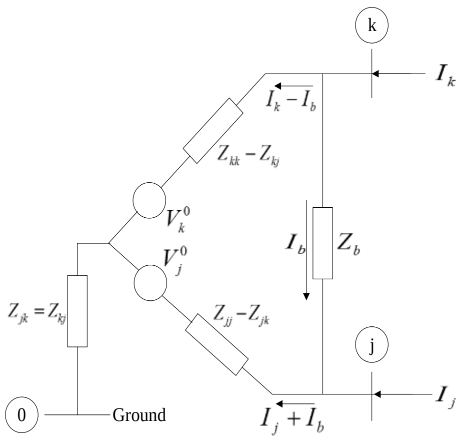

Figure 4: Thevenin equivalent circuit by adding a line between two existing buses

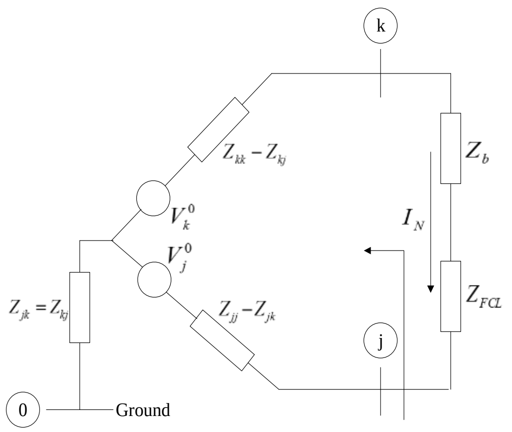

Figure 5: Thevenin equivalent circuit with FCL fired up

The total result of inserting Z_{FCL} into the system can be measured as adding a new branch with the following impedance to the system

$$Z_p = \left(-Z_p\right)//\left(Z_b + Z_{FCL}\right) = -\frac{Z_b\left(Z_b + Z_{FCL}\right)}{Z_{FCL}} \tag{9}$$

Therefore the change to the diagonal entries of Z_{bus} after the active FCL fired up at a branch between buses *j* and *k* is

$$\Delta Z_{ii} = -\frac{\left(Z_{ij} - Z_{ik}\right)^2}{Z_{ij} + Z_{kk} - 2Z_{jk} + Z_p} = \frac{C_2}{C_1 + Z_p} \tag{10}$$

The fault current deviation at a bus after the FCL fired up can be written as

$$\Delta I_{i,F} = \frac{V_i}{Z_{ii} + \Delta Z_{ii}} - \frac{V_i}{Z_{ii}} \tag{11}$$

Replacing (10) into (11), which can be altered as

$$\Delta I_{i,F} = -\frac{V_i}{Z_{ii}\left(C_1 + Z_p\right)Z_{ii} + C_2} \tag{12}$$

If the FCL is utilized to constrain the fault current from original $I_{i,N}$ to $I_{i,F}$, then Z_p required can be easily computed by (12) and expressed as

$$Z_p = \frac{I_{i,F}}{I_{i,N} - I_{i,F}} \frac{C_2}{Z_{ii}} - C_1 \tag{13}$$

Replacing (13) into (9), the impedance of active FCL needed is

$$Z_{FCL} = -\frac{Z_b^2}{Z_b + Z_p} \tag{14}$$

2.3 LOCATION OF FAULT CURRENT LIMITER

In order to identify the location of fault current limiter we have formulated as nonlinear optimization problem, and different objectives were considered in this study. The objective function consists of minimization of power loss, and economical use of fault current limiter.

2.3.1 Minimization of Power loss:

Optimal placement of FCL can be performed with the reason for minimizing power loss. The aggregate real power loss is computed by using equation (15) which is given as follows:

$$P_{loss} = \sum_{i=1}^{N_b} R_i \times |I_i|^2 \tag{15}$$

Where R_i represents resistance of i^{th} branch, I_i is actual current of i^{th} branch, and N_b indicates number of branches in the network.

2.3.2 Economical use of FCL:

The total impedance utilized for the fault current limiters should be minimalized to reduce the financial costs [26]. Hence, the problem can be expressed as follows:

$$\begin{aligned} & J = \sum_{i=1}^{N_{FCL}} Z_{i,FCL} \\ & s.t\ Z_{i,FCL}^{\min} \le Z_{i,FCL} \le Z_{i,FCL}^{\max} \quad i = 1,\ldots,N_{FCL} \\ & I_f^{sc} \le I_j^{sc,\max} \quad f = 1,\ldots,B_N \\ & I_{k,j}^{f} \le I_{spec} \quad k, j = 1,\ldots,B_L \end{aligned} \tag{16}$$

where $Z_{i,FCL}$ is impedance of i^{th} fault current limiter, N_{FCL} is the number of installed FCLs, $Z_{i,FCL}^{\min}$ and $Z_{i,FCL}^{\max}$ are the minimum and maximum allowed impedance of FCL, I_f^{sc} and $I_f^{sc,\max}$ are the fault current at bus *f* and maximum specified fault current of bus *f*, $I_{k,j}^{f}$ and I_{spec} are the fault current flowing from bus *k* to *j* caused by fault at bus *f* and maximum fault current flowing in the lines. B_N and B_L are the total number of buses and total number of lines in the system.

2.3.3 Formation of objective function:

For the purpose of optimization, the above two mentioned objective function is formulated as follows:

$$\text{Objective Function,} \quad F = Min\left[\sum_{i=1}^{N_b} R_i \times \left|I_i^{\,2}\right| + \sum_{i=1}^{N_{FCL}} Z_{i,FCL}\right] \tag{17}$$

By minimizing the above objective function, we can place or identify the location of FCL to reduce the fault current produced at each bus while distributed generation to the power system. In order to minimize the objective function in our proposed method we have optimization algorithm called Particle Swarm Optimization (PSO).

2.3.4 Particle Swarm Optimization (PSO):

Particle swarm optimization is a stochastic optimization paradigm, which mimics animal social behaviors such as flocking of birds and the methods by which they find roosting places or food sources. PSO starts with the initialization of a population of individuals in the search space and works on the social behavior of the particles in the swarm. Each particle is assigned a position in the problem space, which represents a candidate solution to the problem under consideration. Each of these particle positions is scored to obtain a scalar cost, named fitness, based on how well it solves the problem. These particles then fly through the problem space subject to both deterministic and stochastic update rules to new positions, which are subsequently scored. Each particle adaptively updates its velocity and position according to its own flying experience and its companions' flying experience, aiming at a better position for itself. As the particles traverse the search space, each particle remember its own personal best position that it has ever visited, and it also knows the best position found by any particle in the swarm. On successive iterations, each particle takes the path of a damped oscillatory movement towards its personal best and the global best positions. With the oscillation and stochastic adjustment, particles explore regions throughout the problem space and eventually settle down near a good solution. The algorithm starts by initializing a population of particles in the "normalized" search space with random positions *x* and random velocities *v*, which are constrained between zero and one in each dimension. A particle position vector is converted into a candidate solution vector in the problem space through a mapping. Here equation (17) is regarded as the fitness of the corresponding particle. Updating the position and velocity of particles is performed by using below equations.

$$v_i^{k+1} = wv_i^k + c_1 rand_1 \times \left(pbest_i - u_i^k\right) + c_2 rand_2 \times \left(gbest_i - u_i^k\right) \tag{18}$$

$$u_i^{k+1} = u_i^k + v_i^{k+1} \tag{19}$$

Where v_i^k is velocity of agent *i* at iteration *k*

w is weighting function

c_1 and c_2 are the relative weights of the personal best position and global best position, respectively

rand is random number between 0 and 1

u_i^k is current position of agent *i* at iteration *k*

$pbest_i$ is *pbest* of particle *i*

$gbest_i$ is *gbest* of the group

The weighting function can be calculated by using the below formula

$$w = \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{20}$$

Where $w_{\max}$ and $w_{\min}$ are the maximum and minimum weight, $iter_{\max}$ and $iter$ are maximum and current iteration number. The steps involved in PSO algorithm is shown below:

Step 1: *Initialize the particles randomly.*
Step 2: *Evaluate the fitness function for the each particle by using the equation (17).*
Step 3: *Set the present particles as "pbest".*
Step 4: *Add velocity to initial particles in order to obtain new set of particles.*
Step 5: *Evaluate the fitness value for each new set of particles.*
Step 6: *Compare each individual particle's fitness value to find the new "pbest" between two set of particles.*
Step 7: *Find the minimum fitness value by comparing two set of particles and corresponding particle as "gbest".*
Step 8: *Update the position and velocity of each particle by using equation (18) and (19).*
Step 9: *Iteration of PSO is repeated until convergence is made.*

Figure 6: Steps involved in PSO

The overall process of the proposed method is shown in the flowchart which can be seen in figure 7.

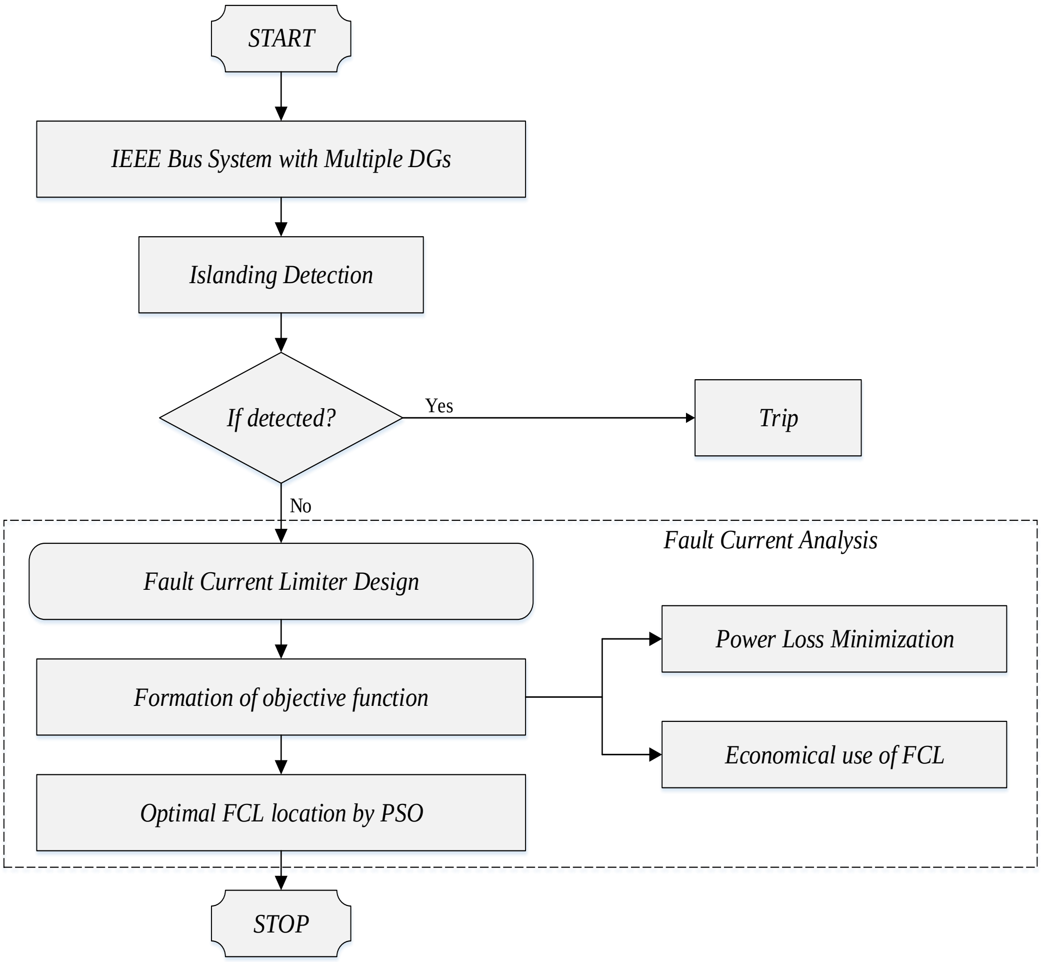

Figure 7: Flowchart of Overall Proposed Method

From the flowchart given in figure 7, we can clearly understood the concept of the proposed method, initially an IEEE bus system with multiple DGs is considered, then the system is detected for islanding condition if detected means the trip signal is given to the circuit and the system is isolated. Then, the fault current limiter is designed and optimally placed in order to reduce the fault currents produced by DGs. The simulation results of the proposed method is given in next section.

3. SIMULATION RESULTS AND DISCUSSION

In this paper we have proposed a method for detection of islanding condition and placement of fault current limiter is done by using particle swarm optimization in a distribution system connected with multiple distributed generations.

System Configuration:
Operating System: Windows 8
Processor: Intel Core i3
RAM: 4 GB

The experiment is conducted and validated on IEEE 30 bus system which is shown in figure 8. The data is on 100 MVA base. The line data and load data is taken from the reference [27].

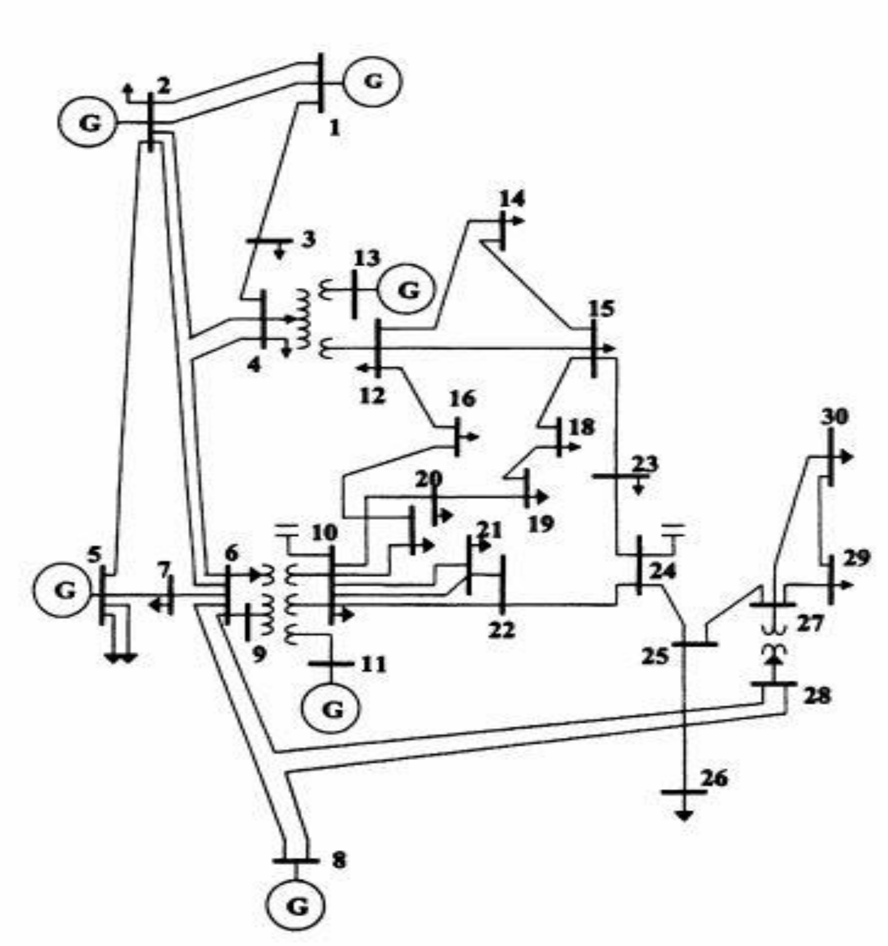

Figure 8: IEEE 30 bus System

To test the proposed method for islanding detection we have made a typical islanding condition of the DG connected at Bus 5 in figure 8 by opening the circuit breaker at the time 83ms between Bus 7 and 6. The magnitude of voltage before introducing islanding condition is shown in figure 9. After introducing islanding there is a large variation in DG loadings, as shown in Figure 10, there is a sudden change in the line to line voltage at the time 83ms. So, the islanding operation condition is easily and rapidly detected by voltage parameter.

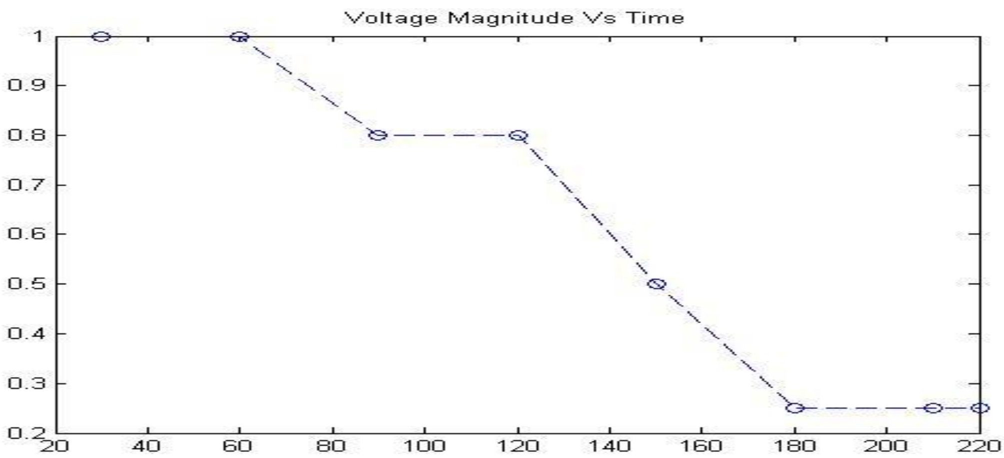

Figure 9: Voltage Magnitude before islanding

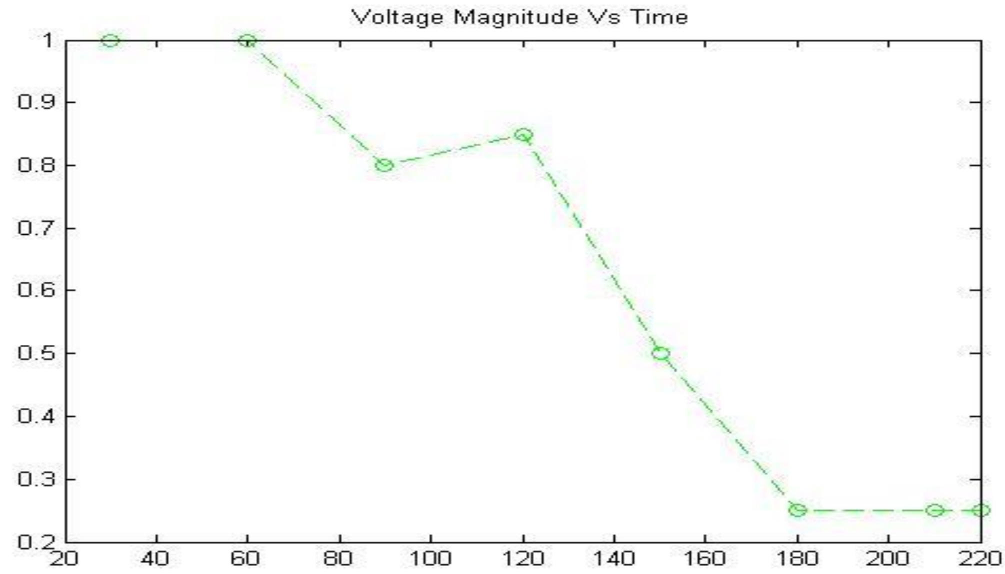

Figure 10: Result for islanding operation with large variation in DG loading in Voltage magnitude.

Similarly, the variation in total harmonic distortion of current is shown in figure 11. However, unlike other parameters, the changes in the THD of the current and voltage unbalance are large enough to detect the islanding operation.

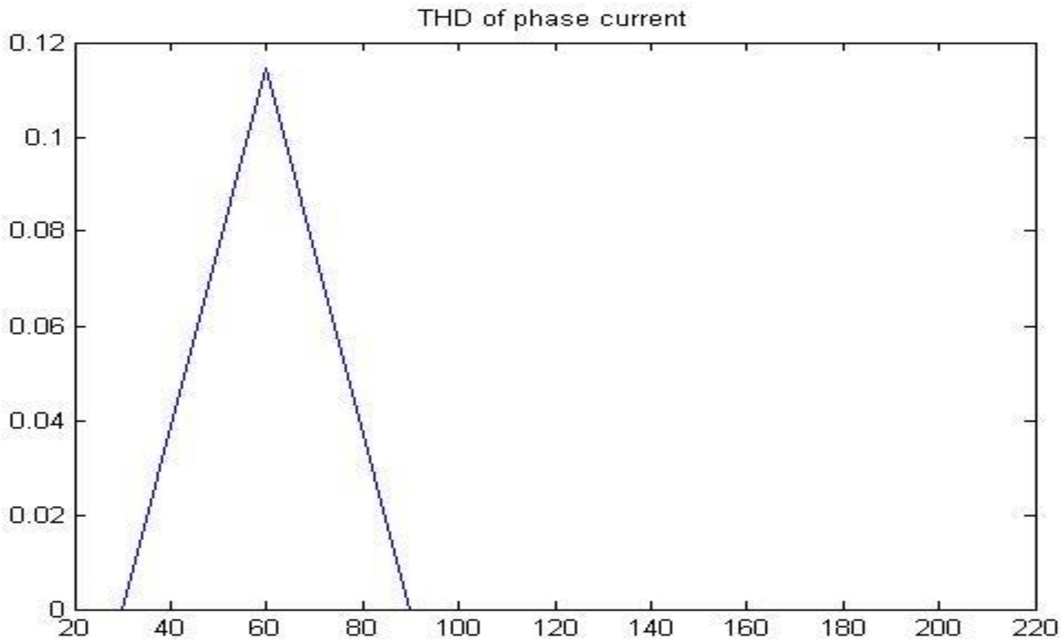

Figure 11: Result for islanding operation with THD of current

The proposed method provides the trip signal for islanding detection at 120 ms to the circuit breaker connected near to the DG connected at bus 5. To evaluate the effectiveness of the proposed method for solving more complex problems, we have introduced the fault current in the bus 21 and 12 by exceeding the ratings of the circuit breaker. The circuit breaker rating is assumed to be 2kA. The short circuit current in the bus 21 and 12 is 2.2kA. The total power loss after introducing fault current is 2.9977 kW. By using our proposed method, the candidate locations and the impedance are calculated by using particle swarm optimization. The best locations for placement of fault current limiter are line 23, 25, and 12. Figure 12 shows the fitness value variations of PSO iterations.

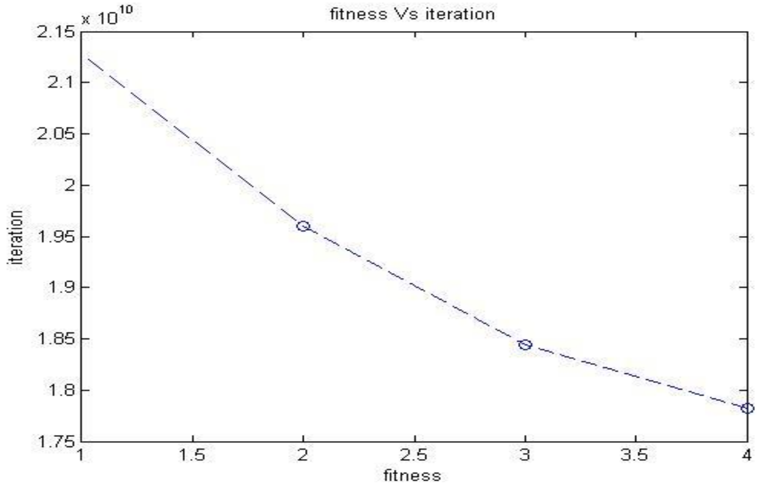

Figure 12: Fitness Graph of PSO

The optimal solutions obtained for this case are as follows:

An FCL with an impedance of 3.0187 ohms should be installed on line 23.

An FCL with an impedance of 2.3187 ohms should be installed on line 25.

An FCL with an impedance of 0.0094 ohms should be installed on line 12.

The short-circuit currents at buses 12 and 21 after FCLs installations are reduced to 1.0234 kA and 1.5623 kA, respectively. Note that only three FCLs are required to suppress fault currents at three buses. Using the proposed PSO technique to solve the optimization problem, we can see that numbers of fault current limiter required are less compared with other techniques. After introducing the fault current limiter the total power loss reduced to 2.1021 kW. In order to prove the effectiveness of our proposed method, we make a comparison with other techniques like Genetic algorithm, Evolutionary Programming which is shown in table 1.

Table 1: Performance Comparison

Methods	**Number of FCL**	Z_{FCL} **(total)**	**Total Power Loss**
Evolutionary Programming (EP)	5	6.125 ohms	2.7852 kW
Genetic Algorithm (GA)	4	5.9814 ohms	2.4982 kW
Proposed Method	3	5.3468 ohms	2.1021 kW

From table 1, we can see that our proposed has achieved minimum power loss with less number of fault current limiters compared with other techniques. From this, we can say that our proposed method is best method for optimal placement of fault current limiters in the distribution system.

4. CONCLUSION

This paper presents efficient islanding detection alongside optimal location of fault current limiter (FCL) placement in an distribution network associated with different DGs. Total Harmonic Distortion of the current and voltage unbalance of the terminal output are utilized as the observing parameters for power islanding detection. The combination of FCLs into distribution network gives a compelling approach to stifle huge fault currents and may get to impressive reduction in investment cost on higher limit CBs. For a huge loop framework, its viability would rely on upon the best possible decision of the impedance and location of FCL. Particle Swarm Optimization (PSO) based method proposed in this paper was discovered successful for seeking the optimal solution. Experimental results have shown the effectiveness and exactness of the proposed method. PSO is utilized to locate the minimum number of FCLs and select the conceivable littlest circuit parameters of FCLs to guarantee that bus fault currents are inside CB ratings.

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