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Intelligent Protections Strategy For A Complex Micro grid Network Using Adaptive Relays and Detailed Comparison With Unidirectional, Bidirectional relays on different scenarios

Priyanka Baghel
Email: baghelpriyanka31@gmail.com
Department of Electrical & Electronics Engineering UIT RGPV, Bhopal

ABSTRACT

Protection relays are critical aspect of any power system. Relay coordination is an important aspect in the protection system design as coordination schemes must guarantee fast, selective and reliable relay operation to isolate the power system fault sections. Traditionally non directional over current relays are used to isolate fault sections. When connected in radial distributions systems, DGs can affect both current magnitude and direction. Traditional protection system assumes the flow of power from upstream to downstream systems. Upstream here includes major power generation units like power stations, while downstream system includes distribution system and consumer loads. DGs affect this profile because they can both act as energy source or energy consumer. Hence traditional protection will fail and cannot be used in case DGs are connected to distributed system.

In our work we have proposed various techniques to solve these potential problems due to introduction of DGs. We have considered an islanded micro-grid and proposed a strategy to use Micro-processor based intelligent programmable relays in order to solve protection problems. In order to test the effectiveness of our proposed solutions we have chosen a test case based on IEEE std. 1547.4 [19].we are proposing the combination of bi-directional and smart Relays which can communicate with each other to know the status of plug and play DGs and Loads. This information is used to adaptively adjust the pickup current and other parameters of time delay functions. We have considered different fault conditions and different connected DGs and Loads scenarios. Exhaustive simulations were carried and results were presented. It was concluded that Adaptive Bi-directional relays outperforms all other types are very effective to trip in all possible fault conditions and in different possible scenarios.

Keywords: Distributions Generation, Micro grids, Protection relays, Smart Adaptive Relays

I INTRODUCTION

International energy policies are strongly promoting the development of Renewable energy sources (RES) and Energy efficiency technologies. Most of these power plants, RES and Combined heat and power (CHP) are connected to distribution networks and are known as distributed generation or simply DG [1]. Distributed energy resources (DER) refers to electric power generation resources that are directly connected to medium voltage (MV) or low voltage (LV) distribution systems, rather than to the bulk power transmission systems. DER includes both generation units such as fuel cells, micro-turbines, photo-voltaic, etc., and energy storage technologies like batteries, flywheels, superconducting magnetic energy storage, to mention but a few.[2] These systems, together with solar photovoltaic (PV) modules, small wind turbines (WTs), other small renewable (such as biogas digestors), heat and electricity storage, and controllable loads are expected to play a significant role in future electricity supply. These technologies are herein collectively called distributed energy resources (DERs). [3] Integrating DG into an electricity network, especially close to load centres, has many significant benefits but also brings with it many drawbacks such as voltage drop, and power losses [4]. The direction of power flow in distribution networks was almost always from the higher to the lower voltage levels [5]. for a particular fault, all the relays connected in the radial feeder sees the fault current but are made to operate at different times by selecting different time current characteristics through relay settings [6]. Microgrids are defined as low voltage (LV) or in some cases, e.g. Japan, as medium voltage (MV) networks with distributed generation (DG) sources, together with storage devices and controllable loads (e.g. water heaters, air conditioning) with a total installed capacity in the range of few kWs to couple of MWs [7]. The installation of DG close to loads will reduce flows in transmission and distribution circuits with loss reduction as a consequence [8]. “Microgrid” is a collection of loads and microgenerators along with some local storage [9]. In [10], Authors have examined some of the most important economic benefits brought about by DG. The successful development of micro generation depends on the regulatory framework defined for its operation, including the economic regulation [11] [12].

An overview of several methodologies which have been adopted to solve optimization problem in distributed Generation in order to maximize benefits is discussed in [13]. In radial networks the magnitude and direction of current changes than originally predicted. This causes malfunction of traditional over current relays. [20-22]. Protective coordination of overcurrent relays applied in distribution systems with DGs becomes very difficult to achieve because it lacks the flexibility of adaptive relay setting for changes of the network configuration and of the operational status of wind generators. [22-27] DG is generally interconnected into the distribution network [28], which is traditionally a single-source network. As a result, the original operation and control of the relay protection in distribution network will malfunction [29]. [30] concludes that the interconnection of DG will cause changes to amperage, direction, and time duration of the short-circuit current. [31] considers that the various impacts of DG on the behavior of relay protection, including incorrect tripping, relay de-sensitization or even trip failure, mainly depend on the interconnecting positions.

II Problem Description

Definite time overcurrent and inverse time overcurrent protection are popular for protection of micro-grids. However for coordination between primary and secondary over current relays, inverse time protection is considered more appropriate. Time delay function is defined to calculate delay time as shown below:

$$t = K * \left(\frac{A}{\left(\frac{I_f}{I_{pick}}\right)^p - 1} + B \right)$$

Where K, A, B and p are constants while t is delay time. Ipick is the threshold current above which relay will trip the faulted circuit after a time delay. This time delay t is calculated by equation shown above. Delay time will be shorter if fault current is much higher than pickup current Ipick. Backup protection is always installed in the case primary protection fails to trip due to any failures. This secondary protection always have time delay longer than primary protection which makes sure that for same fault current primary protection trips first. Effectively secondary protection will only trip if primary protection fails. The gap between primary protection and secondary protection relays is called Coordination time interval (CTI). It is essential to carefully design this CTI. In the subsequent part we are highlighting different reasons which leads to failure of conventional protection relays.

DGs may connect or disconnect to a distribution system in a plug and play manner. This may significantly alter both magnitude and direction of currents. Traditional protection schemes assumes unidirectional current flow. In traditional protection scheme, it is assumed that same current will flow from primary and secondary protection. While in case of DGs the direction and magnitude of current may change. It may be possible that primary protection and secondary protection may see different levels or even different directions of currents. Hence they may malfunction in such scenario.

Similarly loads may also connect to the system in a plug and play manner thereby affecting the current levels. This will in turn affect the settings of pickup currents. Which means if a load is not connected, Ipick current should be say I1. While if load is connected Ipick value is I2 where I1 < I2. So in case when load is not connected, Ipick remains equal to I2 and fault current is between I1 and I2, protection relays will not trip. If we keep Ipick = I1, then in load connected mode a safe current less than I2 may also triggering tripping of protection relays. Overall we can conclude that if the plug and play states of DGs and loads are not known, it is difficult to decide ideal Ipick values to take care of all possible fault scenarios. As a result reliability and sensitivity of protection system can be compromised.

High impedance fault is another problem where traditional protection fail to trip. High impedance fault mostly occurs when power is delivered to remote areas, like remote villages or remote industries. In such conditions, fault current may be too low to trip traditional protection relays or may results very long time delays. Many scenarios is such case leads to failure of traditional protection in different use cases.

Another problem with DGs is presence of different energy sources with different energy generation capacities. There may be case that larger rated DGs in an islanded micro grid may supply to major portion of load demand. These DGs are very important in a micro-grid and failure of such

DG may lead to load shedding or even blackouts to maintain power balance. At times it may happen that temporary fault or failure of a protection may trigger unnecessary loss of such DGs. If other DGs have insufficient power to meet the load demand it may either lead to load shedding or frequency collapse.

In order to test the effectiveness of our proposed solutions we have chosen a test case based on IEEE std. 1547.4 [19]. Figure below shows a test case of micro-grid situated at a natural gas production facility rated at 400V. It has three power sources, i.e. synchronous generator based DGs. It includes total load of 250KW consumed by induction motors. Inductive loads include compressors, drillers, pumps and extruders. Other loads includes lighting loads are resistive loads. The micro-grid operation is managed by Distribution system operator (DSO) which does the scheduling and monitoring operations. DSO also support load management and emergency activities. The communication protocol is based on IEC61850.

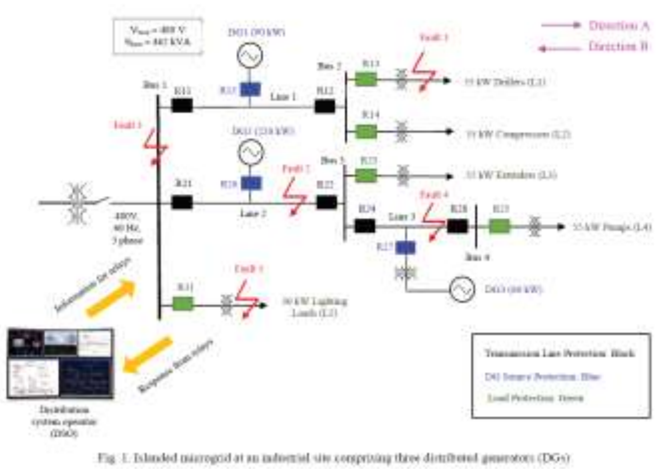

Fig.1: Islanded micro grid at an industrial site comprising three distributed generators (DGs)

As it can be seen in the figure above, micro grid includes three DG units, with capacity of 90KW, 220KW and 60KW respectively. There are five loads included in the micro-grid namely L1, L2, L3, L4 & L5 with four loads of 55KW and one load of 30KW. Different scenario are considered by introducing faults at five locations as shown in the figure above.

Continuous wavelet transform (CWT) is an effective tool to identify the high impedance fault and is suggested by many literatures. The phase displacement relation between continuous CWTs of zero sequence voltage and current at faulty line remains unchanged. Hence the aero sequence components of voltage and current are extracted first. Then Continuous wavelet transforms of current and voltage is calculated. Finally, the phase displacements between CWTs are applied to determine whether a high impedance fault has occurred.

As discussed before, if DGs and Loads are connected in a plug and play manner, it will create problem for traditional protection scheme. Since short circuit current levels changes with changing loads and DGs drop off, time delay function has to be modified accordingly. So time delay function has to be modified in real time. This is only possible if each relay is communicated with different states of DGs and Loads. Let us take an example of a protection relay whose TDFs parameter is affected by on an off of DG1 DG2 & DG3 and Load1 Load2 Load3 load4 & Load5. So total 2^3 x 2^5 = 256 distinct states exists. If load current and fault current is known for each state then pickup current is selected as average of Pickup current and fault current. If only Fault current is available, then pickup current is chosen as half of fault current.

III Proposed Work

In our proposed work we are proposing the combination of bi-directional and smart Relays which can communicate with each other to know the status of plug and play DGs and Loads. This information is used to adaptively adjust the pickup current and other parameters of time delay functions. The effect of each fault on system stability is discussed in detail. Normal currents and fault currents at relevant protection relays are considered for selecting pickup current and other parameters. Effects of three types of protection relays are considered namely traditional unidirectional protection relays, Bi-directional protection relays and communicable bi-directional protection relays. Most possible fault scenarios were analyzed in detailed and based on simulation results we tried to find which type of relay suit best to trip in all fault scenarios. Delay time graphs for different scenarios were presented the simulation results section.

[A] Fault – 1

The location of fault-1 in shown in fig. The zoomed in view of concerned part of the DG network is shown in fig-2. As shown R13 is primary protection relay for Fault-1 while R12 is secondary protection relay. As discussed before secondary protection relay act as backup protection relay in case primary relay fails to trip a fault.

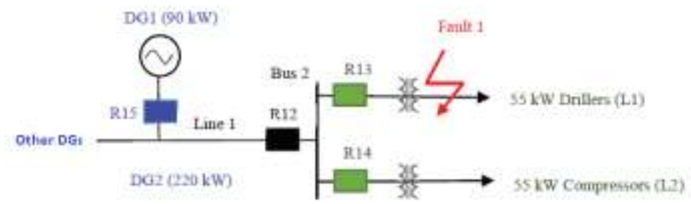

Fig.2: Location of fault 1

R13 is connected to load L1 while R12 is connected to both load L1 & L2. Normal current and fault current values are taken from reference [19]. The values of normal current and low impedance fault current for relay R13 in different scenarios is mentioned in table below :

Scenarios (Primary Relay R13)	(DG1 DG2 DG3 L1 L2 L3 L4 L5)	Normal Current (KA)	Fault Current (KA)
Scenario - 1	(1,1,1,1,1,1,1,1)	0.119	1.033
Scenario – 2	(1,1,0,1,1,1,1,1)	0.119	0.975
Scenario – 3	(1,0,1,1,1,0,0,0)	0.119	0.768
Scenario – 4	(0,1,1,1,1,1,1,1)	0.119	0.821
Scenario – 5	(1,0,0,1,0,0,0,0)	0.119	0.571
Scenario – 6	(0,1,0,1,1,0,0,0)	0.119	0.798
Scenario – 7	(0,0,1,1,0,0,0,0)	0.119	0.399

Table 1: Values of normal current and low impedance fault current for relay R13

Similarly the values of normal current and low impedance fault current for secondary protection relay R12 in different scenarios is mentioned in the table below :

Scenarios (Secondary Relay R12)	(DG1 DG2 DG3 L1 L2 L3 L4 L5)	Normal Current (KA)	Fault Current (KA)
Scenario - 1	(1,1,1,1,1,1,1,1)	0.238	1.100
Scenario – 2	(1,1,0,1,1,1,1,1)	0.238	1.036
Scenario – 3	(1,0,1,1,1,0,0,0)	0.238	0.826
Scenario – 4	(0,1,1,1,1,1,1,1)	0.238	0.891
Scenario – 5	(1,0,0,1,0,0,0,0)	0.119	0.571
Scenario – 6	(0,1,0,1,1,0,0,0)	0.238	0.864
Scenario – 7	(0,0,1,1,0,0,0,0)	0.119	0.399

Table 2: Values of normal current and low impedance fault current for relay R12

In order to compare our proposed solution we have taken three cases for each scenario. To protect the DG system from fault-1 traditionally unidirectional non adaptive relay is used. So for our comparison, in first case we will use a traditional unidirectional relay with pickup current average of normal relay current and highest possible fault current. As can be seen in the tables above, normal current and highest fault current for primary protection relay is 0.119 & 1.033 KA while for secondary relay it is 0.238 & 1.100 KA. Hence pickup current for case-1 is chosen as 0.576 KA and 0.669 KA respectively. Being unidirectional non adaptive relay, pickup currents will remain same for all scenarios as well as independent of current direction.

For second case we use same relay but it can detect current direction. However current direction in case of fault-1 will always remain in the direction of load, hence bi-directional relay for R13 will behave same as unidirectional relay. While for third case we are considering bi-directional adaptive relay which can both detect bi-directional current and have adaptive pickup currents for each scenario. The pickup current for primary relay R13 for case-1, 2 & 3 is mentioned in the table below:

Scenarios (Primary Relay R13)	Pickup Current Case-1 (Unidirectional Relay)	Pickup Current Case-2 (Bi-directional Relay)	Pickup Current Case-3 (Bi-directional Adaptive Relay)
Scenario - 1	0.576	+ 0.576	+ 0.576
Scenario – 2	0.576	+ 0.576	+ 0.548
Scenario – 3	0.576	+ 0.576	+ 0.444
Scenario – 4	0.576	+ 0.576	+ 0.470
Scenario – 5	0.576	+ 0.576	+ 0.356
Scenario – 6	0.576	+ 0.576	+ 0.458
Scenario – 7	0.576	+ 0.576	+ 0.260

Table 3: : Pickup current for primary relay R13

Similarly, the pickup current for secondary relay R12 for case-1, 2 & 3 is mentioned in the table below :

Scenarios (Secondary Relay R12)	Pickup Current Case-1 (Unidirectional Relay)	Pickup Current Case-2 (Bi-directional Relay)	Pickup Current Case-3 (Bi-directional Adaptive Relay)
Scenario - 1	0.669	+ 0.669	+ 0.669
Scenario – 2	0.669	+ 0.669	+ 0.637
Scenario – 3	0.669	+ 0.669	+ 0.532
Scenario – 4	0.669	+ 0.669	+ 0.564
Scenario – 5	0.669	+ 0.669	+ 0.345
Scenario – 6	0.669	+ 0.669	+ 0.551
Scenario – 7	0.669	+ 0.669	+ 0.260

Table 4: : Pickup current for primary relay R12

[B] Fault – 2

The location of fault-2 in shown in fig-1. The zoomed in view of concerned part of the DG network is shown in fig below. This fault is an interesting case where fault current is fed by both directions and while tripping fault direction has also been considered. For sake of easy understanding we have named the two direction currents as Direction A and Direction B and their respective directions are shown in figure below. In direction A, R21 is acting as primary protection while R11 is acting as secondary protection. While in current direction B, R22 is acting as primary protection whereas R24 is acting as secondary protection relay. Relay R22 should also trip in case of this fault however current direction will remain same here. Hence R26 is not considered for analysis as conventional protection is sufficient here to trip R26. If R21 or R11 fail to trip in this fault, it may lead to failure of DG1 consequently Load L1 and L2 will also shut down. Similarly if R22 and R24 fails to trip in this fault, it may lead to failure of DG3 as a result unnecessary failure of load L4. Also in normal condition in most cases, current in R21 will in direction B while that of R11 is in direction A. But in fault condition current directions will be reversed. Similarly in normal conditions in most cases, current directions in R22 and R24 will be direction A but in fault condition it may get reversed. Hence direction of fault current must be taken into consideration.

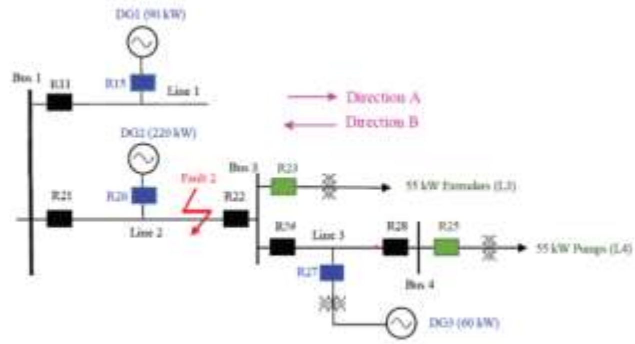

Fig.3: Location of fault 2

The values of normal current and low impedance fault current for relay R21 in different scenarios along with direction is mentioned in table below:

Scenarios (Primary Relay R21)	(DG1 DG2 DG3 L1 L2 L3 L4 L5)	Normal Current (KA)	Current Direction	Fault Current (KA)	Current Direction
Scenario – 1	(1 , 1 , 1 , 1 , 1 , 1 , 1 , 1)	0.161	B	0.108	A
Scenario – 2	(1 , 1 , 0 , 1 , 1 , 1 , 1 , 1)	0.136	B	0.155	A
Scenario – 3	(1 , 0 , 1 , 1 , 1 , 0 , 0 , 0)	0.070	A	0.323	A
Scenario – 4	(0 , 1 , 1 , 1 , 1 , 1 , 1 , 1)	Not considered	NA	Not considered	NA
Scenario – 5	(1 , 0 , 0 , 0 , 0 , 1 , 0 , 0)	0.119	A	0.530	A
Scenario – 6	(0 , 1 , 0 , 1 , 0 , 1 , 1 , 0)	Not considered	NA	Not considered	NA
Scenario – 7	(0 , 0 , 1 , 1 , 0 , 0 , 0 , 0)	Not considered	NA	Not considered	NA

Table 5 : Values of normal current and low impedance fault current for relay R21

The values of normal current and low impedance fault current for relay R11 in different scenarios along with direction is mentioned in table below:

Scenarios (Primary Relay R11)	(DG1 DG2 DG3 L1 L2 L3 L4 L5)	Normal Current (KA)	Current Direction	Fault Current (KA)	Current Direction
Scenario – 1	(1,1,1,1,1,1,1,1)	0.095	A	0.155	B
Scenario – 2	(1,1,0,1,1,1,1,1)	0.070	A	0.201	B
Scenario – 3	(1,0,1,1,1,0,0,0)	0.070	B	0.323	B
Scenario – 4	(0,1,1,1,1,1,1,1)	Not considered	NA	Not considered	NA
Scenario – 5	(1,0,0,0,0,1,0,0)	0.119	B	0.530	B
Scenario – 6	(0,1,0,1,0,1,1,0)	Not considered	NA	Not considered	NA
Scenario – 7	(0,0,1,1,0,0,0,0)	Not considered	NA	Not considered	NA

Table 6 : Values of normal current and low impedance fault current for relay R11

The values of normal current and low impedance fault current for relay R22 in different scenarios along with direction is mentioned in table below:

Scenarios (Primary Relay R22)	(DG1 DG2 DG3 L1 L2 L3 L4 L5)	Normal Current (KA)	Current Direction	Fault Current (KA)	Current Direction
Scenario – 1	(1,1,1,1,1,1,1,1)	0.160	A	0.060	B
Scenario – 2	(1,1,0,1,1,1,1,1)	Not considered	NA	Not considered	NA
Scenario – 3	(1,0,1,1,0,1,0,0)	0.070	B	0.691	B
Scenario – 4	(0,1,1,1,1,1,1,1)	0.025	B	0.563	B
Scenario – 5	(1,0,0,0,0,0,1,0)	Not considered	NA	Not considered	NA
Scenario – 6	(0,1,0,1,0,1,1,0)	Not considered	NA	Not considered	NA
Scenario – 7	(0,0,1,1,0,0,0,0)	0.119	B	0.426	B

Table 7 : Values of normal current and low impedance fault current for relay R22

The values of normal current and low impedance fault current for relay R24 in different scenarios along with direction is mentioned in table below:

Scenarios (Primary Relay R24)	(DG1 DG2 DG3 L1 L2 L3 L4 L5)	Normal Current (KA)	Current Direction	Fault Current (KA)	Current Direction
Scenario – 1	(1,1,1,1,1,1,1,1)	0.036	A	0.060	B
Scenario – 2	(1,1,0,1,1,1,1,1)	Not considered	NA	Not considered	NA
Scenario – 3	(1,0,1,1,0,1,0,0)	0.063	B	0.691	B
Scenario – 4	(0,1,1,1,1,1,1,1)	0.154	B	0.563	B
Scenario – 5	(1,0,0,0,0,0,1,0)	Not considered	NA	Not considered	NA
Scenario – 6	(0,1,0,1,0,1,1,0)	Not considered	NA	Not considered	NA
Scenario – 7	(0,0,1,1,0,0,0,0)	0.119	B	0.426	B

Table 8 : Values of normal current and low impedance fault current for relay R24

Like in case of fault-1, to compare our proposed solution we have taken three cases for each scenario. In first case we will use a traditional unidirectional relay with pickup current average of normal relay current and highest possible fault current. As can be seen in the tables above, normal current and highest fault current for primary protection relay R21 is 0.119 & 0.530 KA while for secondary relay R11 it is 0.119 & 0.530 KA. Hence pickup current for case-1 is chosen as 0.325 KA and 0.325 KA respectively. Similarly normal current and highest fault current for primary protection relay R22 is 0.070 & 0.691 KA while for secondary relay R24 it is 0.063 & 0.777 KA. Hence pickup current for case-1 is chosen as 0.380 KA and 0.420 KA respectively. Being unidirectional non adaptive relay, pickup currents will remain same for all scenarios as well as independent of current direction.

For second case we use same relay but it can detect current direction. Hence along with fault current, current direction is also mentioned in case of Bi-Directional relay. While for third case we are considering bi-directional adaptive relay which can both detect bi-directional current and have adaptive pickup currents for each scenario. The pickup current for primary relay R21 for case-1, 2 & 3 is mentioned in the table below:

Scenarios (Primary Relay R21)	Pickup Current Case-1 (Unidirectional Relay)	Pickup Current Case-2 (Bi-directional Relay) & Direction	Pickup Current Case-3 (Bi-directional Adaptive Relay) & Direction
Scenario – 1	0.325	0.325 (A)	0.054 (A)
Scenario – 2	0.325	0.325 (A)	0.077 (A)
Scenario – 3	0.325	0.325 (A)	0.196 (A)
Scenario – 4	Not considered	Not considered	Not considered
Scenario – 5	0.325	0.325 (A)	0.325 (A)
Scenario – 6	Not considered	Not considered	Not considered
Scenario – 7	Not considered	Not considered	Not considered

Table 9 : Values of pickup current for primary relay R21

Similarly, the pickup current for secondary relay R11 for case-1, 2 & 3 is mentioned in the table below:

Scenarios (Primary Relay R11)	Pickup Current Case-1 (Unidirectional Relay)	Pickup Current Case-2 (Bi-directional Relay) & Direction	Pickup Current Case-3 (Bi-directional Adaptive Relay) & Direction
Scenario – 1	0.325	0.325 (B)	0.077 (B)
Scenario – 2	0.325	0.325 (B)	0.101 (B)
Scenario – 3	0.325	0.325 (B)	0.196 (B)
Scenario – 4	Not considered	Not considered	Not considered
Scenario – 5	0.325	0.325 (B)	0.325 (B)
Scenario – 6	Not considered	Not considered	Not considered
Scenario – 7	Not considered	Not considered	Not considered

Table 10 : Values of pickup current for secondary relay R11

Similarly, the pickup current for Primary relay R22 for case-1, 2 & 3 is mentioned in the table below:

Scenarios (Primary Relay R22)	Pickup Current Case-1 (Unidirectional Relay)	Pickup Current Case-2 (Bi-directional Relay) & Direction	Pickup Current Case-3 (Bi-directional Adaptive Relay) & Direction
Scenario – 1	0.380	0.380 (B)	0.030 (B)
Scenario – 2	Not considered	Not considered	Not considered
Scenario – 3	0.380	0.380 (B)	0.380 (B)
Scenario – 4	0.380	0.380 (B)	0.293 (B)
Scenario – 5	Not considered	Not considered	Not considered
Scenario – 6	Not considered	Not considered	Not considered
Scenario – 7	0.380	0.380 (B)	0.273 (B)

Table 11 : Values of pickup current for primary relay R22

Similarly, the pickup current for secondary relay R24 for case-1, 2 & 3 is mentioned in the table below:

Scenarios (Primary Relay R24)	Pickup Current Case-1 (Unidirectional Relay)	Pickup Current Case-2 (Bi-directional Relay) & Direction	Pickup Current Case-3 (Bi-directional Adaptive Relay) & Direction
Scenario – 1	0.420	0.420 (B)	0.075 (B)
Scenario – 2	Not considered	Not considered	Not considered
Scenario – 3	0.420	0.420 (B)	0.420 (B)
Scenario – 4	0.420	0.420 (B)	0.406 (B)
Scenario – 5	Not considered	Not considered	Not considered
Scenario – 6	Not considered	Not considered	Not considered
Scenario – 7	0.420	0.420 (B)	0.273 (B)

Table 12 : Values of pickup current for secondary relay R24

IV Simulation and Results

In order to simulate the results for different cases we did programming in MATLAB and created a Graphical User Interface (GUI) to generate our results. In this section we are discussing the implementation of different GUIs that we used in our thesis to generate desired simulation results. To generate all desired results we created two GUIs in MATLAB. First GUI is shown below :

Fig.4: First GUI to generate results

As shown above it has three buttons. One for Fault-1, second for fault-2 showing results of Relays R21 and R11 while third one is for fault-2 showing results of R22 and R24. Time delay function graphs of uni-directional, bi-directional and adaptive relays both for primary and secondary protections are displayed in different graph windows. Also it also displays time delay to trip for fault currents in different scenarios. Below is shown the window with results when Fault-1 button is pressed in the GUI.

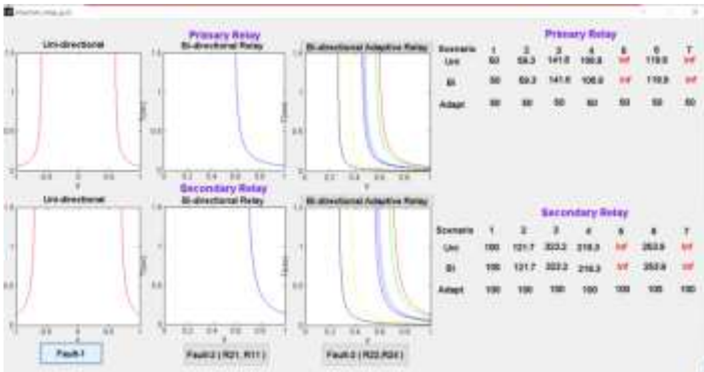

Fig.5: Results for fault-1

As it can be seen all graphs are visible in respective windows for fault-1 and time delays for each scenario for each relay type is displayed in the tables. Similarly below is shown the windows with results when Fault-2 (R21, R11) and Fault-2 (R22, R24) buttons are pressed in the GUI.

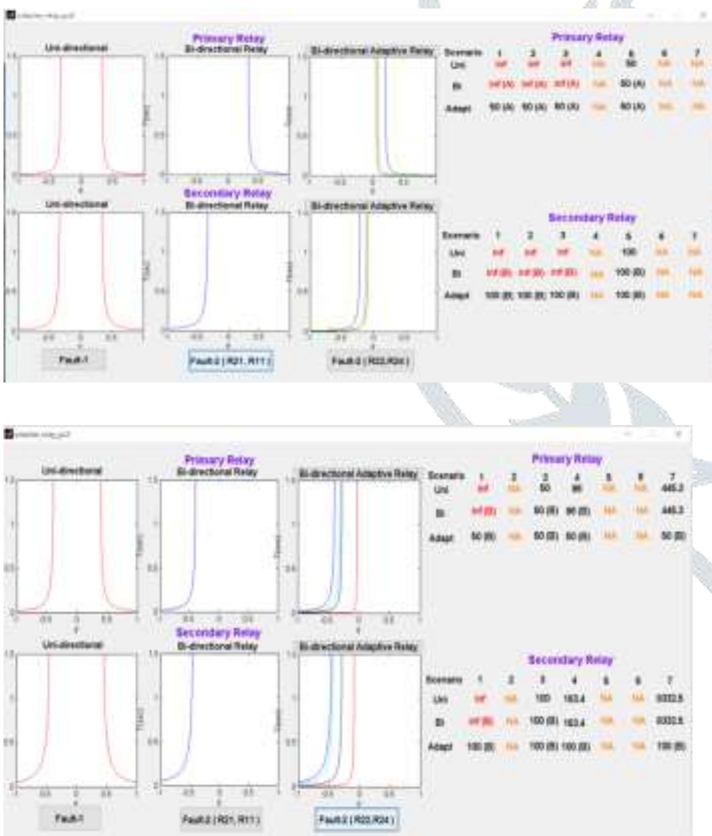

Fig.6: Results for fault-2

Second GUI that we designed for our thesis is to compare each scenario for all three types of relays i.e. uni-directional, Bi-directional and adaptive relays. The GUI is shown below :

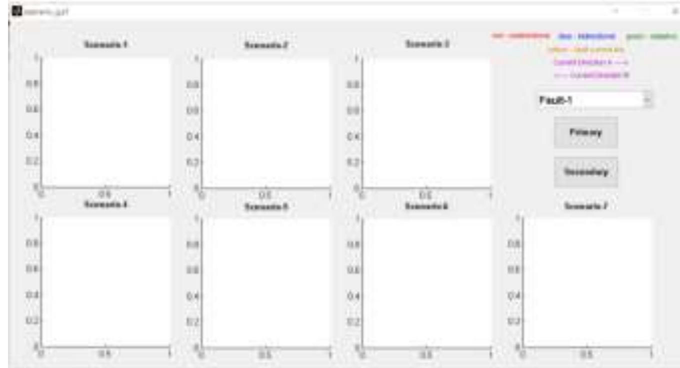

Fig.7: Second GUI to generate results

(R22, R24) and two push buttons, one for Primary Relay graphs and other for secondary relay graphs. There are total 6 sets of graphs as listed below :

1. Fault-1 , Primary Relay
2. Fault-1 , Secondary Relay
3. Fault-2 (R21, R11) , Primary Relay
4. Fault-2 (R21, R11), Secondary Relay
5. Fault-2 (R22, R24), Primary Relay
6. Fault-2 (R22, R24), Secondary Relay

GUI snapshots of all of these sets are shown below :

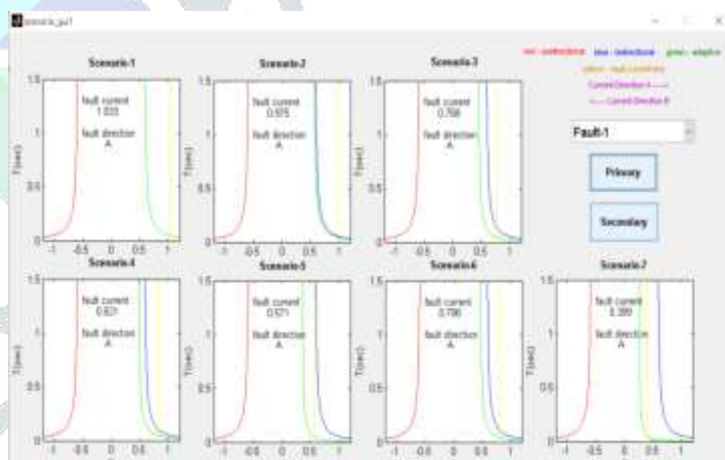

Fig.8: Primary relay graph during fault-1

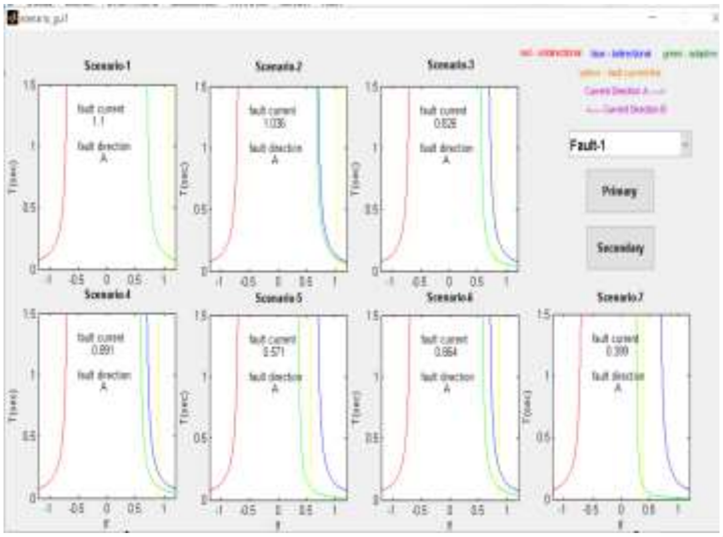

Fig.9: Secondary relay graph during fault-1

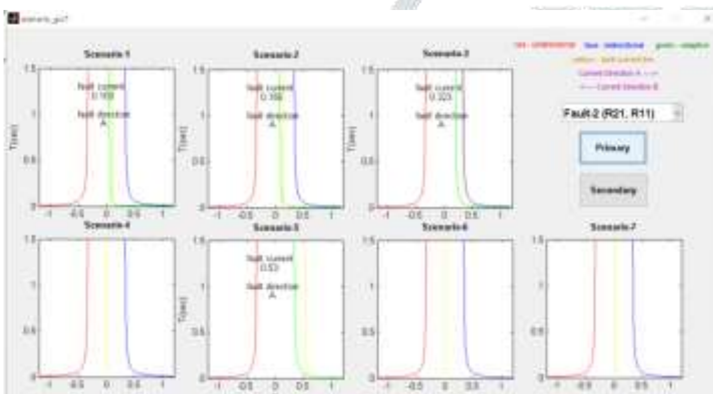

Fig.10: Primary relay graph during fault-2(R21,R11)

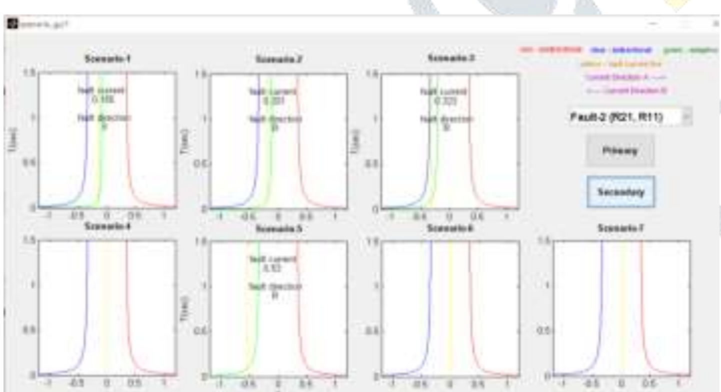

Fig.11: Secondary relay graph during fault-2(R21,R11)

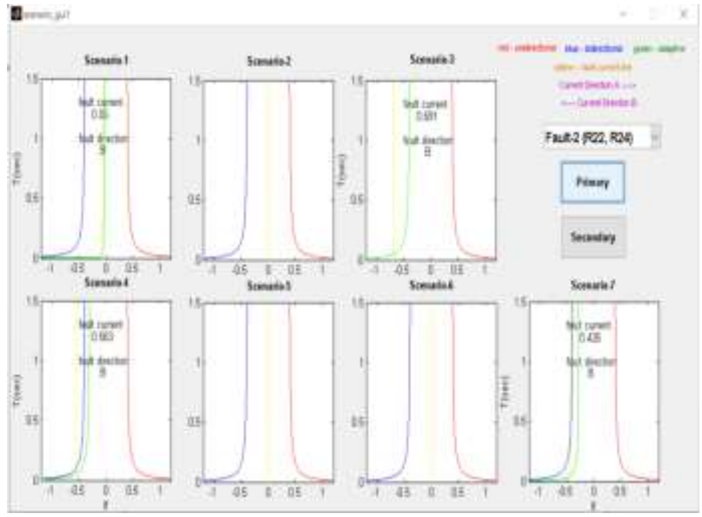

Fig.12: Primary relay graph during fault-2(R22,R24)

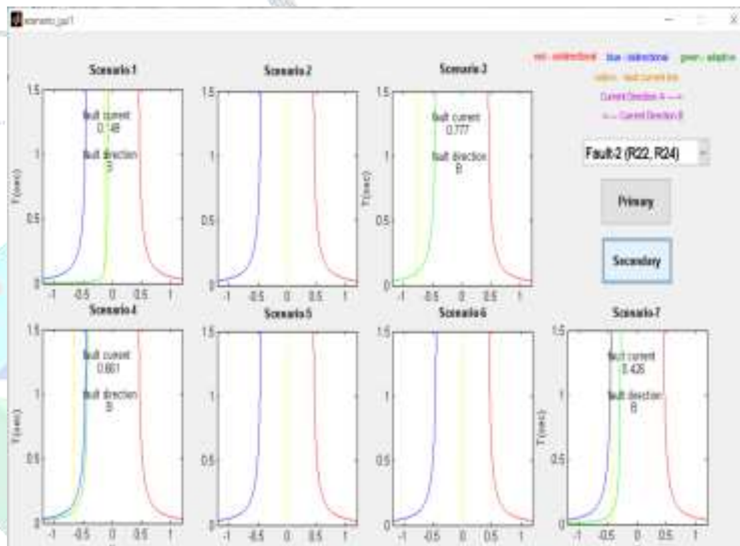

Fig.13: Secondary relay graph during fault-2(R22,R24)

Overall summary of comparison all three types of relays for primary protection R13 is presented in table below. It clearly highlights that Adaptive is effect is all cases unlike uni-directional and bi-directional relay.

Scenarios (Primary Relay R13)	Case-1 & Case-2 (Unidirectional & bi-directional Relay)		Case-3 (Bi-directional Adaptive Relay)	
	Isolate fault	Time delay	Isolate fault	Time delay
Scenario - 1	Success	Expected time delay	Success	Expected time delay
Scenario – 2	Success	Expected time delay	Success	Expected time delay

Scenario – 3	Success	Longer time delay	Success	Expected time delay
Scenario – 4	Success	Longer time delay	Success	Expected time delay
Scenario – 5	Fails	Fails to trip	Success	Expected time delay
Scenario – 6	Success	Longer time delay	Success	Expected time delay
Scenario – 7	Fails	Fails to Trip	Success	Expected time delay

Table 13 : Comparison between Unidirectional , bi-directional & Bi-directional Adaptive Relay for primary protection R13 in different scenarios

Overall summary of comparison all three types of relays for secondary protection R12 is presented in table below. It clearly highlights that Adaptive is effect is all cases unlike uni-directional and bi-directional relay.

Scenarios (Secondary Relay R12)	Case-1 & Case-2 (Unidirectional & bi-directional Relay)		Case-3 (Bi-directional Adaptive Relay)	
	Isolate fault	Time delay	Isolate fault	Time delay
Scenario - 1	Success	Expected time delay	Success	Expected time delay
Scenario – 2	Success	Expected time delay	Success	Expected time delay
Scenario – 3	Success	Longer time delay	Success	Expected time delay
Scenario – 4	Success	Longer time delay	Success	Expected time delay
Scenario – 5	Fails	Fails to trip	Success	Expected time delay
Scenario – 6	Success	Longer time delay	Success	Expected time delay
Scenario – 7	Fails	Fails to Trip	Success	Expected time delay

Table 14 : Comparison between Unidirectional , bi-directional & Bi-directional Adaptive Relay for secondary protection R12 in different scenarios

Overall summary of comparison of all three types of relays for primary protection R21 is presented in table below. It clearly highlights that Adaptive is effect is all cases unlike uni-directional and bi-directional relay.

Scenarios (Primary Relay R21)	Case-1 & Case-2 (Unidirectional & bi-directional Relay)		Case-3 (Bi-directional Adaptive Relay)	
	Isolate fault	Time delay	Isolate fault	Time delay
Scenario - 1	Fails	Fails to trip	Success	Expected time delay
Scenario – 2	Fails	Fails to trip	Success	Expected time delay
Scenario – 3	Fails	Fails to trip	Success	Expected time delay
Scenario – 4	NA	NA	NA	NA
Scenario – 5	Success	Expected time delay	Success	Expected time delay
Scenario – 6	NA	NA	NA	NA
Scenario – 7	NA	NA	NA	NA

Table 15 : Comparison between Unidirectional , bi-directional & Bi-directional Adaptive Relay for primary protection R21 in different scenarios

Overall summary of comparison all three types of relays for secondary protection R11 is presented in table below. It clearly highlights that Adaptive is effect is all cases unlike uni-directional and bi-directional relay.

Scenarios (Primary Relay R11)	Case-1 & Case-2 (Unidirectional & bi-directional Relay)		Case-3 (Bi-directional Adaptive Relay)	
	Isolate fault	Time delay	Isolate fault	Time delay
Scenario - 1	Fails	Fails to trip	Success	Expected time delay
Scenario – 2	Fails	Fails to trip	Success	Expected time delay
Scenario – 3	Fails	Fails to trip	Success	Expected time delay
Scenario – 4	NA	NA	NA	NA

Scenario – 5	Success	Expected time delay	Success	Expected time delay
Scenario – 6	NA	NA	NA	NA
Scenario – 7	NA	NA	NA	NA

Table 16：Comparison between Unidirectional , bi-directional & Bi-directional Adaptive Relay for secondary protection R11 in different scenarios

Overall summary of comparison of all three types of relays for primary protection R22 is presented in table below. It clearly highlights that Adaptive is effective in all cases unlike uni-directional and bi-directional relay.

Scenarios (Primary Relay R21)	Case-1 & Case-2 (Unidirectional & bi-directional Relay)		Case-3 (Bi-directional Adaptive Relay)	
	Isolate fault	Time delay	Isolate fault	Time delay
Scenario - 1	Fails	Fails to trip	Success	Expected time delay
Scenario – 2	NA	NA	Success	Expected time delay
Scenario – 3	Success	Expected time delay	Success	Expected time delay
Scenario – 4	SUCCESS	Longer time delay than desired	Success	Expected time delay
Scenario – 5	NA	NA	NA	NA
Scenario – 6	NA	NA	NA	NA
Scenario – 7	SUCCESS	Extremely longer time delay than desired	Success	Expected time delay

Table 17：Comparison between Unidirectional , bi-directional & Bi-directional Adaptive Relay for primary protection R22 in different scenarios

Overall summary of comparison all three types of relays for secondary protection R24 is presented in table below. It clearly highlights that Adaptive is effective in all cases unlike uni-directional and bi-directional relay.

Scenarios (Primary Relay R21)	Case-1 & Case-2 (Unidirectional & bi-directional Relay)		Case-3 (Bi-directional Adaptive Relay)	
	Isolate fault	Time delay	Isolate fault	Time delay
Scenario - 1	Fails	Fails to trip	Success	Expected time delay
Scenario – 2	NA	NA	Success	Expected time delay
Scenario – 3	Success	Expected time delay	Success	Expected time delay
Scenario – 4	SUCCESS	Longer time delay than desired	Success	Expected time delay
Scenario – 5	NA	NA	NA	NA
Scenario – 6	NA	NA	NA	NA
Scenario – 7	SUCCESS	Extremely longer time delay than desired	Success	Expected time delay

Table 18：Comparison between Unidirectional , bi-directional & Bi-directional Adaptive Relay for secondary protection R24 in different scenarios

V CONCLUSION

Protection relays are critical aspect of any power system. Most serious negative impact DGs have is associated with protection concerns. When connected in radial Distributions systems, DGs can affect both current magnitude and direction. Traditional protection system assumes the flow of power from upstream to downstream systems. Hence traditional unidirectional protection fails to isolate faults in different scenarios. In our work we have proposed use of Adaptive Bi-directional protection relays which can also communicate with each other and read the plug and play status different DG units and Loads states. Accordingly they can adjust time delay functions for different scenarios. To analyze the performance of adaptive relays we did simulations for different fault conditions under different DG and Load plug and play states and compared the results with uni-directional and Non Adaptive bi-directional relays. In order to test the effectiveness of our proposed solutions we have chosen a test case based on IEEE std. 1547.4. Mainly two faults were simulated exhaustively. For example for fault-1 R13 relay act as primary protection while R12 act as secondary protection. Different DG and loads states were considered. Time delay functions were simulated and plotted for all seven scenarios for all three types of relays i.e. Uni-directional, Bi-directional and Adaptive Bi-directional. It was concluded that both uni-directional and Bi-directional relays could trip with desired delay time in 2 scenarios, with longer time delays in 3 other scenarios while failed to trip in 2 scenarios. While Adaptive relays could trip with desired time delays in all scenarios. Similarly for Fault-2 R21 and R22 act as primary protection while R11 and R24 act as secondary protection. There are four effective scenarios left in case of fault-2, except one uni-directional and bi-directional relays failed to trip in all other three scenarios. While Adaptive relays could trip with desired time delays in all scenarios. Hence Adaptive relays can effectively solve protection problems of DG based Micro-Grids.

Future scope of our work involves studying and implementation of Smart protections relays in renewable energy sources based micro-grid. Overshore Wind turbines uncertainty can also be solved to lot extent using Smart relays. Coordination algorithms can be further optimized as per Indian scenario. Problems like grid failures can be minimized to great extent using Smart relays.

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