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A Novel Relay used for Fault Detection and Isolation in Distribution Networks Containing of Several DGs

Karthikumar K [1], Senthilkumar V [2], Karuppiah M[3] , Rajakumari B[4] Arunbalaj A[5]

[1,3,5]Assistant Professor/EEE,Veltech, Avadi,Chennai-600062
[2]Associate Professor/EEE, College of Engineering, Guindy, Anna University, Chennai
[4]Assistant Professor/EEE,Velammal Institute of Technology,panchetti,Chennai-601204

Abstract—**Presence of Distributed generators (DGs) in the Distribution network using overcurrent relays for protect the Distribution network is a challenging task because of the changes in fault current levels and reverse power flow. Especially, in the presence of current limited converter interfaced DGs, using overcurrent relays are may fail to detect and isolate the faulty section while it is grid connected or islanded mode of operation. In this paper a novel Inverse type relay is presented here to protect a distribution network, which may have several DG connections. The characteristic of this new relay is designed based on the measured admittance value of the protected line. ITA relay is capable of detecting faults under changing fault current levels. The novel relay performance is valuated using PSCAD simulation.**

***Keywords*— Normalised admittance, Relay grading, Relay reach setting, Distribution System, Distributed Generation, Protection, Unsymmetrical fault.**

I. INTRODUCTION

The electrical distribution networks are radial and the current flow from substation to customers in a unidirectional manner [11]. In the radial distribution system, the maximum available fault current is at the substation bus or feeder source, and the fault current decreases with distance from the substation source due to the Effects of feeder line impedance. Protection scheme for distribution system, mainly consisting of fuses and reclosers and, in some cases, relays in conjunction with circuit breaker, has traditionally been designed assuming the system to be radial.

The effect of DG on coordination will depend on size, type, and placement of DG [6]. The radial feeder configuration has been fully utilized to simplify protective relaying schemes in the existing conventional feeder protection systems, particularly resulting in simple relaying coordination between upstream and downstream protective devices. However, the presence of the DGs has basically changed the radial structure of the distribution circuit from the feeder protection point of view and as DGs being sources of fault currents, and the protection design advantages of utilizing radial flows of currents are lost. Fault conditions can cause serious hazards to people, high risk to normal power distribution operations damages to utility facilities, interruption of the customer services, etc. In general, the main advantages of radial configuration are its simplicity and being low cost. In radial configuration, the number of disconnecting devices reduces and design of a protection system is not complicated. Recently, great attention has been paid to applying Distributed Generation (DG) throughout electric distribution systems, and presence of these generation units results in not having a radial distribution network, consequently raises some problems such as losing coordination of protection devices.

Overcurrent (OC) protection is used to protect radial networks from faults. The DGs connection in a feeder can cause bidirectional power flow, so it is adversely affect protection coordination [2]. Depends upon the situation the fault current levels in the network will change. When the fault occurs in the system according to the IEEE standard 1547[13], DGs should be disconnected from the network. However such conditions are will reduce the system reliability, especially which the penetration level of DGs increases. Therefore new protection methods are required for DG connected distribution networks to improve supply reliability. Fault currents may be limited by the fault impedance to values that are comparable to high load current values and become undetectable by protective devices. High impedance faults present a challenge to setting of protective devices to detect and clear faults. Conventional overcurrent and distance protections may not reliably detect high-impedance faults.

II. KEY DEVICES FOR FEEDER PROTECTIONS

The following provides a brief description of three key devices used for feeder protections. They are protective relays.

An understanding of basic characteristics of these devices is essential for designing a practical protective relaying system.

Protective Relays: Relay is a device that detects the abnormal condition in the electrical circuits by constantly measuring the electrical quantities in the line. During the fault condition electrical quantities are (current, voltage and/or phase angle) changed then sensors and operates contacts based upon predetermined criteria. These contacts are wired to the trip coil of a circuit breaker. A relay is also a control device to operate a circuit breaker after a pre-set time interval.

Instantaneous overcurrent relays: These relays respond to the magnitude of their input current. If the input current magnitude exceeds a specified flexible current magnitude, called the pickup current, then the relay contacts close instantaneously to energize the circuit breaker trip coil. If the input current magnitude is less than the pickup current, then the relay contacts remain open, blocking the breaker trip coil.

In this paper, a novel inverse time admittance (ITA) relay is presented [1]. The ITA relay utilizes the measured admittance of the protected line to identify a faulted condition in a network. It will be shown later that these relays are insensitive to fault current level. Therefore these relays can overcome the deficiencies of OC relays. The proposed relay performance is validated by PSCAD/EMTDC simulations.

III. DIFFERENCE BETWEEN OC RELAY WITH ITA RELAY

Several protection schemes have been proposed by researchers for DG connected distribution networks. However, most of them need a reliable communication medium. In [2] and [3], protection algorithms are proposed to locate a fault and isolate the faulty zone from the network. In [2], protection of the distribution network is achieved using neural network. In this, the system has different zones and the relay at the substation communicates with the zone breakers to take appropriate actions.

A current protection scheme based on communication to a multi-source distribution system has been proposed in [5]. Wide area measurement is used to decide the appropriate protection actions to locate the fault through the use of a communication channel. A method proposed in [6] is based on analyzing the sign of wavelet coefficients of the fault current transient to locate and isolate a faulted segment. In this, relay agents are proposed to implement the proposed protection scheme. A multi agent approach based on communication is proposed in [11] to facilitate coordination between different protective devices in the presence of DGs. However, the ITA relay presented in this paper is capable of operating without any communication amongst relays under changed fault current levels in a network. The comparison between OC relay and ITA relay is given below.

Consider the line segment in a radial distribution feeder as shown in Fig. 1. The node *R* represents the relay location, while *F is* an arbitrary fault point at distance *X* from the relay is denoted by node *F*. The IEEE standard inverse time OC relay tripping characteristic is given by [12].

$$t_p = \left[\frac{A}{M_I - 1} + B\right] \times TDS \qquad 1$$

Anywhere *A*, *B* and ρ the constants are used to select the relay characteristic curve, M_I is the ratio between the fault current seen by the relay and the relay pickup current and the tripping time is denoted by t_p. The time dial setting (TDS) is used for the coordination of the OC relays. Let the relay pickup current be denoted by I_p. Then M_I in (eqn. 1) is given by,

$$M_I = \frac{I_f}{I_p} \qquad 2$$

OC relay in the network, constants (*A*, *B*, *p* and TDS) are pre-determined and only depends upon fault current level only the M_I values will changes. Therefore M_I will lonely decide the OC relay tripping time. If the fault current I_f changes in the presence of DGs due to their intermittent nature, different relay tripping times can be experienced. Also, if these relays are used to isolate the faults from downstream side of a converter connected radial feeder, the fault may not be detected due to lower fault current levels.

Therefore, the settings of OC relays will be difficult due the intermittent nature of DGs. Let us assume that an OC relay is set to detect an upstream fault by lowering its pickup current. Nuisance tripping can then occur if the loads downstream from the relay are at their minimum, while the DG generation is at maximum.

To overcome the issue associated with faulted section isolation using conventional OC relays, either the relay settings should be changed continuously or a relay that is not dependent on fault current level should be used, depending on the DG connections. In this regards, the ITA relay, whose features are explained below, has a superior performance.

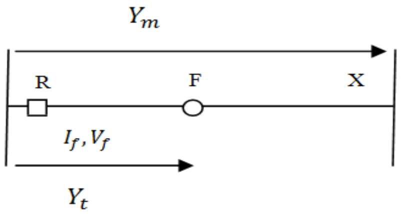

Fig. 1 Faulted line with relay

Instead of multiple of pickup current M_I, another quantity, called normalised admittance Y_r, which is not dependent on the network fault current level, it is dependent on the ratio of measured admittance and total admittance is introduced. The ITA relay characteristic is given by

$$t_p = \left[\frac{A}{{Y_r^{\rho}}_{f}-1}+K\right] \qquad 3$$

Where A, ρ and k are constants and Y_r is the normalised admittance, which is defined as

$$Y_r = \left|\frac{Y_m}{Y_t}\right| \qquad 4$$

Where,

Y_t = total admittance of the protected line segment,

Y_m = measured admittance between the points R and K (see Fig. 1).

The voltage at the relay point, corresponding to the pickup current I_p , is defined as V_p. To obtain the same sensitivity for the ITA relay as that of an OC relay, the total line admittance should be set to the admittance given by I_p and V_p. The normalised admittance can be expressed for the feeder shown in Fig. 1 as

$$Y_r = \frac{Y_m}{Y_t} = \left(\frac{I_f/V_f}{I_p/V_p}\right) \qquad 5$$

Equation (2) and (5) we attain

$$Y_r = \frac{M_I}{M_V}, \text{ Where } M_V = \frac{V_f}{V_p} \qquad 6$$

M_V can be defined as the multiple of pickup voltage. Note thatM_V, 1 when a fault occurs in the system. It can be seen from (6) that the ITA relay uses both current and voltage multiples instead of only current-based multiple used in OC relays. As a result, an ITA relay detects faults effectively irrespective of the available fault current in the network.

The constants in the ITA relay characteristic can be chosen according to the required fault clearing time and coordination requirements. However, the normalised admittance should be greater than 1.0 for relay tripping. This implies that the measured admittance is greater than the total admittance during a fault, that is

$$Y_r > 1 \Rightarrow \left|\frac{Y_m}{Y_t}\right| > 1 \ \Rightarrow |Y_m| > |Y_t| \qquad 7$$

The ITA relay reach can be set by choosing a suitable value for Y_t. For a particular relay, different values of Y_t can be assigned to generate a number of required zones.

The ITA relay has different types of protection elements such as earth elements and phase elements to detect different types of faults. All elements are designed to operate based on the measured admittance of the protected line. Any upstream relay always provides the backup protection for the immediate downstream relay. A detailed description of ITA relay fundamentals, relay grading and relay reach settings is given in [11].

The ITA relays use directional elements [13] to differentiates current levels, thereby allowing DGs to supply power to unfaulted sections either in grid-connected or islanded mode of operation. PSCAD Simulation studies are conducted to evaluate the novel ITA relay performance and how the DGs are operating without the affection of fault.

IV. SIMULATION RESULTS

The novel ITA relay can isolate a faulted section under high and low fault current levels. Relay can also respond under changing fault current levels, thereby allowing DGs to supply power to unfaulted sections either in grid-connected or islanded mode of operation. Simulation studies are conducted to evaluate the ITA relay performance of fault isolation and without any affection in DGs [13].

A. FAULT ISOLATION IN A RADIAL FEEDER CONTAINING DG'S

After fault occurred in the distribution system it must be quickly detect and disconnect from system, Therefore the faulted section isolation using ITA relays is investigated for different fault current levels. Consider the radial feeder containing three DGs as shown in Fig. 2 and Fig. 3. The system parameters are given in Table 1. It is assumed that all the DGs are connected to the feeder. But all DG's are always may not be connected in distribution system. The ITA relays R1, R2 and R3 are located at BUS-1, BUS-2 and BUS-3, correspondingly. The relay reach settings and tripping characteristics for each zone are given in Table 2.

The relay response is observed by creating single line to ground (SLG) faults at location between Bus 2 and Bus 3 along the feeder. Results are obtained through PSCAD simulation. The ITA relay response is observed by changing the DG connectivity to the network since all the DGs may not be connected all the time. The fault clearing time of respective relay(s) for a SLG fault with fault resistance of 0.01Ω is listed in Table 3 and duration of the fault is 0.05sec.

ITA relays are capable of isolating the faulted section in the feeder from both upstream and downstream side irrespective of the number of DGs (SCIG) connected. After successful fault isolation, DG's supply power to the unfaulted sections without disconnecting from the feeder.

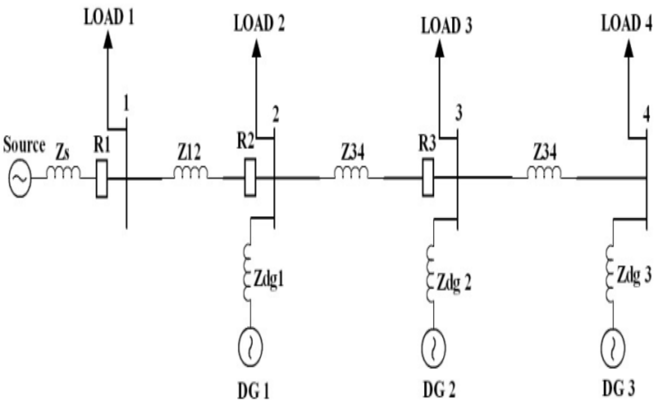

Fig. 2 DG connected radial distribution feeder

TABLE 1 SYSTEM PARAMETERS

System Data	Value
System frequency	50 Hz
Source voltage	33kV rms (L-L)
Source impedance(Z_s)	0.078 + j0.8634 Ω
DG's impedance (Z_{DG})	0.39 + j3.927 Ω
Feeder impedance$(Z_{12} = Z_{23} = Z_{34})$	0.585 + j2.9217 Ω

TABLE 2 DG'S PARAMETER

DG's Data	Ratings
Grid voltage	33kV
Each DG's Power output	200kW
Load Power	100kW,200kW,300kW

B. *PSCAD SIMULATION DIAGRAM FOR 4 BUS TEST SYSTEMS*

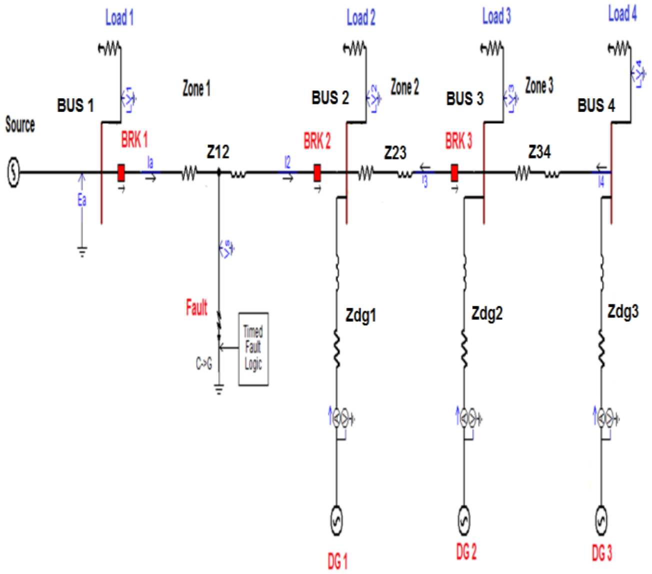

Fig. 3 Simulation Diagram for Radial Distribution Feeder with DG's

TABLE 2 RELAY REACH SETTING AND TRIPPING CHARACTERISTICS FOR EACH ZONE

Relay zone	Tripping characteristics and reach
Zone - 1	$Y_{t1} = \frac{1}{1.2 \times (0.585 + j2.9217)}$ $t = \frac{0.0037}{Y_r^{0.2} - 1} + 0.02$
Zone - 2	$Y_{t1} = \frac{1}{1.2 \times (0.585 + j2.9217)}$ $t = \frac{0.003}{Y_r^{0.04} - 1} + 0.02$
Zone - 3	$Y_{t1} = \frac{1}{1.2 \times (0.585 + j2.9217)}$ $t = \frac{0.0037}{Y_r^{0.04} - 1} + 0.02$

C. *FAULT CURRENT AND VOLTAGE FROM GRID AND DG'S*

The SLG fault occurred at the middle of the busses 1 & 2, 2 & 3, 3 & 4 the ITA relay tripping time is shown above; let us consider the fault between Bus 1 & Bus 2. Fault is near to the main grid and slightly more distance between the DG's compare to the Grid. After the fault occurred in the middle of the busses instantaneously grid is affected and supplying enormous range of current 18.5kA Fig. 4 shows below. Furthermore the three DG's affected and DG 1 is got more interruption of the fault and three Wind sources are supplying more current(Fig. 4) for the particular phase fault current is 12.5kA. When the fault will occur in the DG's connected Distribution system instantaneously the particular faulty zone and particular faulty phase the current increase enormous value and voltage is zero Fig. 4 and 5 shows below.

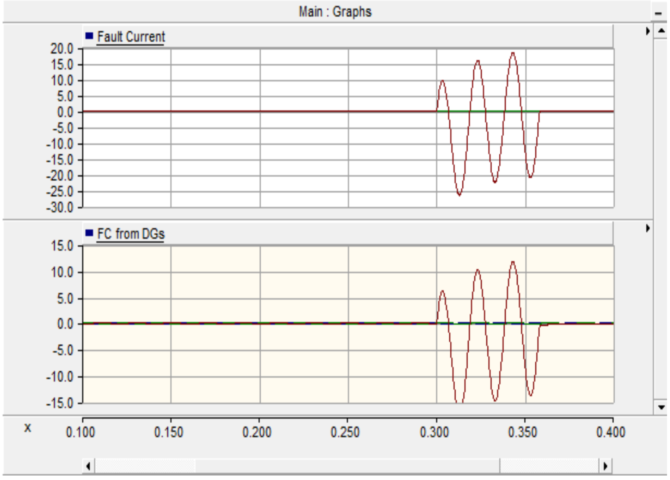

Fig. 4 Fault current waveform from grid and DG's

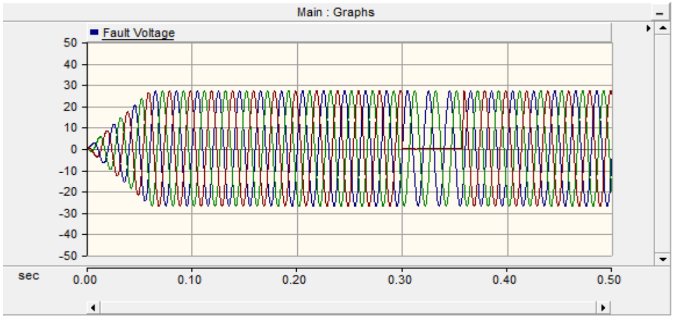

Fig. 5 Fault voltage waveform between the bus 1 & 2

After the fault condition current flowing through faulted phase is increased more for the particular line at the time of fault instant, same time voltage is very low or zeros in that particular phase Fig. 5 shows.

D. IMPEDANCE VARIATION OF DURING THE FAULT CONDITION

However, basically when the fault will occur in any transmission & distribution system, instantaneously at the time of fault condition impedance of the particular line is very low or nearer to zero Fig. 6 shows. Impedance is nearer to zero and then admittance is high at the time of fault duration Fig. 7 shows below. Here the duration of the fault is 0.05sec manually given in PSCAD simulation.

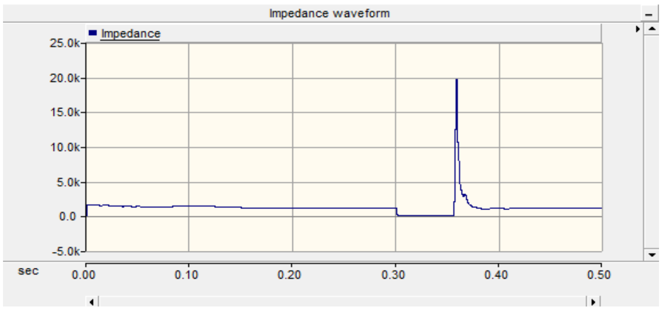

Fig. 6 Impedance waveform for during the fault condition

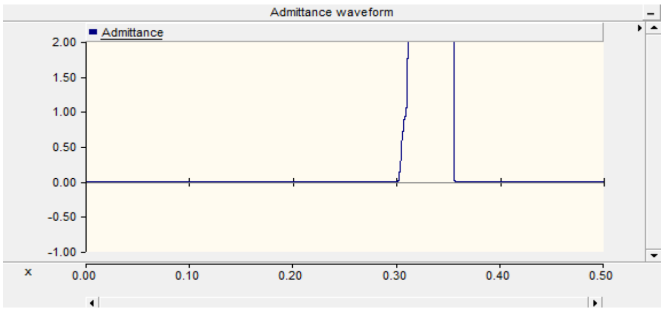

Fig. 7 Admittance waveform for during the fault condition

E. CIRCUIT BREAKER OPERATION FOR FAULT ISOLATION

The novel ITA Relay is detect the fault and supply information to the circuit breaker initiate the operation of circuit interruption and isolates the defective section from the rest of system. The below waveform represents the relay 1 give the tripping signal to the circuit breaker 0.037sec fig. 8 and Relay 2 tripping time is 0.040sec fig. 9.

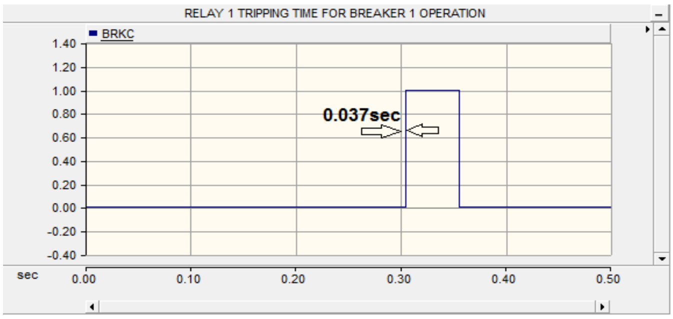

Fig. 8 Relay 1 response for a fault between BUS-1 and BUS-2

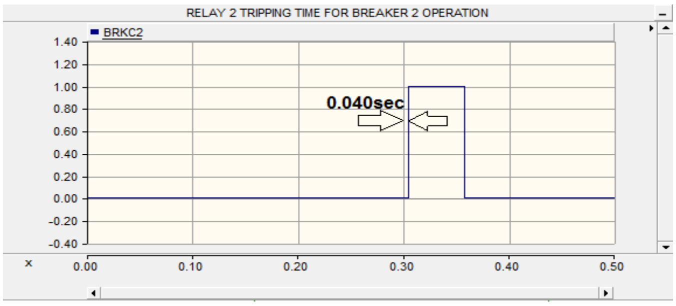

Fig. 9 Relay 2 response for a fault between BUS-1 and BUS-2

F. DG's Reaction Of After The Fault Isolation

Below the graph Fig. 10 and 11 represents the DGs supplying voltage and current of after the successfully fault isolation in feeder. Vs1, Vs2 and Vs3 denote the output of DG 1, DG2 and DG 3 supplying voltage waveform without any interruption of during the fault time at 0.30sec. The three DG's are continuously generating the power supplying to the Distribution network without any interruption of the fault.

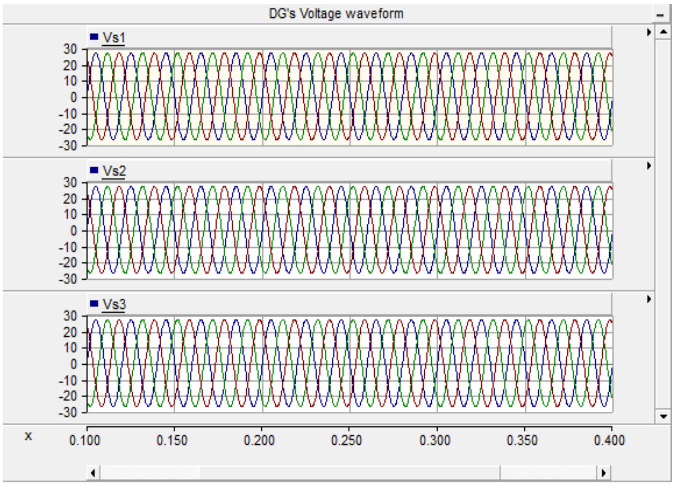

Fig. 10 Dg's voltage waveform for during the fault condition

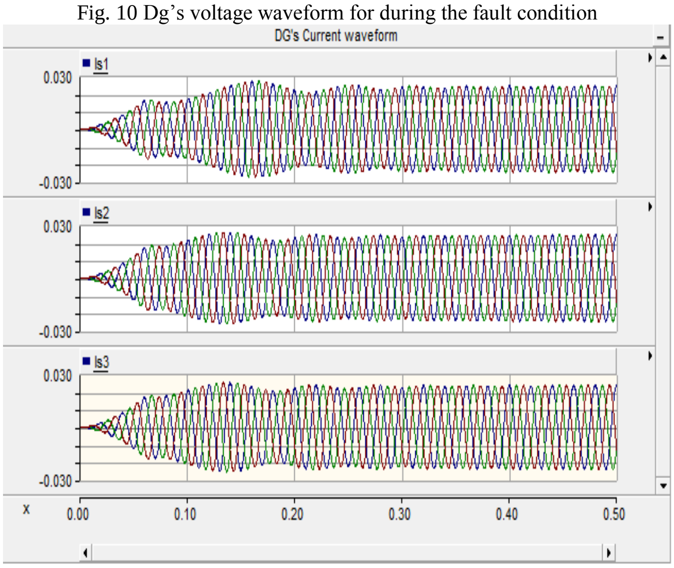

Fig. 11 Dg's Current waveform for during the fault condition

TABLE 3 ITA RELAY RESPONSES FOR DIFFERENT SYSTEM CONFIGURATION

Fault location	DG connectivity, sec		
	All DGs	DG1 and DG2	DG3 only
Bus 1 and Bus 2	R1=0.037 R2=0.040	R1=0.037 R2=0.040	R1=0.043 R2=0.050
Bus 2 and Bus 3	R2=0.038 R2=0.045	R2=0.045 R3=0.046	R2=0.045 R3=0.046
Bus 3 and Bus 4	R3=0.045	R3=0.044	R3=0.045

V. CONCLUSION

A novel inverse time relay characteristic fundamentally based on the measured admittance at relay location is discussed in this paper. This proposed relay has a variety of advantages over the existing overcurrent and distance relays. The relay has the ability to isolate the faulted segment of the feeder form upstream and downstream side of the fault without affection of DG's.

Moreover these relays operate to isolate the faults under low fault current level environment having an inverse time characteristic nature. This will facilitate the network to operate in islanding operation increasing the reliability, if there is enough generation from DGs. Furthermore the relays ensure the protection in the islanding system conditions as well. To illustrate the effectiveness of the proposal, the new inverse time admittance relay performances are evaluated in a radial distribution network consisting converter connected DGs. Investigations have exposed that these relays have the ability to isolate both forward and reverse faults adequately based on measured admittance at the relay location.

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