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Study on Voltage Based Relay on Power Distribution System with DG

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Abstract

Under voltage and over voltage protection initially placed at generating stations. Voltage based protection is applied at power distribution system with or without distributed generations (DG). This paper first design of voltage based relay and it is tested to the distribution system similar of current based relay. When fault is associated distribution system, near of the fault sections magnitude of voltage going to down and simultaneously check of magnitude of current then voltage based relay make safe healthy system by tripping the faulty sections. From the source side to fault section voltage magnitude is higher to lower, In voltage based relay there is easy to control coordination because of voltage dip near to fault. If penetration of DG or not, isolated or grid connected does not effect to selecting fault voltage magnitude. Simulation outputs shows this method is more reliable, more selective with appropriate speed without changing of relay setting values. For the minimum operating time and coordination of voltage relay and current relay using genetic algorithm technique is used.

Keywords

Distribution system, Distributed Generation (DG), Voltage based relay

1. Introduction

The one-way power flow from the power grid down to the loads formed the basis of conventional protection schemes for radial distribution systems. Overcurrent relays, automatic reclosers, fuses, and circuit breakers are protective devices that are used from the beginning to the end of the use. These safety measures, however, could not be adequate to guarantee proper functioning in the new technology of distribution networks integrated by DGs. Conventional electrical distribution systems are radial in nature [1].

Overcurrent (OC), relays, reclosers, fuses, and circuit breakers are the protections that are most frequently utilized at this voltage level. The main purpose of electrical power system protection devices is to quickly identify and remove any unhealthy systems. [2]. Backup protection should be set up to eliminate issues caused by major protection system malfunction (fault in a relay or in breakers). Backup security may be offered at the same station or on nearby lines with a suitable time delay.

If the properties of the primary and backup relays satisfy the boundary limits, coordination between them is possible. In order to safeguard the electrical system from selective tripping, relay coordination is crucial. It also aids in calculating the delay time for all backup relays. To prevent any improper operation of the protective devices, the relay must trip for a failure in its area.

As per the thumb rule of the protection system, the relay should not trip for a fault outside its zone except to back up a failed relay or circuit breaker. Backup protection must be coordinated with primary protection such that the primary protection has sufficient time to remove the fault before the backup relay.

To Protection of the distribution system (DS) with distributed generation (DG) is a complex problem due to some issues including DG interface technology, daily change of DG output, and DS grid-connected or islanded (stand-alone) operational mode [3]. A voltage-based protection technique for distribution systems with distributed generating is presented in this proposed article (DG). An detailed investigation of voltage behavior under fault situations is used to develop a novel protective relay characteristic since every system fault is accompanied by a voltage dip at the ends of the damaged line. [4]. The proposed paper is independent of the type, size, and location of DG units, as well as grid-connected or islanded (stand-alone) mode of operation of the distribution system.

2. Methodology

Voltage based relay is first modeled in MATLAB SIMULINK. The voltage based relay is then tested in a 5 bus radial system for different fault conditions and for varying setup value of voltage relay. Then a full protection system is developed for 5 bus radial system, first considering only the voltage relay and then considering only the current relay. The performance of voltage relay and current relay are compared. Then, to study the effect of DG integration on the protection system, a DG is integrated into the network. The effect of DG on protection system is studied for both the voltage and current relay.

2.1 Modelling of Voltage Relay

The operation of voltage relay is dependent on the magnitude of the voltage at the relay location. The operation time of relay is defined by equation 1.

$$t = TDS \times (\frac{A}{(\frac{1}{K})^p - 1}) \times Log_2(\frac{1}{K})(\frac{1}{K}) + D \quad (1)$$

$$K = (\frac{V_{sc}}{2} \times (1 - \frac{V_{sc}}{2}))^m \quad (2)$$

V_{sc} is the fault voltage magnitude per unit based on the nominal voltage of the system, t is the total relay operating time, A, D, p and m are the constant parameters. TDS is the time dial setting. m and TDS value taken from optimization tools [5, 6].

To properly distinguish a fault condition from an undervoltage condition, a current starter is used. Current starter is used alongside the voltage relay. While voltage relay uses the voltage at the relay location for its operation, current starter uses the current value at the same relay location to distinguish fault current from load current and to distinguish a faulty section from a de-energized section. Inequality 3 and 4 are the conditions respectively used by current stater to restrain or allow the operation of voltage relay.

$$I_{CS} > I_r \times OF \quad (3)$$

$$I_{CS} < I_r \times OF \quad (4)$$

I_{CS} is the current seen by the current stater. I_r is the rated current flowing through the branch where the relay is located. OF is the overloading factor which addresses the possible overloading in the line. Voltage based characteristics curve is shown in figure 1.

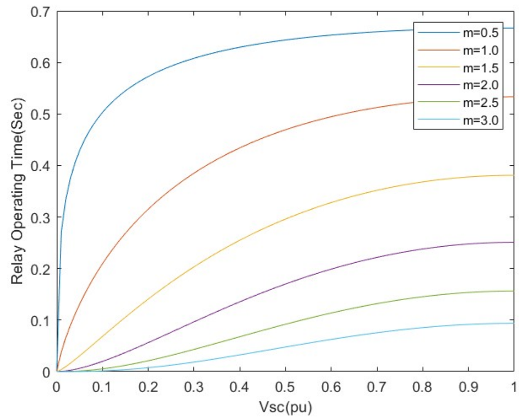

Figure 1: Voltage based characteristics curve

2.2 Protection Coordination on the Radial System

Five relay, each for the five bus is considered. The setup value of the relay is optimized with the objective of reducing the total operating time of the protection system while also maintaining the coordination between the devices for all fault condition. Equation 5 is the objective function used for optimization problem.

$$Min\ OT = \sum_{i=1}^{n} t_i \quad (5)$$

Here, OT is the total operating time of the protection system. t_i is the sum of operating time of primary and secondary relay for a fault at bus i. n is the total number of fault location considered. The objective is to minimize the total operating time of the protection devices. Inequality 6 is used to maintain coordination between primary and secondary relay.

$$t_{k,i} - t_{j,i} \geq CTI \quad (6)$$

Here, $t_{j,i}$ is the operating time of primary relay j for the fault at bus i and $t_{k,i}$ is the operating time of secondary relay k for the fault at bus i. For, current based relay the operating time of each relay is defined by equation 7.

$$t = TMS \times \left(\frac{k}{\left(\frac{I_{relay}}{PS}\right)^{\alpha} - 1} \right) \tag{7}$$

Here, TMS is the time multiplier setting of the relay. I_{relay} is the current seen by the relay. PS is the plug setting of the relay. k and α are the constants which define the operating characteristics of the relay. The value of k and α for different overcurrent relay are listed in table 1.

Table 1: k and α for different types of Overcurrent Relay

Curve Characteristic	k	α
IEC Standard Inverse Curve (SIC)	0.14	0.02
IEC Very Inverse Curve (VIC)	13.5	1
IEC Extremely Inverse Curve (EIC)	80	2
IEC Long time Standard Inverse Curve (LTSIC)	120	1

The TDS range for voltage relay is defined by equation 8. TDS_{min} is equal to 0.01 and the TDS_{max} is equal to 3. TDS_r is the TDS setup value for voltage relay r.

$$TDS_{min} \leq TDS_r \leq TDS_{max} \tag{8}$$

The m range for voltage relay is defined by equation 9. m_{min} is equal to 0.1 and the m_{max} is equal to 3. m_r is the TDS setup value for voltage relay r.

$$m_{min} \leq m_r \leq m_{i,max} \tag{9}$$

The TMS range for current relay is defined by equation 10. TMS_{min} is equal to 0.01 and the TMS_{max} is equal to 3. TMS_r is the TMS setup value for current relay r.

$$TMS_{min} \leq TMS_r \leq TMS_{i,max} \tag{10}$$

The PS range for current relay is defined by equation 11. $PS_{r,min}$ is equal to maximum load current seen by current relay r times the overloading factor (i.e. 1.6) and the $PS_{r,max}$ is equal to the minimum fault current seen by the current relay r during a fault condition. PS_r is the PS setup value for current relay r.

$$PS_{r,min} \leq PS_r \leq PS_{r,max} \tag{11}$$

The minimum operating time of relay is set to 0.08 seconds.

2.3 Genetic Algorithm

The survival of the fittest principle serves as the foundation for the genetic algorithm (GA) method to optimization. The GA is an evolutionary algorithm since it mimics the evolutionary processes. The weakest elements are eliminated while the strongest elements grow stronger in this process.

Genetic algorithm (GA) is used to solve the optimization problem. The setup value of relay is considered as the variable to be optimized using GA. The total operating time of the protection system is used as the fitness value for the GA. The protection coordination constraints is used as the constraints for GA. The upper and lower limit of the relay setup value is used to define the range of the value. For 5 relays with two setup value, a total of 10 variables are optimized using GA. The population size for each generation of GA is considered as 200. At each iteration (generation), 5%(10 individuals) are selected as elite population (10 best individual are passed to next generation unchanged), 76%(152 individuals) are obtained from crossover operation and 24%(38 individuals) are obtained from mutation operation. The maximum generation count for GA is 1000 and the fitness tolerance value for GA is 1e-6.

From the above figure 1 it is clearly shown that different values of m have different graphs, if we chose higher value of m slope of curve is more negative. With using different level of curve it is easy to selecting the minimum operating time with itself coordination. when fault is associated near at any place of distribution feeder nearer relay senses lower voltage magnitude and to send signal to circuit breaker for trip.

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3. Result and Discussion

The developed model of voltage relay is tested in 5 bus radial system in MATLAB platforms. For the test, two voltage relay is placed in bus 2 and 4. Two fault condition, triple line to ground fault at bus 3 and single line to ground fault at 5 is considered separately. The test setup is shown in figure 2. The SIMULINK model of voltage relay is as shown in Figure 3.

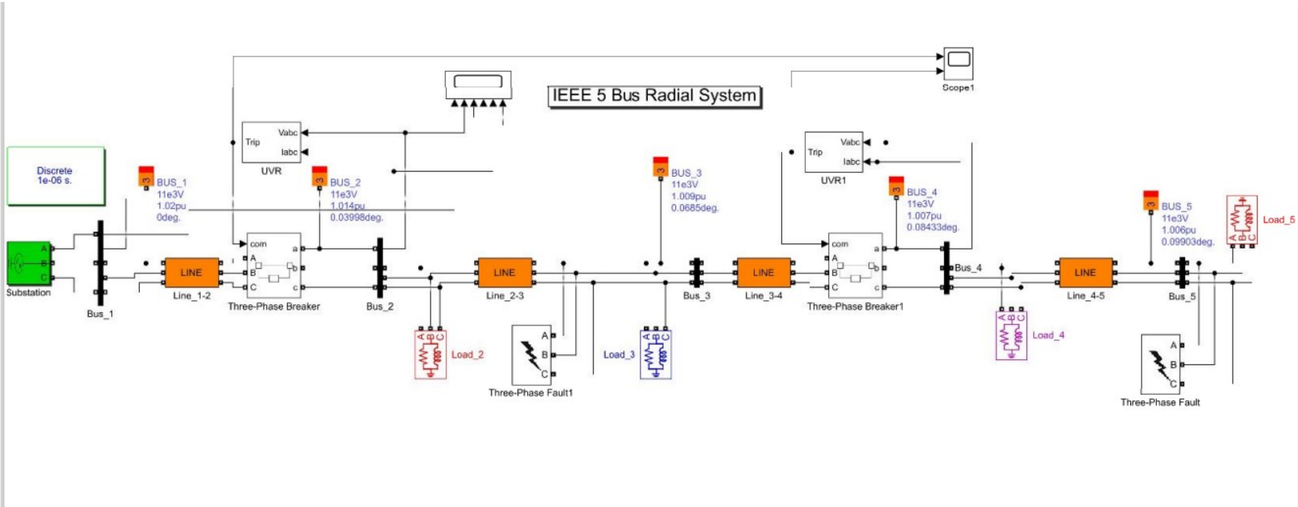

Figure 2: IEEE 5 bus distribution system without DG

3.1 Testing of Voltage Relay

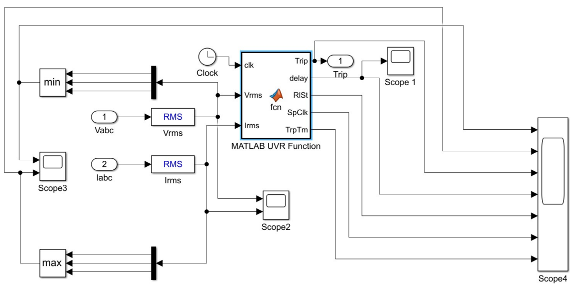

Figure 3: Developed voltage based relay

This relay senses voltage as well as current for better protection decision during fault condition. Voltage relay setting are as shown in table 2.

Table 2: Specification of voltage relay

Parameter	features
Under voltage threshold setting %	30
Nominal phase voltage	11KV
Over current threshold setting %	25
Frequency Hz	50
DDMT Setting (m)	2
DDMT Setting (TDS)	1

This setting values can be selected from the voltage relay as per requirements. Value of 'm' and 'TDS' taken from the using optimization algorithms for minimize the total operating time of voltage relay.

The test with integration of DG at bus 4 was also considered. A power inverter based DG of active power 300kW was added to the system at bus 4.

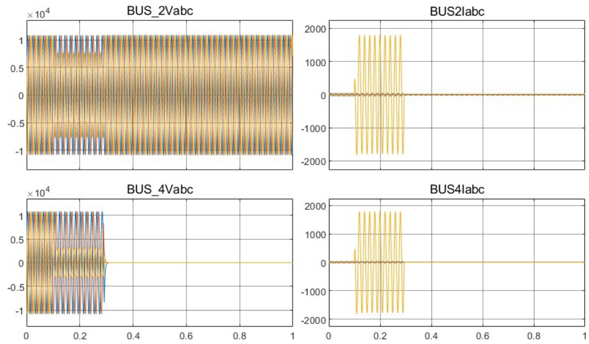

Figure 5: Voltage and current waveform after fault at bus 5

In figurer 5 shows the relay connected bus 2 and bus 4 voltage waveform can be seen clearly as well as corresponding current waveform after applied unsymmetrical line to ground (LG) fault at bus 5.

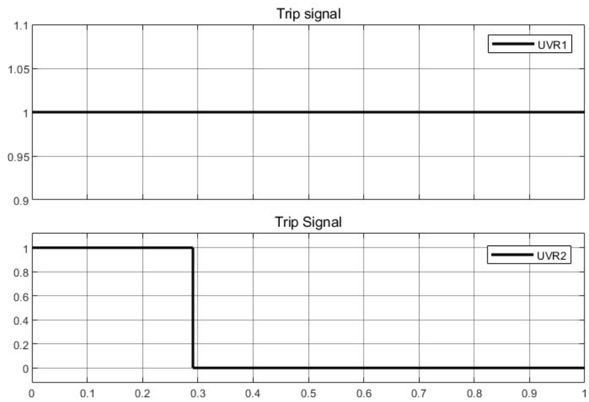

Figure 6: Trip signal of voltage relay 1 and 2 at bus 5

Two relay are connected bus 2 and 4, fault is applied

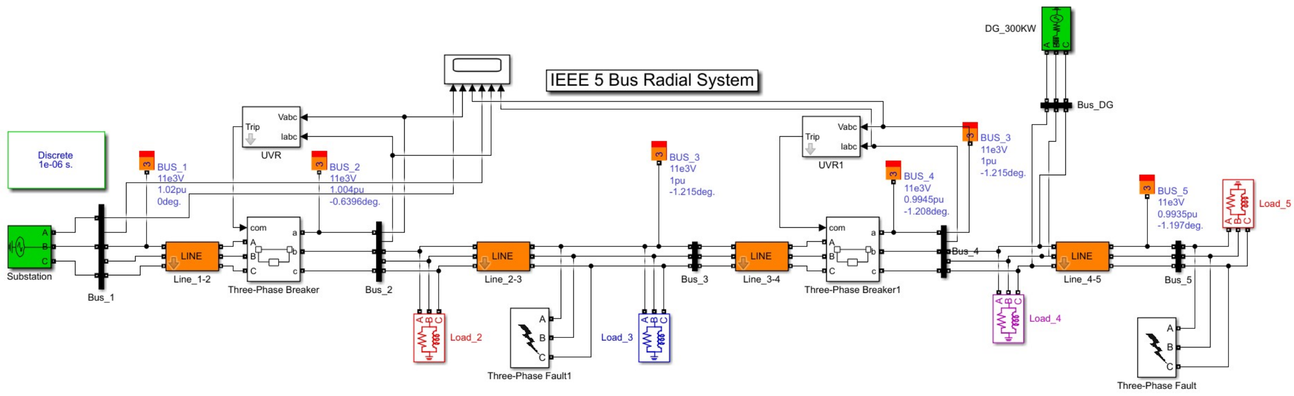

Figure 4: IEEE 5 bus distribution system with DG

far from the source at bus 5. The voltage relay bus 4 of fault at bus 5 is close to fault therefore magnitude of voltage very low as compare to the far relay. So there lowest voltage magnitude sensing relay send trip signal to circuit breaker. In figurer 6 having relay 1 no trip signal but relay 2 have trip signal.

Similarly other symmetrical and unsymmetrical fault are applied at bus 5, there same as LG fault of trip signal of relay but only difference is that wave form of voltage after fault.

After tested of voltage based relay on radial distribution system it is checked for the coordination. Made of voltage based relay 2 disable and fault is applied at bus 5. At that situation relay 2 must trip because having minimum voltage magnitude relay 1 but relay 2 is disabled so cannot covey signal to circuit breaker for trip. So relay 2 is primary relay and relay 1 is backup relay for this case. Relay 1 send trip signal to breaker as shown in figure 9, So it is worked for coordination system.

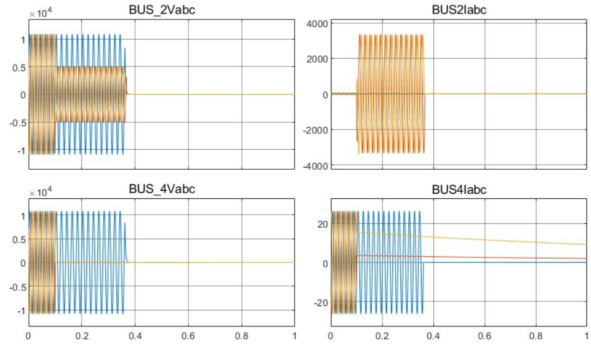

Figure 8: Voltage and current waveform after fault bus 3

In figure 8 shows the waveform of voltage and current of bus 2 and 4 after applied double line to ground LLG fault at location of bus 3. Trip signal of both relay as shown in figure 9, location of fault is near bus 2 therefore lower voltage magnitude sensing relay 2 send trip signal to circuit breaker. Here also all symmetrical and unsymmetrical fault are applied at bus 3 and trip signal results come as same.

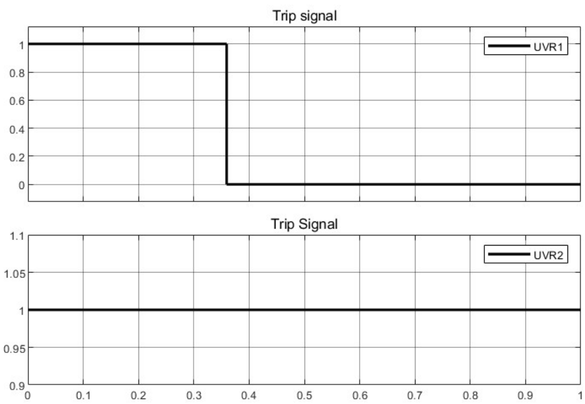

Figure 7: Trip signal of relay 1 and 2

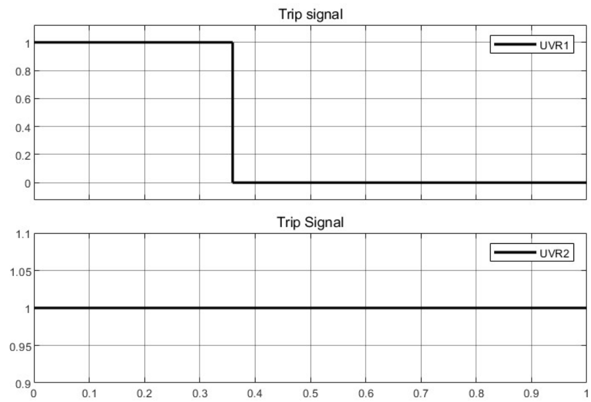

Figure 9: Trip signal of voltage relay 1 and 2 after fault at bus 3

Discussing the result of voltage relay tested with distribution system without DG means radial distribution system is that when fault is presents in electrical networks fault current magnitude goes very high as depends upon fault impedances at same time fault voltage magnitude goes very down than rated value. For the proper setting of relay with standard value and easy for understand fault voltage magnitude converted to the per unit basis, which changes only o to 1. From Figure 1 value of m is changes, there curve between relay operating time and fault voltage magnitude are also changes. It shows that when location of fault is far from the source from fault to fault voltage magnitude is increase, so this voltage relay first trips far end breaker then after comes near to near with sources.

As per same distribution system of Figure 2, a 300KW synchronous based distributed generation is penetrated with per phase line resistance (R) = 0.84111 ohm, per phase line impedance (L) = 0.82271 henry, line length is added on bus 4 for test of voltage based relay on distribution system.

With DG or without DG similar type of symmetrical and unsymmetrical faults are applied, voltage based relay protection is not applied yet on distribution system. For radial distribution system current time graded overcurrent protection also reliable but when connecting DG it has more difficult and malfunctioning effect due to scenario changes flow of current and contribution of fault current magnitude. A voltage based relay more reliable than overcurrent relay using DG conditions.

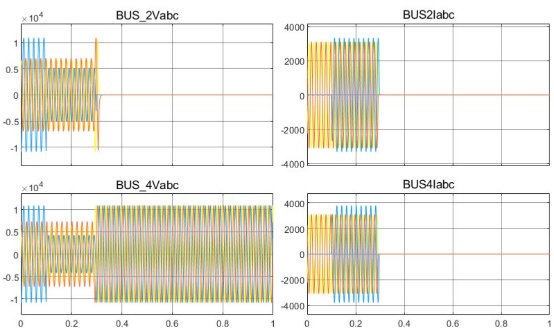

Figure 10: Voltage and current waveform after fault at bus 3 with DG

When LG fault at bus 3, fault current supply from one side grid and another side with DG as shown in figure 11. Both breaker must trip at this condition, because tripping one section but can supply from other section on fault area. First of all relay 2 senses lower voltage than first one, therefore second breaker send the trip signal and after fist breaker trip for fault isolation. After trip of second breaker DG continue supply the power to healthy part on isolating mode.

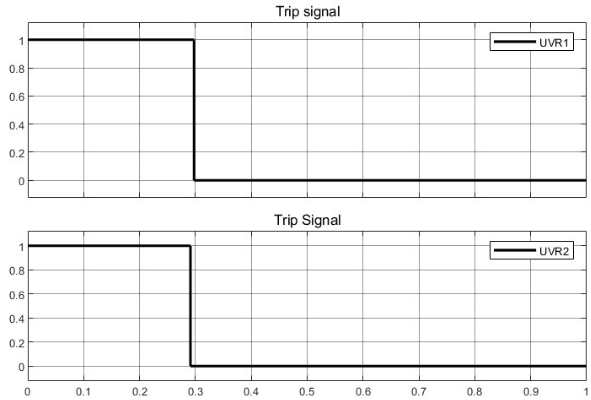

Figure 11: Trip signal of voltage relay 1 and 2 at bus 3 with DG

3.2 Protection coordination on radial distribution system

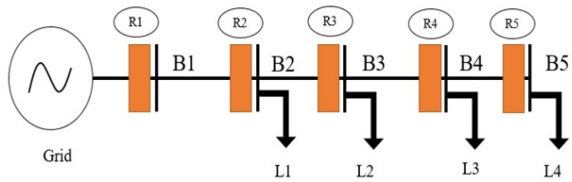

Figure 12: Comparison of total operating time for case without DG

Five relays R1 to R5 are connected every bus. Loads L1 to L4 is connected from bus B2 to B5 respectively. Fault F1 to F5 is also applied near bus B1 to B5 separately.

At first load flow and fault analysis is done for all cases and using GA optimization finding fitness value of total operating time relay for voltage relay and current IDMT relay all characteristics. Figure 13 shows the comparison of total operating time voltage relays and other IDMT characteristic. It shows that voltage relay operating time is lowest than other.

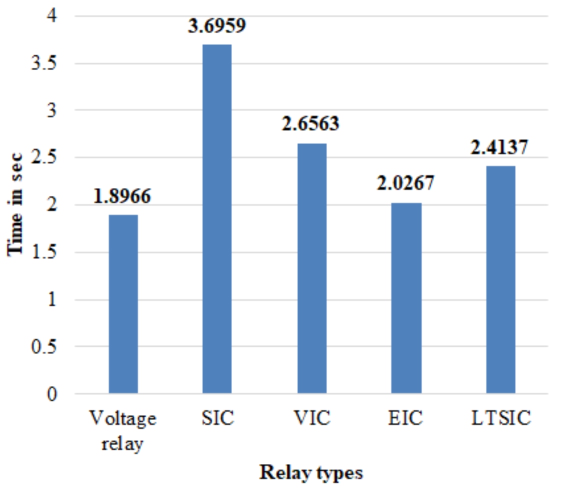

Figure 13: Comparison of total operating time for case without DG

The coordination table of voltage based relay and overcurrent IDMT very inverse relay is achieved in Table 3 and 4.

Table 3: Coordination table for Voltage Relay without DG

Fault Location	Primary Relay	Time in sec	Backup Relay	Time in sec
Bus 1	R1	0.08		
Bus 2	R2	0.08	R1	0.556
Bus 3	R3	0.08	R2	0.3758
Bus 4	R4	0.08	R3	0.2854
Bus 5	R5	0.08	R4	0.2801

Table 4: Coordination table for IEC VIC Current Relay without DG

Fault Location	Primary Relay	Time in sec	Backup Relay	Time in sec
Bus1	R1	0.1113		
Bus 2	R2	0.2847	R1	0.485
Bus 3	R3	0.3056	R2	0.5057
Bus 4	R4	0.202	R3	0.4021
Bus 5	R5	0.08	R4	0.2826

3.3 Protection coordination distribution system with DG

Its circuit is similar to the Figure 12 is but 84KW DG is added at bus 4 and again using GA optimization total operating time of voltage based relay is least time than other relays.But it is observed that very small time is more than without DG case. Its coordination is achieved of primary and backup relay of voltage relay and IDMT very inverse overcurrent relay are shown in Table 5 and 6

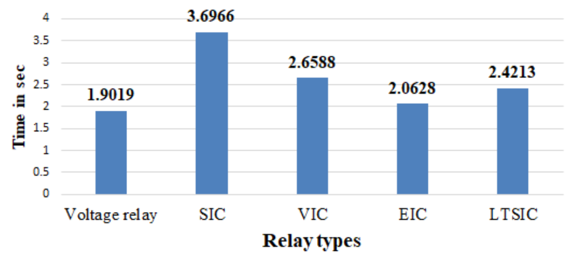

Figure 14: Comparison of total operating time for case with DG

Table 5: Coordination table for Voltage Relay with DG

Fault Location	Primary Relay	Time in sec	Backup Relay	Time in sec
Bus1	R1	0.08		
Bus 2	R2	0.08	R1	0.556
Bus 3	R3	0.08	R2	0.3758
Bus 4	R4	0.08	R3	0.2854
Bus 5	R5	0.08	R4	0.2848

Table 6: Coordination table for IEC VIC Current Relay with DG

Fault Location	Primary Relay	Time in sec	Backup Relay	Time in sec
Bus1	R1	0.08		
Bus 2	R2	0.1442	R1	0.3443
Bus 3	R3	0.2115	R2	0.4116
Bus 4	R4	0.1532	R3	0.3533
Bus 5	R5	0.08	R4	0.2847

4. Conclusion

This paper conclude that the module of voltage based relay used in power distribution system worked properly.This techniques or method is validated both connected DG or without DG conditions and also mode of operation. Main conclusioin are:

- Many methodologies and different algorithms are researched to minimize the relay operating time of overcurrent relays. This thesis also concludes that voltage-based relay total operating time is minimum than overcurrent relays' IDMT characteristics.

- With or without the connection of distributed generation, the magnitude of the fault voltage changes from 0 to 1 per unit, making it simple to control protective relays.
- Large investments are required for distribution system automation for communication accessories and pieces of equipment, voltage based protection can be used for the communication-less method.
- This proposed method use of simple and low-level calculations.
- The results show that this method is selective with appropriate speed under different fault conditions.

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