Overcurrent Protection of Distribution Network with Distributed Generation

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***Abstract*— Penetration of distributed generation (DG) into the distribution network has changed the nature of conventional power distribution system, which was radial in nature. Power flow is now bidirectional and thus the increased penetration of DGs imposes a challenge on the conventional protection scheme which is only meant for passive distribution network. This paper deals with the protection of active distribution network (ADN). Huge penetration of DGs in the distribution network is expected in the near future, thus the proposed protection method assumes that the distribution network will have a significant penetration of distributed generation in islanded scenario and the fault current is maintained upto 5 to 7 pu during a shift from grid connected to islanded mode. The overcurrent relays (OCR) protects the downstream faults whereas the directional overcurrent relays (DOCR) are used for the protection of upstream faults. The overcurrent relays settings are obtained with the help of short-circuit analysis of network in grid connected and in islanded mode. The simulations are done using DIgSILENT power factory.**

***Index Terms*-- Active distribution network (ADN), adaptive protection, distributed generation (DG), DigSILENT power factory, and overcurrent protection.**

I. INTRODUCTION

There is huge research on renewable energy sources, which are now embedded into the power distribution network to increase the reliability of the power system networks. Distributed generation (DG) are those type of generation, which is of limited size i.e. upto 10MW and are interconnected at the substation, distribution network and consumer's end. DG technologies include wind turbine, fuel cell, PV cell, small and micro turbine. Integration of DG in distribution network has great impact on the distribution system as well as on the protection of distribution systems [1-2]. One of the major problems is the bidirectional power flow and the need of short tripping time, due to increased short circuit current of distribution system with the penetration of distributed generation [3]. The impact of DG integration on protection scheme depends on the type of DG as well as the nature of distribution system [4].

When there is a fault on distribution network, there is a bidirectional power flow with the contribution of DG and overcurrent relay should have directional element to sense the fault current direction whether it is a downstream current or an upstream current. The introduction of renewable generation sources in the distribution system can significantly impact the stability, reliability and voltage condition at customer and utility equipment [1-5]. The fault current of the distribution network depends on the short circuit capacity of power sources. The transmission grid generally has higher short circuit capacity as compared to small DG. Therefore during islanded condition, the fault current seen by protective relay is less than the fault current when the distribution system is connected to the grid [5]. Synchronous-based DG has higher fault current levels than the inverter-based DGs. The inverter based DG fault current is typically in the range of 1 to 2 per unit. The addition of DG affects the protection coordination of overcurrent relays [6] and there has been a lot of research for finding optimal relay settings for such scenarios [7-8]. Some researcher insists on adaptive protection which switches the relay setting whenever there is a change in mode of operation i.e. grid connected to islanded mode [5], [9-10]. Adaptive protection schemes without the communication link is presented in [3][5][10-11], whereas [12-13]presents the schemes which make use of communication system for knowing the mode of operation. However, these schemes were proposed for networks which have small penetration of DGs, the scenario will be different when there will be huge penetration of DGs.

Huge penetration of DGs in the distribution network is expected in the near future, thus the proposed protection method assumes that the distribution network will have a significant penetration of distributed generation in islanded scenario and the fault current is maintained upto 5 to 7 pu during a shift from grid connected to islanded mode. Directional overcurrent relay are applied to protect the upstream fault and overcurrent relay are applied to protect the downstream fault in case of fault in the distribution system.

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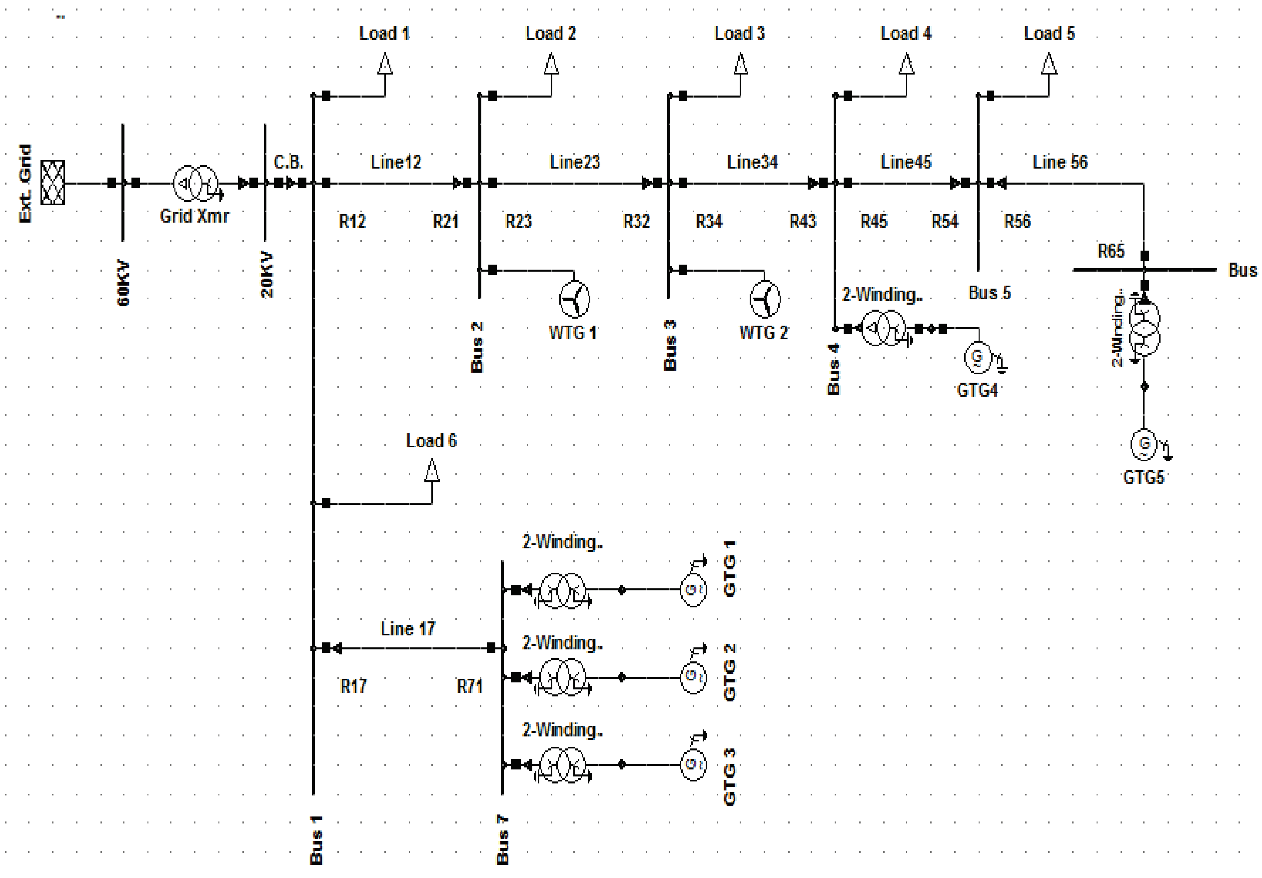

Fig. 1 Test Distribution System

This method uses the communication less overcurrent relay protection of distribution system. Section II describes the test distribution network. Section III explains the proposed methodology. Section IV presents the simulation results and discussions. Section V concludes the paper. This protection scheme is implemented with the help of DIgSILENT power factory.

II. Test Distribution System

Fig. 1 shows the test distribution system. The distribution system consists of five gas turbine generator and two wind turbine generator. The wind turbine generator are doubly fed induction generator (DFIG) interfaced with grid through power electronics converters. The gas turbine generators are 2 MW capacity connected at 3.3 kV. There are 7 buses and 6 loads. The generator data, line data and load data are given in Table I, Table II and Table III, respectively. Line 12 and R_{12} in the paper stands for line from bus 1to 2 and relay at the beginning bus 1 and the end bus 2 of the protection zone respectively.

Table I. Generator Data

Name	Rated Power (MW)	Rated Voltage (kV)	Power Factor	Turbine Speed (rpm)
WTG 1	0.8	0.66	0.7	20
WTG 2	4	0.66	0.7	18
GTG 1-5	2	3.3	0.85	2500

Table II. Line Data

Line	Resistance (Ohm/km)	Reactance (Ohm/km)
Line 12	0.1344	0.0632
Line 23	0.1912	0.0897
Line 34	0.4874	0.1284
Line 45	0.1346	0.0906
Line 56	0.1346	0.0906
Line 17	0.341	0.7241

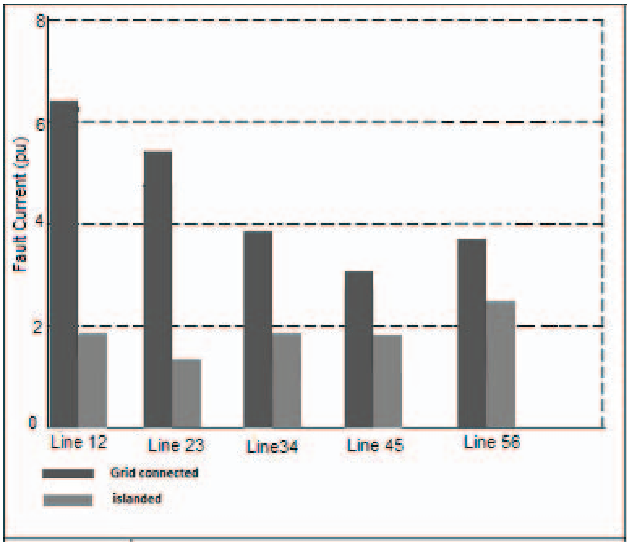

Fig. 2 Comparison of fault current during grid connected and islanded mode of operation

III. PROPOSED METHODOLOGY

Fault current in the distribution network depends on the short-circuit capacity. Grid connected distribution network with DG has higher fault current due to increased short circuit capacity as compared to fault current of distributed generation in islanded mode. Fig. 2 gives the variation in fault current of the distribution system in grid connected and islanded mode of operation. If there is a significant penetration of DGs in the distribution system as expect in near future then the fault current can be maintained at 5 to 7 pu in islanded mode also and hence the optimal overcurrent relay tripping characteristics can be used to protect the network from heavy fault current. If there is a fall in DGs operation below a set level, then the protection system can be switched to adaptive protection schemes [3][5] and [10-13]. There is lots of islanding detection method for islanding detection of DGs. In this paper [14] is used for knowing the mode of operation, as we don't want to cease the DGs operation. This information is needed to know the total number of DGs in operation in islanded mode. However, study in this paper is limited to the assumption that a fixed number of DGs are in operation in islanded mode and the fault current is maintained upto 5 to 7 pu.

A. Optimal Settings for Overcurrent Relay:

A typical inverse time overcurrent relay consists of two elements, an instantaneous part, and a time overcurrent part. The equation for overcurrent relay is given as

$$t_o = \frac{0.14 X TMS}{\left[\left(\frac{I_F}{I_P}\right)^{0.02} - 1\right]} \quad (1)$$

Table III. Load Data

Load	*Active Power(P_L) (MW)*	*Reactive Power(Q_L) (MVar)*
Load 1	0.4523	0.2003
Load 2	1.5124	0.3115
Load 3	1.7131	0.3012
Load 4	1.3131	0.2521
Load 5	2.3131	0.4522
Load 6	4.6471	1.2607

where t_o, I_F, I_P and *TMS* are operating time, fault current, pickup current and time multiplier setting of an overcurrent relay, respectively.

The overcurrent relay has two value to be set, the pickup current (I_P) and the time dial setting (TDS).The pickup current is the minimum current value for which relay operates. The time dial setting defines the operation time of the device for each current value. Bidirectional power flow in case of fault at transmission line can be prevented with the help of overcurrent and directional relay in which overcurrent relay is used to protect the downstream fault current and directional relay is used to protect the network from upstream fault. With the short circuit analysis, fault current at each line in both mode (Grid and islanded) is calculated. For the proper coordination of overcurrent relay in distribution network with distributed generation, the pickup current (I_P) of overcurrent relay should be selected according to the islanding fault current so that relay can operate in both grid and islanded mode and can be prevented from false tripping. The operating time of all relay should be selected in such a way to isolate the minimum faulty network. Overcurrent relay adopted with a coordination time interval margin of 0.2s so that relay can hold coordination for large variation in fault current in grid and islanded mode. Necessary condition for satisfactory operation of overcurrent relay is given below

$$\textbf{Pick up current } (I_p) < I_{\text{fault current (islanding case)}} \quad (2)$$

The operating times of overcurrent relay should be such that it obeys the following condition:

$$T_{R56} < T_{R45} < T_{R34} < T_{R23} < T_{R12} \quad (3)$$

The operating times of directional relay should be such that it obeys the following condition:

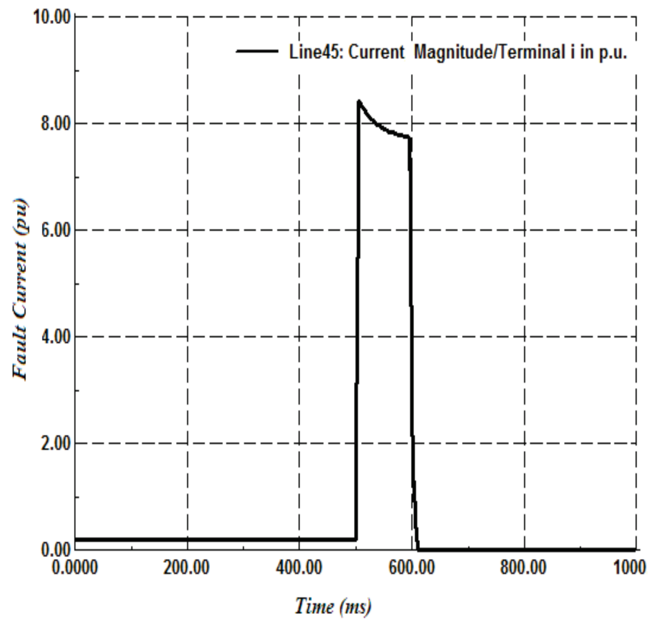

Fig.3 Fault current at line 45 in grid connected mode

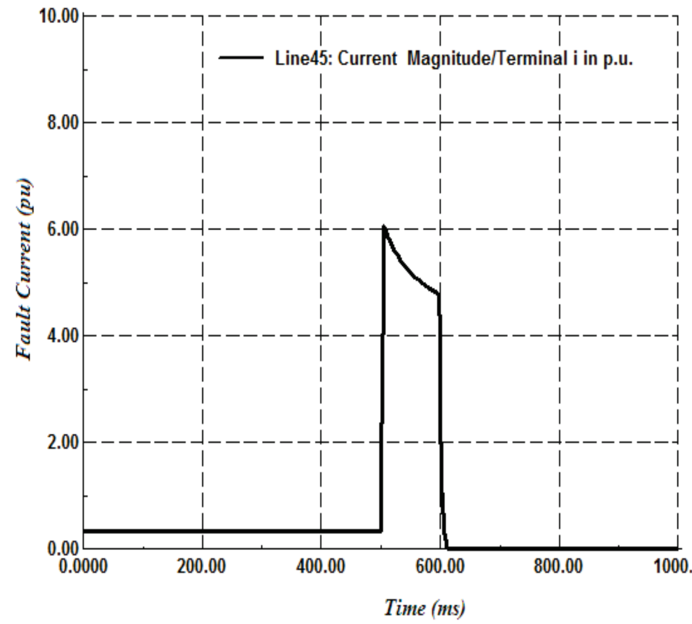

Fig.4 Fault current at line 45 in island mode

$$T_{R17} < T_{R21} < T_{R32} < T_{R43} \qquad (4)$$

Relay R_{71} and R65 are overcurrent relay which is connected at the end of the distribution line. The operating time of these two relay are set according to short circuit analysis and have no effect on the operation of other relays. The pick-up current and relay settings for all relays are given in Table IV.

IV. Simulation Results

The simulation model is run for 1 s and islanding is done at 0.5s by opening the grid circuit breaker from 20kV line. The relay takes 10 ms to close its trip contact and circuit breaker takes 60 ms to clear the fault. Fault is simulated in line 45 and this particular is case is discussed in this paper. For the fault in other lines, the same strategy can be adopted.

A. Fault Simulation in line 45in grid connected mode

A three phase fault with fault resistance of 0.05 ohm is simulated at the middle of line 45 at time instant of 0.5 second, when the distribution network is connected to the grid. Fig 3 represents the fault current graph. In case of fault at line 45, relay 45 operate first at time instant of 100 ms, relay 34 at time instant of 145 ms and other relay follow the order in coordinated manner for back up protection. Fig. 3 represents the value of fault current which is equal to 8 pu and is prevented by isolating the distribution network from both side with relay and circuit breaker operation. Relay coordination graph during grid connected mode is given in Fig.6, the operating time of all relay is shown, in which relay 45 will operate first then 34, 23 and 12 in the suggested coordination order.

Table IV. Relay Settings

Relay	Instantaneous Pick up current (A)	Time Setting	Current Setting (A sec)	Time dial Setting
R_{12}	700	0.20	2	0.3
R_{23}	820	0.15	3.5	0.1
R_{34}	870	0.15	3	0.1
R_{45}	640	0.10	1.3	0.1
R_{56}	640	0.05	0.6	0.1
R_{65}	640	0.05	1.2	0.1
R_{71}	720	0.25	2.0	0.3

B. Fault Simulation in line 45in island mode

Fig. 4 gives the value of fault current in island mode at line 45, which is less than fault current in grid connected mode as in Fig 3. It can be seen that if all the distributed generation in the island mode is kept operating, then they together contribute almost 6 pu of fault current as can be seen from Fig.4. In Islanded mode, the relays will give satisfactory operation when their characteristics are optimally coordinated. Relay coordination graph during island mode is given in Fig.6, the operating time of all relay is shown, in which relay 45 will operate first then 34, 23 and 12 in the suggested coordination order.

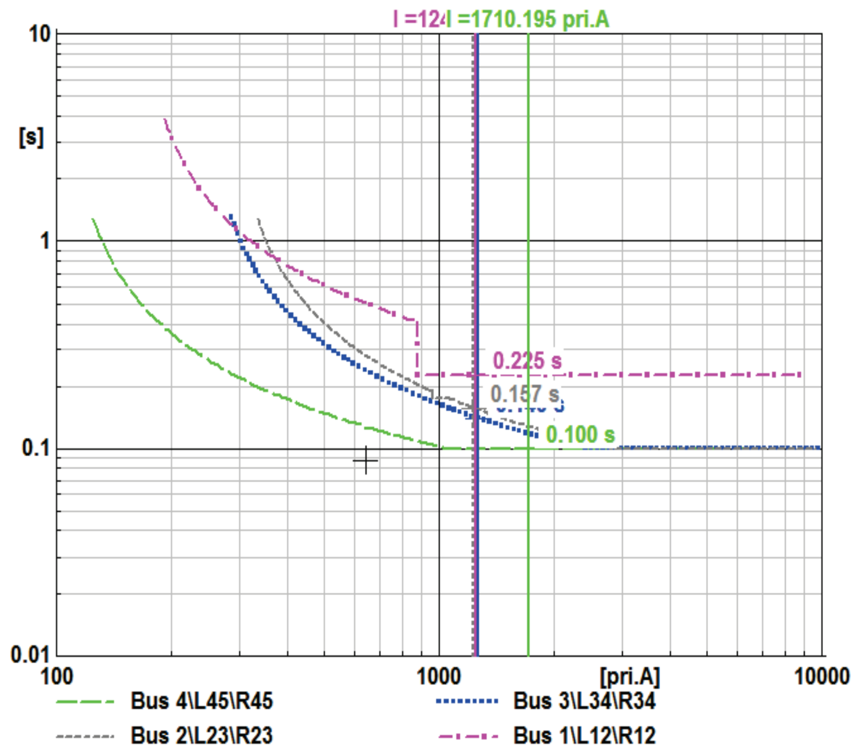

Fig. 5 Relay trip characteristics for fault at line 45 in grid connected mode

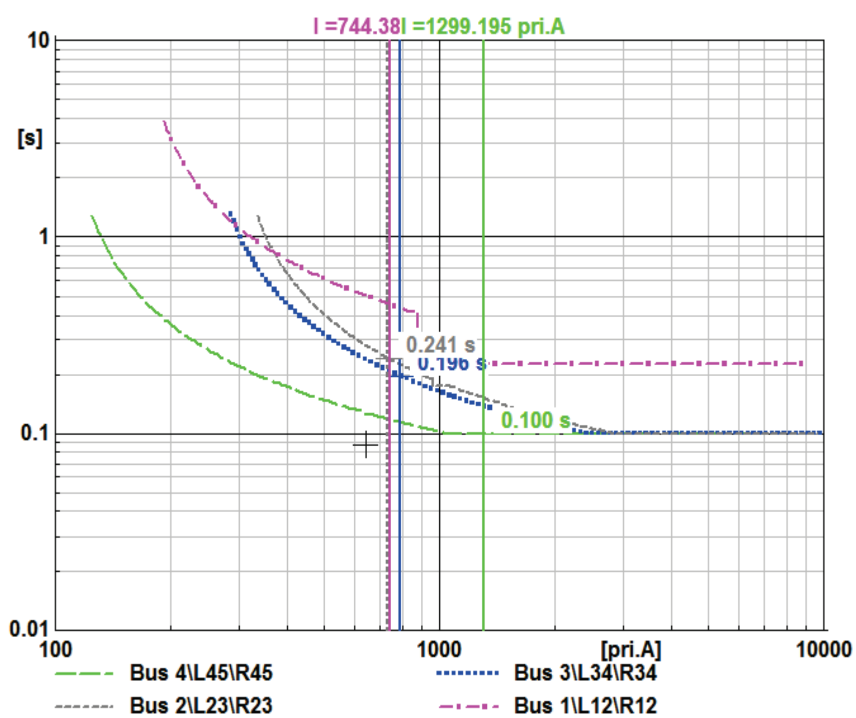

Fig. 6 Relay trip characteristics for fault at line 45 in island mode

Table V. Tipping Time

FAULT LOCATION	Tripping Time (s)			
	FORWARD RELAY		BACKWARD RELAY	
	Primary Relay	Back up Relay	Primary Relay	Back up Relay
L 12	R 12	R 17	R 21	R 32
	220	235	130	142
L 23	R23	R12	R32	R 43
	182	225	145	160
L 34	R 34	R 23	R 43	R 54
	115	128	138	156
L 45	R 45	R 34	R 54	R 65
	100	145	142	167
L 56	R 56	R 45	R 65	-
	75	100	145	-

The relay characteristics should be selected in such a way to avoid the false tripping or malfunctioning during fault condition and also provide the backup protection in case of main relay is not operated. Table V gives the tripping time for forward and backward, primary and backup relay for different fault locations, which is valid for the grid connected and island mode of operation if all the DGs are kept operating in the island mode. By the optimal setting of overcurrent relays, all the relays are able to detect the fault and can operate in both (grid and islanded) mode to isolate the faulty section.

V. CONCLUSION

Simulation results shows that the proposed protection scheme works well when a significant amount of fault level is maintained during the islanding of active distribution network. However, if the amount of fault level goes below the set amount which can be obtained by knowing the status of working DGs, the protection system has to switch to adaptive protection scheme. Since, in the near future there will be heavy penetration of DGs and there is always a possibility that a significant fault level is maintained in the network. Therefore adaptive protection is needed only when the fault level goes below a set level. The overcurrent relay settings are obtained which works well within the said scenario. The proposed scheme uses overcurrent relays (OCR) to protect the downstream faults whereas the directional overcurrent relays (DOCR) are used for the protection of upstream faults. In future, this scheme can be clubbed with adaptive protection scheme along with communication links to cover all type of scenarios.

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