The Journal of CPRI,
Vol. 12, No. 3, September 2016 pp. 445-452

Adaptive distance relay scheme for a DG based network using RTDS™

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The power generated from Distributed Generations (DGs) such as wind and solar are eco-friendly and sustainable. Investigation on the impact of DGs on the power system network is presently a challenging task for the researchers. If the power generated from these energy sources are bulk and dispatchable then they are directly integrated into the transmission network. As transmission network is protected by distance relays, in-feed from DG will results in reach problems. This paper investigates on how the in-feed from DG source affects the operation of existing distance relays leading to over reach and under reach problems. The distance relay group settings are set in such a way that from the status of DG Breaker, the relay automatically switches to new settings which shows an adaptive approach, i.e., by communicating breaker status to the relay input contacts to make the relay adaptive based on the changes in the network topologies and to avoid maloperation of relay for effective protection, security of equipment and reliability of power transfer. This proposed adaptive scheme is implemented on a test transmission network simulated using Real Time Digital Simulator (RTDS) ™.

Keywords: *Distributed generation, distance relays, transmission network, adaptive algorithm, group settings.*

1.0 INTRODUCTION

The distributed generation integration into power transmission network has both merits and demerits. They help in improving bus voltages, enhancement in power reliability, peak load sharing, and system loss reduction [1]. But DGs power injection leads to change in topology of power transmission networks. Conventionally transmission lines and sub transmission lines are protected by distance relays. These relay settings are made based on existing configuration of power transmission networks. Power output from DGs is highly unpredictable. Depending upon size and availability of DGs, they are connected to transmission system for bulk transfer of electric power to the load centers.

In the present scenario, very small portion of DGs power is pushed into the grid. In future due to the exponential increase in demand, the DGs contribution is expected to increase further. Under such conditions, the performance of distance relay needs to be ascertained. They may mal-operate due to in-feed of fault currents from the connected DGs. As number of DGs in the transmission system increases, the in-feed contribution also increases. The in-feed from new DGs will not be similar to the conventional sources. These sources are intermittent and highly unpredictable in nature which leads to variable in-feed fault currents to distance relays.

In this paper, the system is modelled under RTDS™ environment through RSCAD™ simulation software and DG along with a transformer is

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modelled as equivalent source, this is connected to a bus in the sub transmission network through a breaker. Based on the status of breaker, network condition gets changed and this information is fed to the relays. The settings are changed based on breaker status which is communicated from simulator to the relay through digital output ports. The relay used is of "Siemens SIPROTEC 7SA52™" - Numerical type.

2.0 DISTANCE PROTECTION AND EFFECTS FROM DG IN-FEED

Distance protection commonly has three zones of protection to protect the line from faults [2]. Three zones of protection are shown in Figure 1.

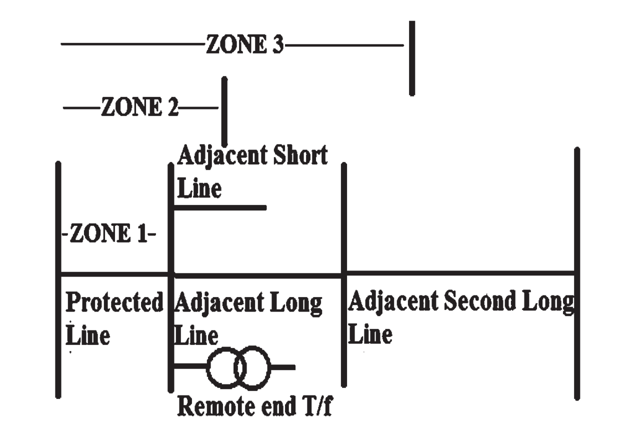

FIG. 1. SINGLE LINE DIAGRAM WITH THREE ZONES

Normally these three zone protection schemes are used in order to cover a section of line and provide backup protection to adjacent sections. Zone settings are made according to following criteria [3] [6].

- **Zone 1** : 80% of protected line and operating time of the relay is instantaneous.
- **Zone 2**: 100% protected line and 50% adjacent short line and time delay is 350 milli sec.
- **Zone 3** : 120% of the protected line + 100% of the longest line emanating from the far end bus bar or 100% of the protected line + 100% of the longest line emanating from the far end bus bar + 25% of the longest line emanating from the far end of the second line considered and time delay is 1 sec.

2.1 With out DG in-feed effect

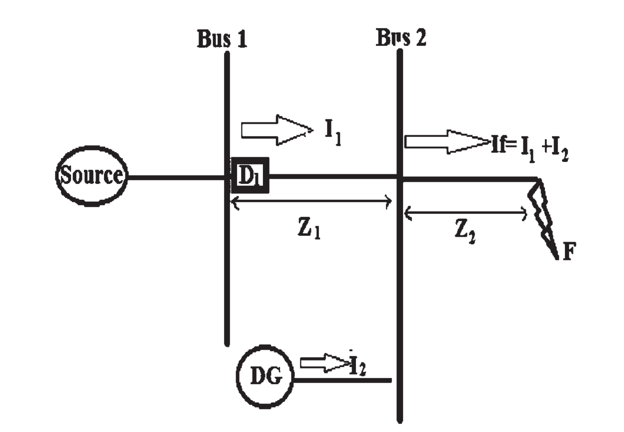

FIG. 2. EFFECT OF DG IN FEED ON RELAY D_1

For a fault beyond bus 2, Impedance seen by relay D_1 which is located at bus 1 is calculated using Kirchoff's voltage law under normal conditions (without DG) are shown in Equation 1 and 2.

$$V_1 = I_1 Z_1 + I_2 Z_2 \quad \ldots(1)$$

$$\frac{V_2}{V_1} = Z_1 + Z_2 \quad \ldots(2)$$

where V_1= voltage seen by relay at bus 1

I_1= current flowing in transmission line section 1(between bus 1 and 2)

I_2= current injected at bus 2 by the DG

Z_1= impedance of line section 1

Z_2= impedance of line section 2 (from bus 2 to fault point F).

2.2 With DG in-feed effect

From Figure 2, DG contributes current I_2 and during fault, relay at bus 1 measures impedance which will be different from the actual value. This is due to the fact that current seen by relay is less than the total fault current at point F due to in-feed [8] at remote end. It is shown in Equation 3 and 4.

According to Kirchoff's voltage law for fault at F, in the fault loop the algebraic sum of voltages should be zero and hence

$$V_1 = I_1 Z_1 + (I_1 + I_2) Z_2 \quad \ldots(3)$$

$$V_1 = Z_1 + \left(\frac{I_2}{I_1}\right) Z_2 \quad \ldots(4)$$

The term $\frac{I_2}{I_1} = K$ is a factor with which impedance change can be noticed.

The impedance as seen by the relay

$$Z_m = Z_1 + (1 + K)Z_2 \quad \ldots(5)$$

Z_m = Impedance seen by the relay under reach

From Equation 4, the term $\left(\frac{I2}{I1}\right) Z_2$ is the additional impedance seen by the relay D_1 located at bus 1 and it is clear that impedance measured by relay is more than the actual impedance which is termed as under reach problem. It results in the relay mal-operation with existing relay settings. This additional value of K times Z_2 is to be added to the relay settings to overcome the problem of under reach.

2.3 Over reach

With the effect of DG in-feed, the relay setting has to be changed to operate effectively. With the help of equation 3 and from the value of K, new settings are obtained with which the relay works satisfactorily. Now with the new settings of relay the problem arises when the DG breaker is opened and without feeding the fault, the fault is not seen by the relay due to the location beyond bus 2. This problem is said to be over reach.

In order to overcome the above problem, the DG in-feed should be properly communicated by sending feedback to the relay and opting for change of group settings. This leads to an adaptive approach in the protection scheme.

3.0 SIMULATION AND RESULTS

3.1 System Description

The test transmission network consists of 3 bus system with 2 transmission lines, source at bus 1 and the DG with transformer is represented as an equivalent source connected to bus 2 through breaker, the distance relay D_1 is on T_1 at bus 1 is shown in Figure 3.

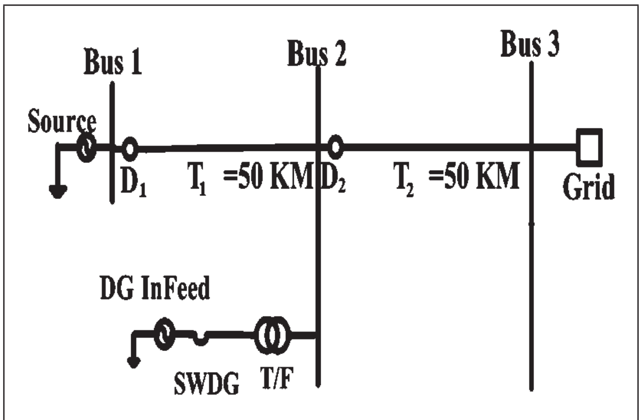

FIG. 3. A 66KV SUB TRANSMISSION TEST SYSTEM WITH DG AT BUS 2

Impedance of the T_1= 9.62 Ω

Zone 1 = 80% of T_1= 7.7 Ω

Zone 2 = 11.55 Ω

Zone 3 = 17.32 Ω

These settings are considered for an initial relay setting of test system without DG and it is considered to have Group A settings (refer Table 1).

3.2 Modelling of DG

DGs generally have capacities which can vary from 1 MW to 50 MW with voltage level from 1 kV to 50 kV. The net effect of DGs contribution to bus fault is first calculated and represented by an equivalent source.

3.3 Network impedances and zone settings

Transmission line length, impedance and zone settings are considered as per Figure 1. The performance of forward looking distance relay are analysed with and without in-feed conditions. Three zone settings of relay impedances are shown in Table 1.

TABLE 1

	GROUP A	GROUP B
Distance Relay	**Without In Feed**	**With In Feed**
Zone 1	7.7 Ω	7.7 Ω
Zone 2	11.55 Ω	14.78 Ω
Zone 3	17.32 Ω	35.56 Ω

Zone 1: From Table 1, it is observed that the relay D_1 has no problem in zone 1 operation, as in-feed has no effect on it. i.e. for the faults in zone 1, with and without in-feed will show same response as shown in Figure 4.

3.4 Fault at 75% of T_1 from bus 1

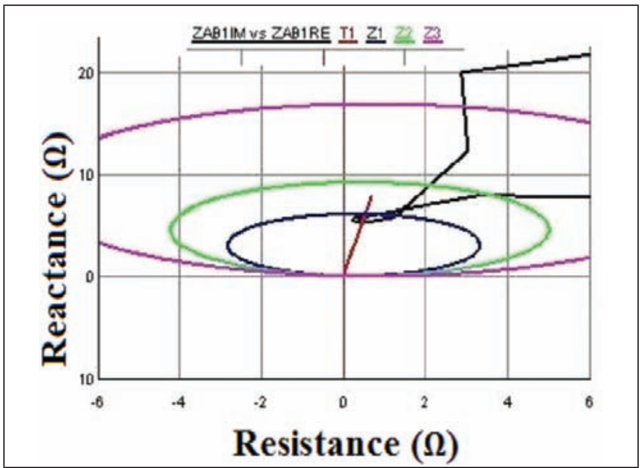

FIG. 4. FAULT AT 75% ON T_1

Figure 4 with relay set as Group A,the impedance locus for LLLG fault at 75% of line length on T_1, with and without DG doesn't effect the operation of relay D_1 tripping**.**

3.5 Fault at 15% of T_2

With the relay set as Group A and when DG is not connected, if the fault is applied at 15% of line 2, relay measured impedance is exactly equal to 100% of T_1 + 15% T_2.

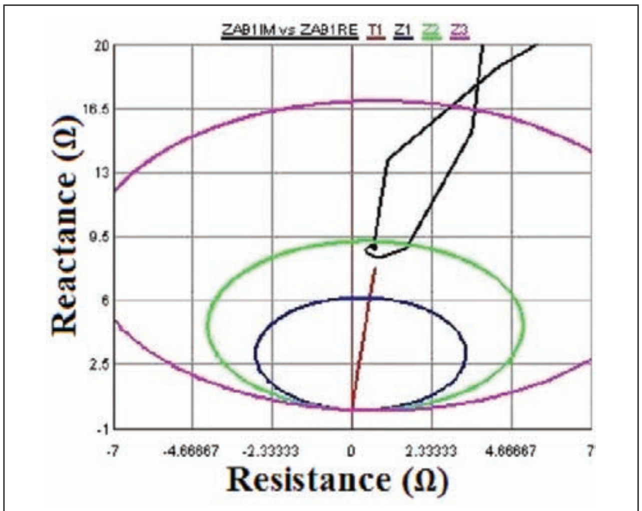

FIG. 5. FAULT AT 15% OF T_2 WITHOUT DG

Figure 5 shows impedance locus for LLLG Fault at 15% of line length on T_2

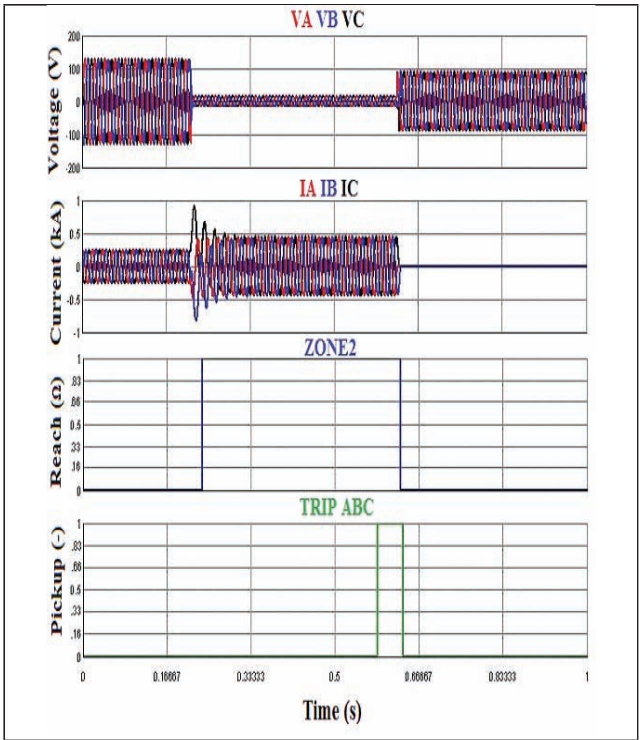

FIG. 6. FAULT AT 15% OF T_2 WITHOUT DG

Figure 6 shows the waveforms of PT voltages, CT currents, zones and trip signals under fault at 15% of T_2 without DG.

3.6 With DG

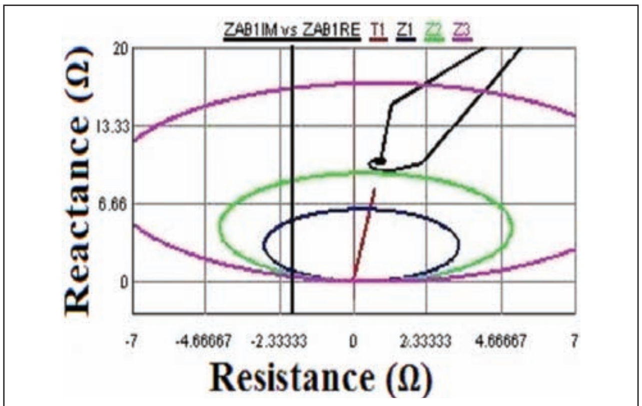

FIG. 7. FAULT AT 15% OF T_2 WITH DG IN-FEED

With the relay set as Group A and when DG is connected, the impedance locus seen by relay is shown in Figure 5, it is clear that relay measured impedance is more than the actual for the same fault at 15% of line 2, the relay measured impedance falls outside the zone 2 i.e., zone 3 introducing "under reach problem". The above problem is rectified by adopting separate group settings.

4.0 GROUP SETTINGS

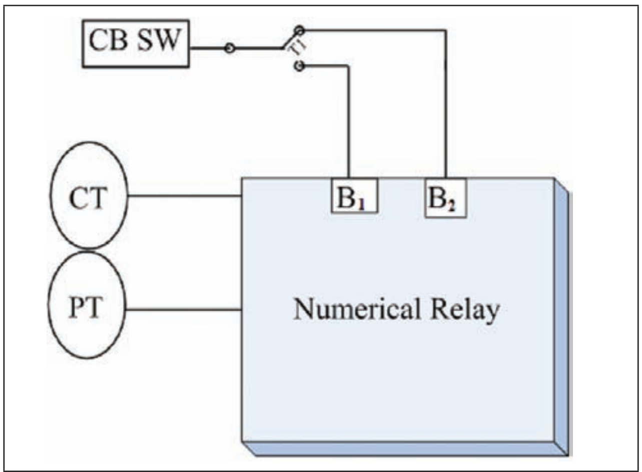

FIG. 8. NUMERICAL RELAY SCHEMATIC DIAGRAM

Figure 8 shows the schematic diagram of a numerical relay where CT represents current transformer, PT represents potential transformer, B_1, B_2 represents binary inputs and CBSW represents circuit breaker switch.

The status of the DG breaker is given by the circuit breaker switch CBSW. CBSW status is assigned as binary digit (0, 1) from RTDS™ to the relay input contacts through a cable and these binary input contacts which indicate the status of breaker. There will be four group settings namely Group A, B, C and D which can be opted with binary inputs B_1 and B_2 (0/1 states). Any one of the group settings can be chosen in the relay, based on breaker status, it is to be noted that only one group can work at a time. i.e. B_1 is ON when CBSW is 0 and B_2 is ON when CBSW is 1.

The new group setting B is programmed in relay which is selected when there is in-feed from DG. Once the CBSW i.e. DG breaker status is given to the relay and CB is closed, the Group B settings becomes active and the relay operates in zone 2 for the same fault at 15% at T_2 with DG as shown in Figure 7. The decision of selection of Group A or B is termed as adaptive approach [4][5][7] in this protection scheme.

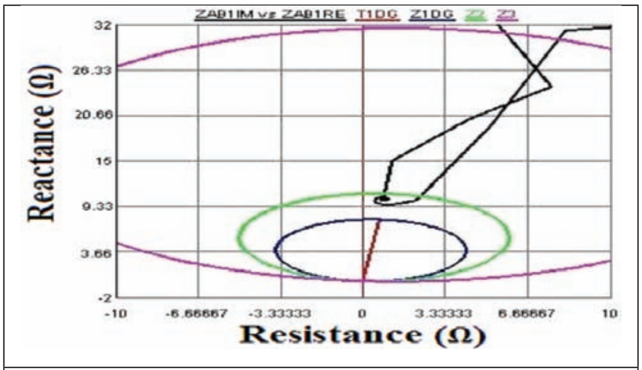

FIG. 9. FAULT AT 15% OF T_2 WITH GROUP B SETTINGS

Figure 9 shows the impedance locus for fault at 15% of line length with LLLG fault on T_2 in Zone 2, which was earlier having the problem of under reach shown in Figure 7 has been solved.

4.1 Over reach

When Group B settings is active in the relay and if the DG in feed is cut down the relay will undergo over reach [8] is shown by the following fault conditions. Fault at 40% of line 2 without DG in-feed and with Group B settings is shown in Figure 10.

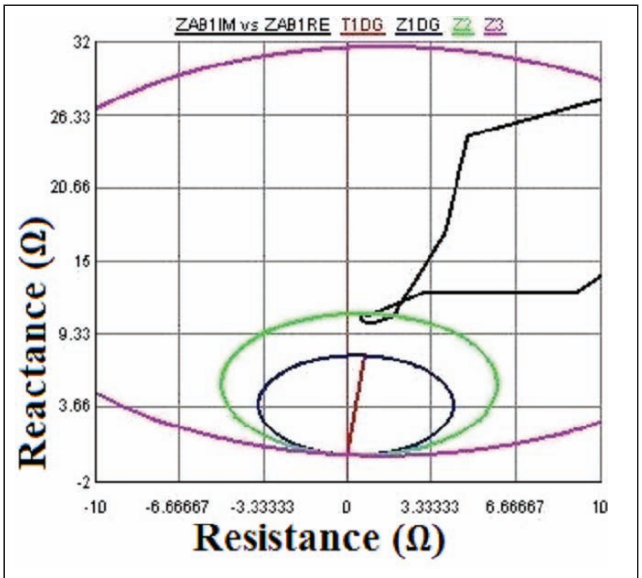

FIG. 10. FAULT AT 40% OF T_2 WITH GROUP B SETTINGS IN THE RELAY

The impedance locus during the fault is super imposed on the relay characteristic and it is shown in Figure 8. This is due to relay over reach, which can be overcome by communicating DG breaker status to the relay through binary inputs and relay activates Group A settings.

The operation is explained with the help of flow chart is shown in Figure 11.

4.2 Flowchart of adaptive relay settings

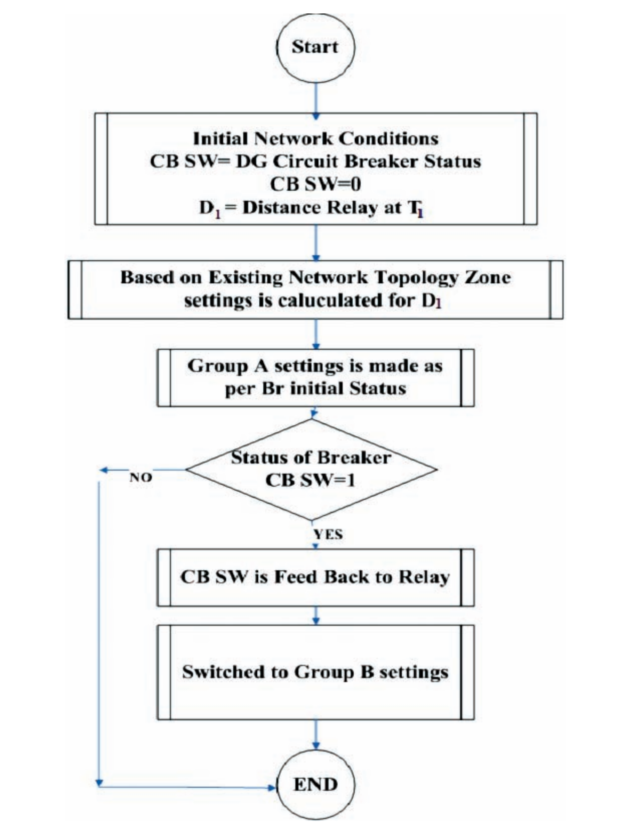

FIG. 11. FLOW CHART OF ADAPTIVE RELAY SETTINGS

By switching between two groups settings over and under reach problem can be resolved.

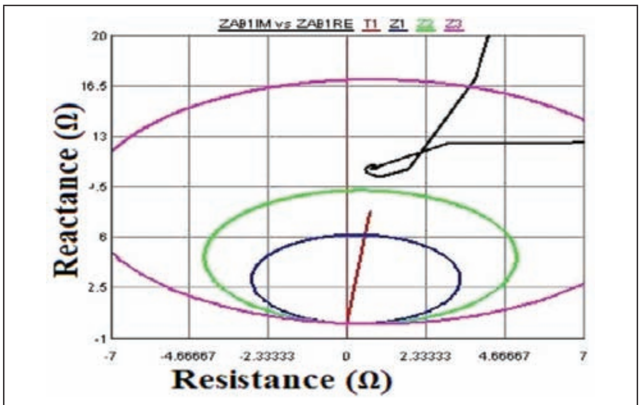

FIG. 12. FAULT AT 40% OF T_2 WITH GROUP B SETTINGS IN THE RELAY

5.0 CONCLUSIONS

This paper presents a novel approach on adaptive distance protection scheme using numerical relay in a medium transmission system with single in -feed of DG. A sample transmission network is taken where a DGs in-feed capacity of 2 kA is fed during fault. As DGs penetration is not constant in terms of in-feed range, multiple group settings are adapted. With the circuit breaker status communication to the relay and adoption of settings based on the circuit breaker status the adaptive nature of the relay is justified.

It is found that due to this adaptive approach and the group settings adopted,under reach problem of zone 2, i.e., 14.78 Ω which is measured by D_1 relay undergoes blinding of protection is rectified to original settings of 11.55 Ω and also over reach of relay in zone 3 i.e. 35.56 Ω instead of covering 17.32 Ω under no in-feed of DG results in mal-operation is also rectified. This proposed method is visualized with the help of simulations and the elimination of over and under reach problems are demonstrated.

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