Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 2, Number 3 January-March (2015) pp. 219-223
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An Adaptive Relay Coordination for Microgrid and Main Grid

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Abstract—*Renewable energy resources are varying widely in their wide spread availability and economical nature across the world. They are non-polluting, while the structures built to harness them can have positive or negative environmental impacts. Increasing level of distributed generation systems causes large number of operational and controlling issues. When the contribution from the distributed generation sources is high it leads to mal-operations in the relay coordination. In this paper, a novel method for coordination of directional overcurrent relays is proposed. Here we have adopted conventional technique for coordination of the directional over current relays. The protective scheme is designed by considering both grid connected and autonomous modes of operations. Both time setting and fault currents have been taken as the coordination parameters. The proposed methodology for the settings of the directional overcurrent relays for the typical microgrid and main electrical grid has been modelled and simulated using ETAP software.*

Index Terms*: Microgrid, Relay Coordination, ETAP software.*

1. INTRODUCTION

Sun, wind, tides, waves, rivers and the heat from radioactive decay in the earth's mantle and biomass are all abundant and ongoing in nature, so the term "renewables". The power of falling water in rivers has been significantly tapped for electricity from many years. Presently utilization of wind is increasing rapidly and it is now acknowledged as a one of the mainstream energy source. Solar energy is also used in agriculture and forestry, via photosynthesis, and increasingly it is harnessed for heat. Turning to the use of abundant renewable energy sources other than large-scale hydro for electricity, there are challenges in actually harnessing them. Apart from solar PV systems which produce electricity directly, the question is how to make them turn dynamos to generate the electricity. If it is heat which is harnessed, this is via a steam generating system.

Integration of small and medium size renewable distributed energy resources (DERs) into main electric distribution system is one of the most challenging problems that the power systems are experiencing [3]. Microgrids are able to operate independently, as well as in conjunction with the main grid in order to enhancing the continuity of service and offering superior power quality, higher reliability, and operational optimality. Adoption of the microgrid concept results in certain problems for the protective relays. Fault currents for grid connected and islanded operation of micro grid will be different. The short circuit current varies significantly. Depending upon location of faults with respect to distributed generators and existing protection equipment, problems like bidirectional power flow and change in voltage profile occurs. Modification in fault current level, device discrimination, reduction in reach of impedance relays, reverse power flow, sympathetic tripping, islanding, single phase connection, selectivity are the key protection issues.

The process of determining the "best fit" timing of current interruption when abnormal electrical conditions occur is termed as relay coordination or it can be stated as process of determining the setting for the relays that will provide an orderly shutdown and determine the sequence of relay operation [8]. The term relay coordination covers the concept of discrimination, selectivity and backup protection. It determines the optimum relay settings to protect the equipment and to ensure continuity of power supply to healthy part of network. Relay coordination is necessary to achieve proper fault identification and fault clearance sequence. Relays must operate quickly as possible to isolating the faulted section of the network and allowing for continued operation of the healthy circuits. In the event of failure of primary relays, backup relays must operate after providing for sufficient time discrimination called coordination time interval (CTI).

The paper [1] contain optimal sizing of fault current limiter and optimal setting of directional over current relays is proposed and solution obtained using the genetic algorithm with the static penalty constraint-handling technique. The paper [2] contains Effects of the different network topologies in the optimization problem are considered. Large number of coordination constraints should be taken into account in the problem formulation. The hybrid genetic algorithm (HGA) is selected as a powerful tool in solving optimization problem. The paper [3] proposed a new method for optimum coordination of overcurrent relays is proposed and is based on only constraints. The paper [4] contains the coordination of directional overcurrent relay for different modes of operation for microgrid and distribution grid has been developed using MATLAB coding. Configuration changes of the network are taken into account. It consider both linear and nonlinear relay characteristics model. The paper [5] implements a practice to obtain optimal minimum fault current limiter values (FCL) to limit DRG fault currents and restore relay coordination status without altering the original relay settings.

2. STRUCTURE OF TEST SYSTEMS

2. 1 Main Grid

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power. Most of the generating stations are located far away from the populated area or cities; however the utilization of electrical energy is more in the cities. Hence high-voltage transmission lines are essential that carry power from distant sources to demand centers, and distribution lines that connect individual customers

In this paper mainly focus on the distribution side, since the microgrids are always connected in the distribution side. A single line diagram of the typical main grid is shown in Fig. 1. It is a radial distribution side feeder have 4 number of buses consists of 4 loads at different buses. It hasdifferent loads and the power is supplied from a power grid. The required line data and the bus data are taken from reference papers [7].

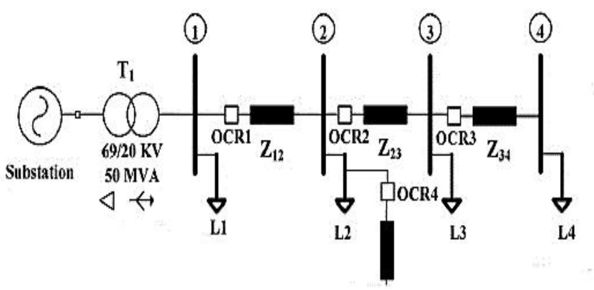

Fig. 1: Typical Distribution Feeder

2.2 Microgrid

A small-scale power grid that can operate independently or in conjunction with the area's main electrical grid called as microgrid. Any small-scale localized station with its own power resources, generation and loads with definable boundaries qualifies as a microgrid. Fig. 2 shows a single-line diagram of the system used to investigate typical micro-grid operational scenarios. The basic system configuration and parameters were extracted from the benchmark system of the IEEE Standard 399-1997 with some modifications to allow for autonomous micro-grid operation [6].

The system is composed of a 13.8-kV, three-feeder distribution subsystem. The 13.8-kV distribution substation is equipped with a three-phase 1.5-MVAr, fixed shunt-capacitor bank. A combination of linear and nonlinear loads (L1 to L5) is supplied through three radial feeders of the subsystem. Loads L1 to L5 are composed of linear branches. The aggregate of and constitutes a sensitive load within the distribution subsystem.

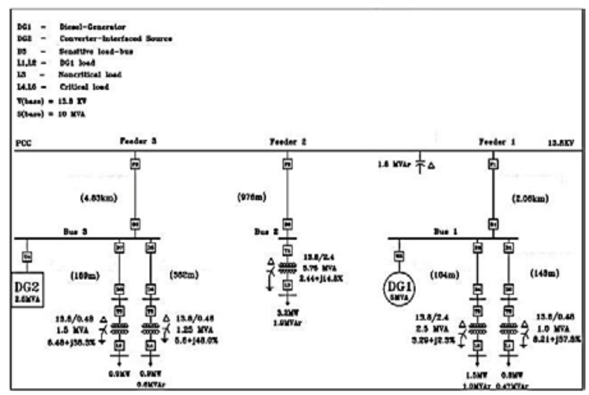

Fig. 2: Typical Microgrid System

3. RELAY COORDINATION PROBLEM

In a conventional relay coordination problem total operating time of primary and backup relay is optimized. So, objective is minimizing the total operating time of primary relays and backup relays. The variables chosen for the relay setting are time dial setting (TDS) and plug setting (PS).

3.1 Relay Characteristics

Different linear and nonlinear overcurrent relay characteristics are reported in the literature [1-5]. Without loss of generality, in this paper, the following nonlinear and popular characteristics function based on IEC standard is considered:

$$t_i = \frac{0.14 * TMS_i}{\left(\frac{I_i}{Iset_i}\right)^{0.04} - 1} \tag{1}$$

Where TMS_i and $Iset_i$ are the time multiplier setting and pickup current setting of the th relay, respectively Ii and is the fault current passing through ith relay. It can be seen that the nonlinearity in relay characteristics function is related to pick up current variable. If the parameter Iset is assumed to be determined prior, then the relay characteristics will be a linear function of TMS variable. In this case, the coordination problem can be formulated as a linear programming problem.

3.2 Primary and Backup Protection Constraints

The coordination constraints between the primary relay and its/their backup relay(s) for the near-end and the far-end faults are:

$$t_j^{F1} - t_i^{F1} \geq CTI \tag{2}$$

$$t_j^{F2} - t_i^{F2} \geq CTI \tag{3}$$

Where t_i^{F1} and t_i^{F2} are the operating time of the primary relay for the near-end and far-end faults respectively. Also, $t_j^{F1}$and t_j^{F2} are defined in the same way as the jth backup relay respectively. The Coordination Time Interval (CTI) is the minimum interval that permits the backup relay to clear a fault in its operating zone. In other words, the CTI is the time lag in operation between the primary and its backup relay. It includes many factors, such as the breaker operating time, relay overt ravel time and asafety margin. The value of CTI is usually selected between 0.2 and 0.5 s.

3.3 Bounds on the Relay Settings

The limits on the relay parameters can be presented as follows:

$$TMS_i^{min} \leq TMS_i \leq TMS_i^{max} \tag{4}$$

$$\max(I_{load_i}^{max}, I_{set_i}^{min}) \leq I_{set_i} \leq \min(I_{fault_i}^{min}, I_{set_i}^{max}) \tag{5}$$

The minimum pickup current setting of the relay is the maximum value between the minimum available tap settings $I_{set_i}^{min}$ on the relay and maximum load current$I_{load_i}^{max}$ passes through it. In similar, the maximum pickup current setting is chosen less than the minimum value between the maximum available tap settings $I_{set_i}^{max}$ on the relay and minimum fault current settings $I_{fault_i}^{min}$which passes through it.

4. TEST SYSTEMS AND RESULTS

In this paper, the test systems are taken as the typical microgrid and main grid. The technical data required for the modeling of the respective systems are taken from some of the reference papers [6][7]. ETAP software is used for the directional over current relay coordination of the microgrid and main grid. In order to perform the relay coordination load flow analysis and short circuit analysis are essential [9][10]. Relay coordination results are tabulated in the respective.

4.1 Simulation of Test System and Results

Test systems are modelled with the help of ETAP software, more precisely the typical microgrid is modelled in the software by using the data from reference paper and Main grid is modelled with 30 buses. For the modelling all the technical data are taken from the reference papers. Due to the constraints in the software some slight modifications are done in the microgrid structure [12]. As part of the work, initially complete the load flow analysis and short circuit analysis of the both systems. Simulation diagrams of main grid and microgrid are given in fig 3&4respectively. It includes the protective devices also.

4.1.1 Load Flow Analysis

Load flow analysis, also called as power flow analysis is an important tool using numericalanalysis of a power system. They are necessary for planning, economic scheduling, and control of an existing system as well as planning its future expansion. It is essential not only in order to design the different power system components such as generators, lines, transformers, shunt elements, etc. so that these can withstand the stresses they are exposed to during steady state operation without any risk for damages. The problem consists of determining the magnitudes and phase angle of voltages at each bus and active and reactive power flow in each line. Load flow analysis can be carried out by different techniques. In this analysis load flow analysis is carried out by using Newton-Raphson method [13] since it having numerous advantage over other load flow techniques

4.1.2 Short Circuit Analysis

Power systems are designed to operate under balanced conditions where as in practically systems work mostly under unbalanced condition due to the different reasons. Fault may occur at different point in a power system. Faults can damage or disrupt power system in different ways. Faults may cause abnormal operating condition, usually excessive current at certain point on the system. Large voltages stress on the insulations beyond their breakdown value will result as potentially damage to the system.It is necessary in the occurrence of fault the faulty section should be isolated as rapidly as possible in order to continue the normal operation of the rest of the system is not affected.The relay should immediately detect the existence of the fault and initiate circuit breaker operation to disconnect the faulty section. By using ETAP software we can simulate either symmetrical or unsymmetrical faults. Here we are using symmetrical fault for the analysis of the systems.

4.1.3 Relay Coordination Results

Relay coordination is necessary to achieve proper fault identification and fault clearance sequence. Relays must operate quickly isolating the faulted section of the network only and allowing for continued operation of the healthy circuits. In the event of failure of primary relays, backup relays must operate after providing for sufficient time discrimination. The operation of backup relays must be coordinated with those of the operation of the primary relays [14]. Relay coordination results are tabulated CT ratios in table 1,Plug setting and Time dial setting in table for the integrated microgrid with main grid.

From the result it is clear that the objective of the paper can be achieved to a certain extend by the conventional technique.Conventional technique for the relay coordination helps to minimize the operating time as well as provide the solution for the directional over current relay coordination [15]. The sequences of relay operations are obtained from the simulation results. In ETAP software it can be set the number of flashing devices; here number of flashing devices set as 3. This means that primary protections have two backup protections. In future operating time can optimize using the modified strategy based control technique [16-19]; that is intelligent techniques.

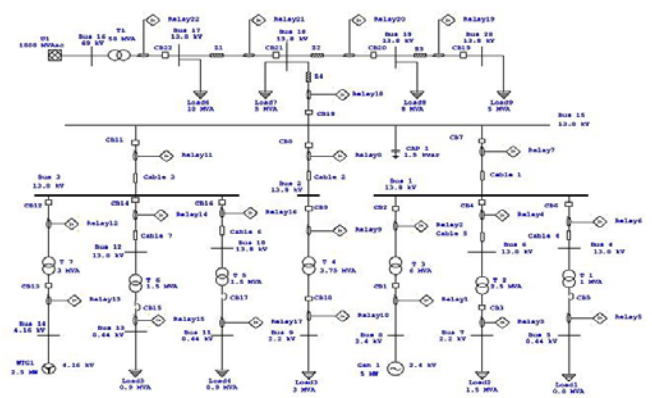

Fig. 3: Simulation Diagram of Integrated Microgrid with Main Grid

Table 1: CT Ratios

RELAY NO	CT RATIO	RELAY NO	CT RATIO
1	2000:5	12	200:5
2	500:5	13	600:5
3	800:5	14	100:5
4	150:5	15	2500:5
5	2000:5	16	100:5
6	100:5	17	2500:5
7	300:5	18	300:5
8	200:5	19	300:5
9	200:5	20	800:5
10	1500:5	21	1000:5
11	300:5	22	2000:5

Table 2: PS & TDS Settings

RELAY NO	PSM	TDS	RELAY NO	PSM	TDS
1	0.72	0.2	12	0.785	0.15
2	0.628	0.15	13	0.868	0.1
3	0.94	0.05	14	0.785	0.2
4	0.88	0.2	15	0.902	0.05
5	0.755	0.05	16	0.785	0.2
6	0.53	0.2	17	0.902	0.05
7	0.87	0.25	18	0.75	0.3
8	0.98	0.15	19	0.86	0.1
9	0.98	0.1	20	0.84	0.2
10	0.752	0.05	21	0.93	0.3
11	0.875	0.25	22	0.75	0.4

5. CONCLUSIONS

The concept of the microgrid and the renewable sources used in the microgrid are studied. Microgrids, by definition, should be operational in both grid connected and autonomous modes. Consequently, it is essential to design microgrids such that they perform satisfactorily in both modes of operation. This paper tackles the protection issue due to the penetration of microgrid to the electrical distribution system. Protective coordination for the microgrid and main grid are considered. Penetration of Distributed Generations to the main grid increases it will severely, affects the relay coordination. As a part of relay coordination load flow analysis, short circuit analysis and star-protective coordination are completed with the help of ETAP software. Directional over current relays are taken for the protection. Conventional technique is used for the relay coordination, by this technique can provide a solution for the directional over current relays and operating time of the relay can be reduced to certain extend.

6. FUTURE SCOPE

The relay coordination for the aggregated system can be done with the help of genetic algoritm to provide the best set of relay coordination and optimize the operating time of the primary and backup protection. Microgrid is one of the solutions to the energy crisis in present scenario. So it is essential to overcome such problems for that we need to more depend onmicrogrids have sources of renewable energy.Definitely, the proposed relay coordination can implement in the real time system [20-21] in future.

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