Optimal Protection Coordination of Micro Grid in Grid Connected Mode and Islanded Mode

Abhijith. D[1] Mr. A. Selvavinayagam[2]
[1]M.E Student [2]Assistant Professor
[1,2]Department of Electronics & Electrical Engineering
[1,2]Sri Muthukumaran Institute of Technology, Chennai

Abstract— Microgrids can be operated either grid-connected to reduce system losses and for peak shaving or islanded to increase reliability and provide backup power during utility outage. Such dual configuration capability imposes challenges on the design of the protection system. Fault current magnitudes will vary depending on the microgrid operating mode. In this paper, a microgrid protection scheme that relies on optimally sizing fault current limiters and optimally setting directional overcurrent relays is proposed. The protection scheme is optimally designed taking into account both modes of operation (grid-connected and islanded). The problem has been formulated as a constrained nonlinear programming problem and is solved using the genetic algorithm with the static penalty constraint-handling technique. The proposed approach is tested on two medium-voltage networks: a typical radial distribution system and on the IEEE 30-bus looped power distribution system equipped with directly connected conventional synchronous generators.

Key words: Fault Current Limiter. Directional Overcurrent, Relay Coordination, Short circuit analysis

I. INTRODUCTION

A Distributed Generation (DG) system is a one of the new method of reducing the energy demand crisis. DG will serve the utility in the distribution side of the electrical system. This will reduce the transmission losses and other losses. Most of the renewable sources of energy are the sources of DG such as solar energy conversion systems, wind energy conversion system, bio mass etc. This system will reduce the losses and improve the line performance to a greater extent. A grid is established by the interconnection of these DG sources are made and the controlling is done, such a grid is called Micro Grid.

The micro grid is the main control area of distributed systems. This grid works in two modes one grid connected mode and islanded mode. In grid connected mode it works in synchronism with the grid and supplies power to the grid and absorbs power from the grid. Now in the islanded mode the DG system is isolated from the grid and supplies the local load. Distribution systems are commonly radial where power flows in one direction from the main substation to the loads [1].

The In [3], it has been shown that the fault current contribution will depend on the type of DG present in the system. For inverter-based DG units, the fault current could reach approximately 1 per-unit (because of the controller limiters). Directly-connected conventional synchronous generators (CSG), on the other hand, have a much more profound effect on the short-circuit levels. In this paper, we will refer to the latter type as CSG for simplicity control criteria.

II. FORMULATION OF THE PROTECTION COORDINATION PROBLEM

A proper operation of the OCR will lead to fewer faults clearing time. This is preferred situation for an ideal relay to operate. The operation time of an OCR is an inverse function of the short - circuit current passing through it. This function is defined by two parameters, namely the time-dial settings (TDS) of the relay, a tuning parameter, and the pickup current (Ip), which is the minimum value of current above which the relay starts to operate. The inverse-time characteristic function most commonly given by

$$t = TDS \frac{A}{\left(\frac{I_{sc}}{I_p}\right)^B - 1}. \quad (1)$$

Where,

- A=0.14;B=0.02
- TDS=Time Dial Setting
- ISC= Short Circuit Current; IP = Pickup Current

The constants A and B vary according to the type of OCR used. It is assumed that inverse-definite minimum time OCRs are being used, and therefore the constants A and B are taken to be 0.14 and 0.02, respectively [7]. The objective is to minimize the coordination times of all relays, while maintaining the conditions of protection coordination. As was explained in Section I, two system configurations (grid-connected and islanded) will be considered in the problem. The objective function is taken to be the sum, T of the coordination times of all relays, which needs to be minimized as follows

$$\text{Minimize } T = \sum_{c=1}^{C}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(t_{cij}^{p} + \sum_{k=1}^{K} t_{cij}^{b_k}\right) \quad (2)$$

Where c is the system configuration identifier, with C being the number of configurations considered, is the fault location identifier, with the total number of fault locations investigated being N, and j is the relay identifier, with the total number of relays being M. The superscript prefers to primary relays, while bk refers to backup relay k, with K being the number of backup relays for each primary. Along with this coordination time interval has to be satisfied.

$$t_{cij}^{b_k} - t_{cij}^{p} \geq CTI \qquad \forall c, i, \{j, k\} \quad (3)$$

Limits on the values that TDS and IP can take must also be set. Practically, IP will typically take only discrete values defined by the manufacturer, but this condition is usually relaxed for simplicity. The value of IPi-min is chosen such that it is larger than the rated load current by a significant margin. Therefore, the following constraints are further defined:

$$I_{p_{i-\min}} \leq I_{p_i} \leq I_{p_{i-\max}}, \qquad \forall i \qquad (4)$$

$$TDS_{i-\min} \leq TDS_i \leq TDS_{i-\max}, \qquad \forall i \qquad (5)$$

The modified problem will involve the use of an FCL installed at the grid side. This is the component that will help to reduce the amount of short-circuit current drawn from the utility. FCLs can be resistive or inductive. In this paper, FCLs of the inductive type are used. The FCLs have fixed ratings once they are installed into the system. Hence, the following constraint is introduced.

$$0 \leq X_{FCL} \leq X_{FCL_{\max}}. \qquad (6)$$

FCLs cannot be present in the system during normal operation since this can cause large voltage drops. For this reason, it is proposed to use FCL of the active type as highlighted in [16]. Active FCLs are switched into the system in the event of a fault and have negligible impedance during normal operation. The inclusion of the XFCL will affect the system admittance matrix. For this reason, heuristic techniques such as the GA are often chosen in such a task due to their ease of implementation.

III. GENETIC ALGORITHM

In the field of engineering genetic algorithm (GA) is a search heuristic that mimics the process of natural selection. This heuristic (also sometimes called a meta heuristic) is routinely used to generate useful solutions to optimization and search problems .Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. In a genetic algorithm, a population of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem is evolved toward better solutions. Each candidate solution has a set of properties (its chromosomes or genotype) which can be mutated and altered; traditionally, solutions are represented in binary as strings of 0s and 1s, but other encodings are also possible. Here a genetic algorithm checks the fitness function of the problem.

A. GA Operators:

The Operators used in GA are Selection, Crossover and Mutation. These Operators are used to get the fitness function.

B. Selection:

During each successive generation, a proportion of the existing population is selected to breed a new generation. Individual solutions are selected through a fitness-based process, where fitter solutions (as measured by a fitness function) are typically more likely to be selected. Certain selection methods rate the fitness of each solution and preferentially select the best solutions. Other methods rate only a random sample of the population, as the former process may be very time consuming.

C. Crossover:

The crossover operators combine a pair of chromosomes to produce new chromosome. The new chromosome has the quality better than the parents and will be fit to survive.

D. Mutation:

Mutation is a genetic operator used to maintain genetic diversity from one generation of a population of genetic algorithm chromosomes to the next. It is analogous to biological mutation. Mutation alters one or more gene values in a chromosome from its initial state.

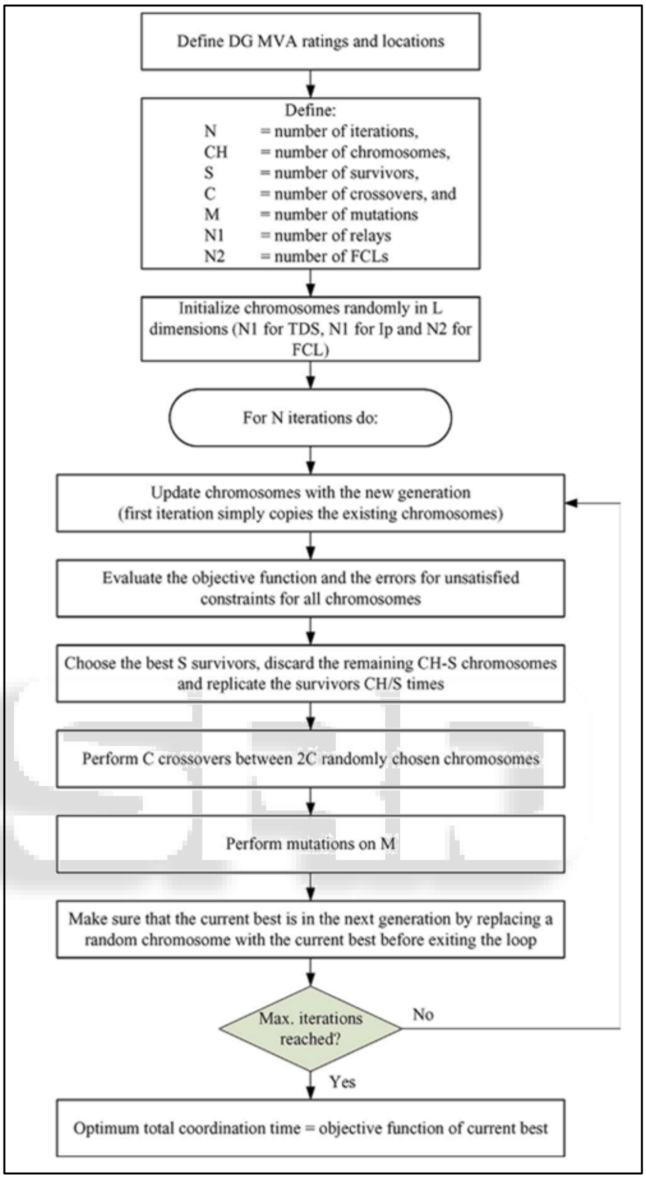

Fig. 1: Flow Chart for GA Implementation

IV. SYSTEM DETAILS

In this paper two test systems are considered a section of Canadian Urban Bench mark Distribution System and IEEE 30 bus system.
Test Systems under Study:

A. Nine Bus Systems:

1) Section of the Canadian Urban Benchmark Distribution System:

The first system tested is based on the Canadian Urban Benchmark 4-bus feeder distribution system [28] and is shown in Fig. 1. Two such feeders, rated at 8.7 MVA and 0.1529 + j0.1406 Ω/km are fed by the utility (short-circuit MVA=500MVA and X/R ratio=6) through a 20 VA, 115 kV/12.47 kV transformer. Four DGs are connected at buses

4, 5, 6, and 9 on the system. The DG MVA ratings tested in this paper range between 3 MVA and 5 MVA. The DGs are connected through 12.47 kV/480 V transformers are given. Each relay should be capable of operating for close-end and far-end faults within its zone. To account for both close-end and far-end faults (three-phase and single-line-to-ground faults), in this paper, three phase faults that occur midway along the line are considered [29]. Therefore, eight additional nodes are introduced at midway points in the system. A short-circuit analysis was then performed at buses 10 to 17. Due to the non-radial nature of the system, each fault is associated with up to two primary relays, one from each side. Each of these primary relays is in turn associated with up to two backup relays. This is best explained by an example. Considering a fault at node 14, it can be seen that there are two primary relays, R9 and R10.ForR9, two backup relays can be defined, namelyR2andR17. Similarly, forR10, the two backup relays areR12andR20. In this way, a matrix of branch short-circuit currents is created that will be used to define the problem. Each of these currents is mapped to a relay in the system, and hence constraints for relays are defined.

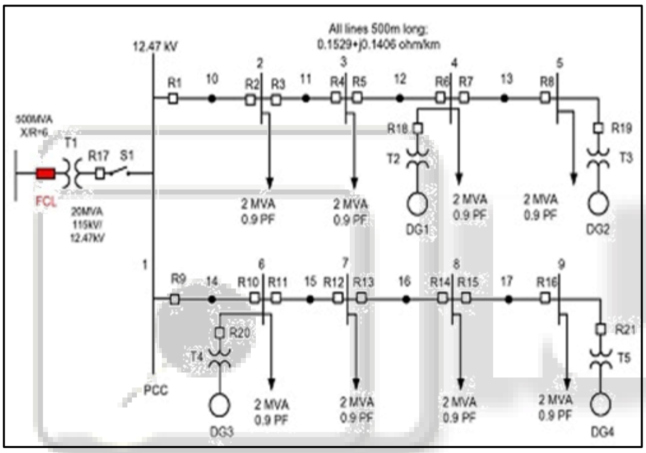

Fig. 2: IEEE 30 BUS SYSTEMS

B. IEEE 30-Bus System:

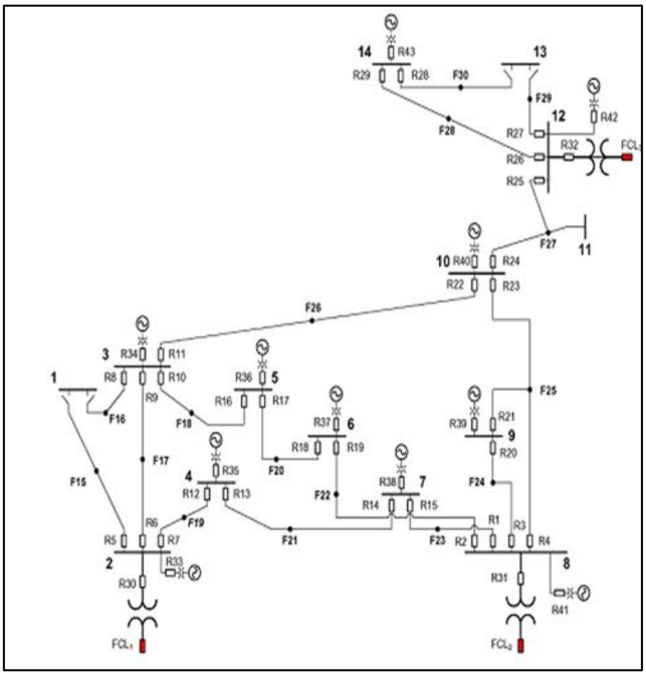

Fig. 3: IEEE 30-Bus System

The distribution system of the IEEE 30-bus test system [30] is shown in Fig. 2. The distribution system is fed through three 50 MVA 132 kV/33 kV transformers connected at buses 2, 8, and 12. DGs are located at various buses in the system as shown in Fig. 2 [16]. Each DG is rated at 10 MVA, operates at unity power factor, and feeds the system through a 480 V/33k V step-up transformer**.**

The system is equipped with 43 directional OCRs (27 of those are on system lines, while the rest protect the utility and DGs). As with the 9-bus system, nodes are introduced at midway points on all lines (F15–F30), representing locations at which fault analysis will be carried out.

V. RESULTS AND DISCUSSION

A. IEEE Nine Bus System:

In this section, the results of the optimization problem formulated above are reported. A discussion of the results is also included.

Parameters	**With GA**	**Without GA**	**Percentage Difference**
Operating time	37.9771	45.131	15.85
Average PSM	1.116	1.091	2.2
Delay Time	0.7697	0.86435	10.97

Table 1:

In the above table given the variation of the relay parameters such as operating time and the average PSM has been given where it shows that the relay coordinated using GA gives better performance.

- Graphical interpretation
- Graph showing operating time variation

Operating time using GA is lesser than the one without GA which improves the performance of the relay.

- Variation of Average PSM

B. IEEE 30 Bus Systems:

In the IEEE 30 bus system the relay parameters comparative study is done.

Parameters	With GA	Without GA	Percentage Difference
Operating time	738.39	779.78	5.2
Average PSM	1.091	1	8.3
Delay Time	2.2581	2.3105	10.97

Table 2:

In the above table of IEEE 30 bus is given the variation of the relay parameters such as operating time and the average PSM has been given where it shows that the relay coordinated using GA gives better performance. The operating time of the relay is reduced and the performance is improved. The Average PSM of the relay is improved and the performance is improved.

VI. CONCLUSION

The microgrid protection is a very important aspect in the present world because of the growing trend in the power scenario. As the demand for the power increases the protection also becoming tough. Here a FCL is defined and incorporated with a overcurrent directional relay to achieve a well defied protection coordination for the microgrid. The operating time of the relay is reduced to a considerable level using the GA algorithm.

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