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Adaptive Differential Protection System for Microgrid

Rahul Kumar Bhardwaj[1], Nisheet Soni[2]
[1]Master Candidate, Jabalpur Engineering College, Jabalpur, Madhya Pradesh – 482005, India
[2] Asst. Professor, Jabalpur Engineering College, Jabalpur, Madhya Pradesh – 482005, India

Abstract: Microgrids are the small version of power system which grants us the integration of distributed generation resources to insure the facilities to the remotely located electric loads as well as have so many advantages over traditional power system like reduced transmission loss, green energy solution and proper use of renewable energy resources. However the resilience offered by microgrid is inconvenient if it is not be able to protect properly in case of any disturbance occurs which is very common in microgrid due to load dynamics. Protective devices used in traditional power grid cannot actually protect microgrid due to variable loads and different fault levels at grid connected modes and islanded modes. The available research about this concern has not been very successful, therefore options like distance, directional over current and differential relay remains effective protection scheme from present standard. Even though these relays are very useful in power system but their effectiveness for microgrid is yet to be analyzed. This paper is presenting the MATLAB simulation based analysis for differential relay type adaptive protection system by taking a complex microgrid model and generating various fault and generation capacities and analyzing it. In this paper different scenarios has been discussed where differential relay seems to be better than distance and directional over current relay protection scheme.

Keyword: Distributed energy resources (DER), Protective device (PD), permissive overreaching transfer trip (POTT), fault ride through capacity (FRT)

I. INTRODUCTION

Day by day the volume of fossil fuels is decreasing at a devastating rate, as the world is consuming more and more energy and in a coming years demand for electrical energy will going to increase. The perfect solution to this problem is microgrid. [1] Microgrid is the integration of distributed energy resources, protective device and local loads. Microgrid has many advantages compare to traditional power system e.g. green energy resources, less expensive and in some point more reliable for increasing future energy demand. Microgrid can operate as a grid connected mode or islanded mode depending upon the situation and it provides smooth transition from grid connected mode to islanded mode and vice versa. [2][4] Microgrid is directly connected to main grid with the help of point of common coupling (PCC). A system which operates as a microgrid generates the energy very close to loads in addition to it if generation capacity of microgrid is more compare to demand then that energy will we fed back to supply mains these features adds the resiliency to microgrid which makes it more favorable than traditional power system. DC microgrid is also available with lots of advantage. [6] Whenever there is any disturbances in the system is detected a control signal will generate and microgrid will be disconnected from the main grid with the help of PCC so that system will be safe, and once the fault is cleared by circuit breakers microgrid can again be connected to main grid according to the signal generated by electronics sensors. [5]

However the Fault current level for grid connected and islanded mode is not same due to its own limitations. In the case of grid connected mode since the conventional protection schemes works on the basis of radial topology in distribution system in which supply is in one end. In this case fault current provided by grid sets protective device (PD) setting according to local impact of fault and PDs are set according to unidirectional current flow. Current flows from feeder to loads in radial distribution system where fault current is less since fault location is far from the feeders.[10] But these data will change in microgrid as DER unit can increase fault current and direction of current can also change which deeds on fault location this results in a bidirectional current flow. [14] By using power electronic devices like convertors can limit fault current and PD becomes desensitized to Fault spatially in islanded mode. Also microgrid can be connected in loop, mess or mix network causing more complex fault current result in poor protection system reliability. Reliability of microgrid in terms of protection and regular energy supply in case of some disturbances in the system is not very high, because regular protection system didn't seems to be too much effective in microgrid. [11]

The purpose of this paper to lights on the protection difficulties we used to face in microgrid, it also shows the benefit of using differential relay over distance and directional over current relay [16][10] and to derive an adaptive protection system based on the differential relay which would work efficiently in this scenario.

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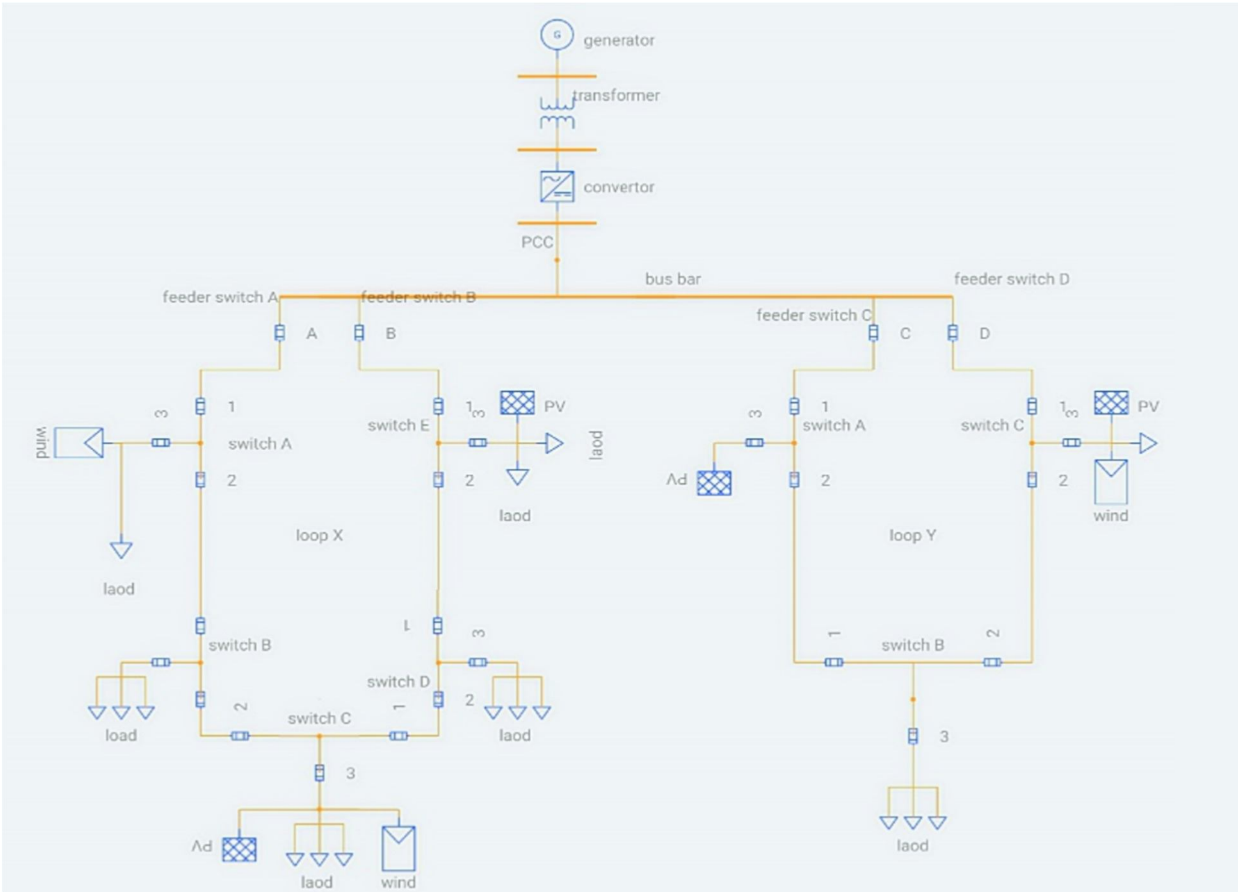

Fig. 1 Microgrid Model

II. PROTECTION SYSTEM CHALLENGES IN MICROGRID –

Protection system Challenges in microgrid has been discussed in [14]. These are the following challenges which make protection system of microgrid more complicated and difficult.

1) When microgrid is working under grid connected mode occurrence of disturbance/fault in microgrid, PD connected to DER must respond when signal of activation from the PCC to protective device is provided. Due to fault ride through capacity (FRT), DER will work continuously and faulty portion of microgrid must be disconnected from the remaining system. Normally setting for fault current is about 10 to 50 times of the rated current. But in some cases non fault cases makes the voltage unbalance at PCC. Identification of this is difficult. So need for a better protection system is necessary. [7]
2) In this case the fault current is something 5 time of rated current. Now PD should be set to 2-10 times to get activate. This makes the relay operation much difficult since current level is different in both cases. Therefore fault level is difficult to predict since fault current depends on operating mode, DG types and DG numbers.[2]
3) Since current flow is unidirectional in conventional power grid. The integration of DER in microgrid allow the current to flow in reverse causes low power quality, protection difficulty and voltage regulation. So bidirectional power flow is also possible in microgrid. [17]
4) When Network is connected to DG and if disturbance/fault takes place in feeder, due to larger distance impedance is much higher for grid than DG impedance. Due to this short circuit current becomes less compare to pickup value of feeder relay results in failure of detection in fault condition. This is known as blinding of protection.
5) When downstream fault occurs in the bus where distributed generator is Connected to utility, impedance in upstream measured is fined to be higher than actual fault impedance. [15] Results in grading problem of relay and delayed operation and in some case no relay operation.

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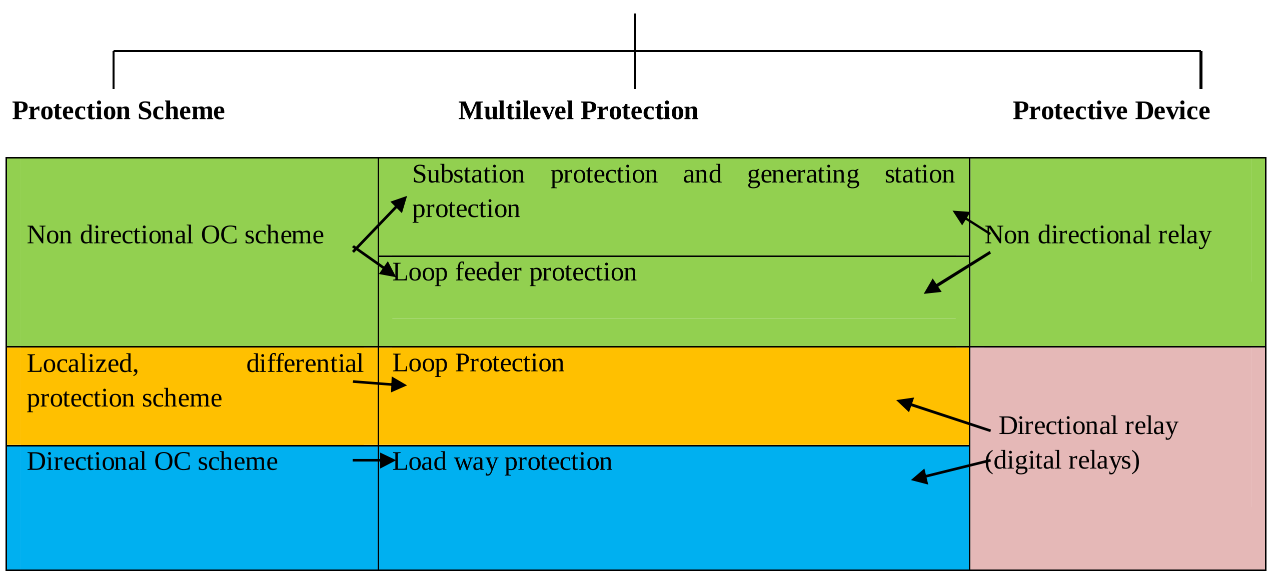
III. SOLUTION TO RELATED PROBLEMS

Primary and secondary (backup) protective system combination should be made, so that faulty portion of the system can be isolated from other part of system. DER unit in main grid makes network complicated. So using different relay and fuses simplifies the issues.

1) *Current Limiter:* By placing current limiter close to the PCC limits the current due to disturbance which is supplied by microgrid to utility and utility to microgrid. So in normal condition FCL is maintained minimum to reduce losses and in maximum for fault. [5]
2) *Adaptive Protection Technology*: Grid connected and islanded mode fault current magnitude is different so we need to adapt to this condition and makes a system in which relay setting must change according to grid connected and islanded mode of operation. In first case relay would be set according to grid connected mode and when microgrid is isolated from main grid so signal must be sent from PCC to makes relay setting according to islanded mode. This will create a adaptive system in which relay will automatically adjusted according to microgrid modes. [14]
3) *Centralized Protection Scheme:* A microgrid management process is responsible for management of condition and status of microgrid in centralized protection Scheme. This management system will set rating of all PD. According to microgrid mode a signal is generated this signal is send to each loop shown in the fig there will be optical fiber communication channel attached to each relay switches. [3]
4) *Hierarchical Protection Scheme:* A simple hierarchical protection schematics is shown in the below fig. By using loop and mess structure of microgrid uninterrupted power supply can be maintained even if one of the sections is isolated due to fault. Figure 2 shows that if there is a fault at the load way level, load relay operate to remove the faulty portion of the system, if load way relay failed to detect the fault then loop relay near to load way relay will operate and remove the faulty part of the system in case of loop fault loop relay near to fault location will operate and if failed to operate then load feeder relay will operate to remove the whole loop from the system. If there is a fault at the outside the microgrid then microgrid will be separated and work as a islanded mode microgrid to continue supply load. [14]
5) *Adaptive Differential Protection Scheme*: protection techniques that are based on couple of differential directional relays which can locate faults, accurately and isolate faulty portion without affecting other part of the network in distribution systems. Differential protection schemes, which pretty much are traditional protection scheme, are suitable for microgrid protection for both island modes and grid-connected. Differential protection schemes can be centralized (coordinated and monitored with the help of central controllers) or decentralized (controlled by local communications between relays). [2] In case of centralized scheme central controller controllers the operation settings of protective device and microgrid network and giver tripping signals to Pd's whenever fault detected. Centralized schemes are much better approach and more accurate with unacceptable time delays for calculating the recurred computation by the central controllers. Decentralized schemes are more adopted by industrial applications, which allow the direct communication between relays with fastest response to faults.

IV. MICROGRID PROTECTION SCHEME



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V. PROTECTION APPROACH

Figure 3 shows that the microgrid protection can be divided into 4 levels: first is load-way level, second is loop level, thirds is loop-feeder level, and last is microgrid level. Table 2 shows the operation rules and protection. Protection strategy is discussed in the following**.** [18]

A. Load-Way Protection

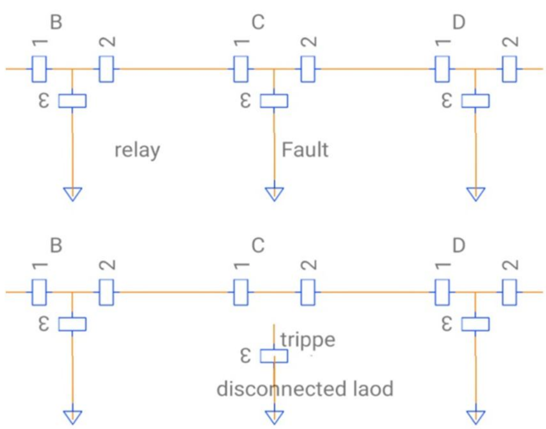

Fig. 3 Load Way Protection scheme

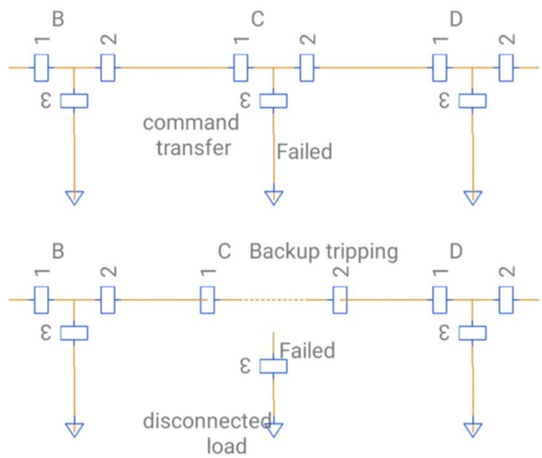

Fig. 4 Load Way Backup Protection scheme

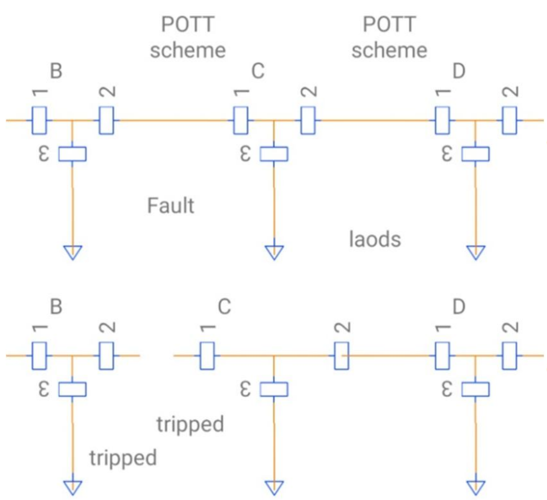

Fig. 5 Loop POTT scheme

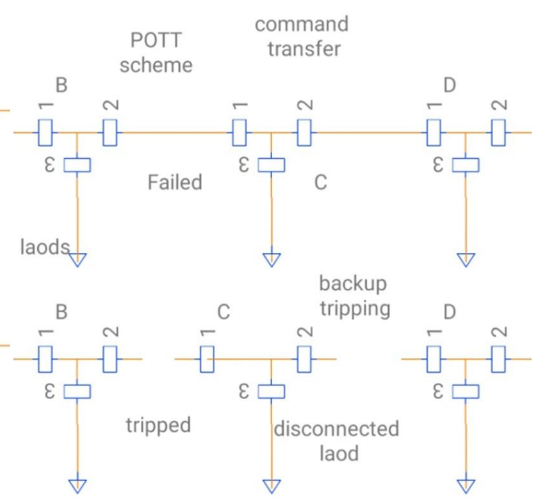

Fig. 6 Loop POTT Backup scheme

All number 3 blocks in figure 2 is the load-way differential OC digital relay, which removes load-way faults. Figure 4 shows a section of loop X with switches B, C, and D. in this figure the current is flowing in the direction of load on each loop Pd. Whenever the fault occurs current will flow toward the faulty point. In figure 4 and figure 5, the load-way protection and load-way backup protection are shown. In figure 4, when a fault at load-way of switch C is cleared by load-way Protective device (C3), the outer Buildings which are connected to switch C will isolate. If the breaker at C3 failed to operate, relay C3 will suddenly send signals to transfer trip to the C1 and C2, which are connected on the same switch. Figure 5 shows the loop Protective device (PD) in switch C, it will give backup protections to C3. When this backup protection scheme operates, the outer loads connected to switch c will isolate. The load-way Protective device is programmed up to 4 shots of automatic re-closing. The other control schemes as well as load-shedding could also be mounted in the load-way protection level. It totally depends on under voltage or overvoltage and under frequency or over- frequency functions for shown relays. [7]

B. Loop Protection

The digital directional relays with communication assisted in figure 2 are shown in the loop-way of switches to generate differential protections at loop levels. Figure 5 &6 showing the loop protection schemes if faults occur in a loop section between switches C and B. In this figure, it has communication link between coupled relays on each sides of each cable part (C1 and B2) to give access to permissive overreaching transfer trip (POTT) protection scheme. [14] In figure 5, when fault occurs in a loop, loop relays will sense fault current. The relays which sense the fault current with positive direction is (D1, C1, and B2) will send signal permissions to their respective coupled relays (D2, C2, and B1), respectively. This time only relay B2 and C1 is going to clear fault since each relay will sense a fault current positive and detect signal permission. Since both relay is detecting positive fault current which indicates that the fault has occurred in the loop section somewhere between them. Figure 5 showing that once B2 and C1 cleared the fault loop will be converted into two parallel line feeders and this will change the loop network to a radial network without interrupting the load. Once the POTT scheme fails the backup protection will come into the picture (in figure 5 C1 fails) from figure 6, when the breaker failure is detected, c1 will send a signal to transfer the trip to C2 to open the breaker at C2. It will create an outage in building load fed by switch C while other loads will continuously going to receive the energy. Differential relays reduce the time intervals for primary protections scheme and provides the accurate fault-clearing and locating scheme in a loop. [12] These relays are high speed digital relay their operating time is less than 1 cycle not including the relays time delay and operating time of breaker. Therefore protection scheme is very accurate and high speed is implemented at the load-way and loop protection levels of the given microgrid. [9]

C. Loop-Feeder Protection

Figure 2 shows that the loop-feeder protection is the higher level of the loop protection scheme, this scheme will act as backup protection for the whole loop. When the fault is not be able to cleared in the load-way or loop results in failure of loop protection schemes and load-way like no communication between Protective device or any Pd failure, the loop in which fault has occurred will be separated from main network by the backup protection provided by loop-feeder Protective device . Loop-feeder relays are non directional differential relays, [13] [8] these are set to be little slower than other two relays but much faster than substation relays. This proposed scheme is better approach since it reacts when the required relay is failed and much faster than the main grid relays. [12]

D. Microgrid-Level Protection

In the microgrid level Protection scheme all the faults which is coming outside the microgrid zone is considered. Normally faults in the main grid is very rare but in order to insure continuous and reliable power supply we must insure that faulty portion should be removed as soon as possible. [9] Since microgrid can operate separately from the main grid called islanded mode of operation. In these modes some relay is provided to separate the microgrid from the main grid. These relay can be non directional OC relay to insure fast and safe operation.

VI. MICROGRID PROTECTION SIMULATION RESULTS

A. Load-Way Fault

In this condition how the load- way fault in grid-connected mode, the protection schemes would clear. Here, microgrid is connected to the main power system so that power can flow according to requirement. In simulation result it is clear that a single-phase to ground fault occurs at time t = 0.3 s on the load-way at switch C in loop X (from figure 2). Figure 7 showing the instantaneous simulation results for the faulted occurring at loop X load way. Here, V_switch-C is the voltage in volts at Vista c, and i_fault, i_relay- C1 and i_relay-C2 are fault currents and relay c1 and relay c2 currents respectively. From figure 8, the fault has been cleared by the load-way protective device mounted at switch C, time taken is t= 0.05s. In this figure, the fault current of load-way of switch C is about 2.7 kA in rms, this current will trigger the relay located at load way at switch C. this time includes the time of OC delay and operating time of relay and breaker. From figure 8, when the load-way Pd failed to clear the fault then the fault is cleared by the backup protection provided at the two loop protective device at switch C. now this time the fault clearing time is about 0.15 s, this includes the total operating time of the primary as well as backup protections. Figure 8 also showing the fault current for the both loop protective device C1 & C2. In both cases load is separated from the microgrid. But duration of fault is less in case when fault is cleared by load way protective device.

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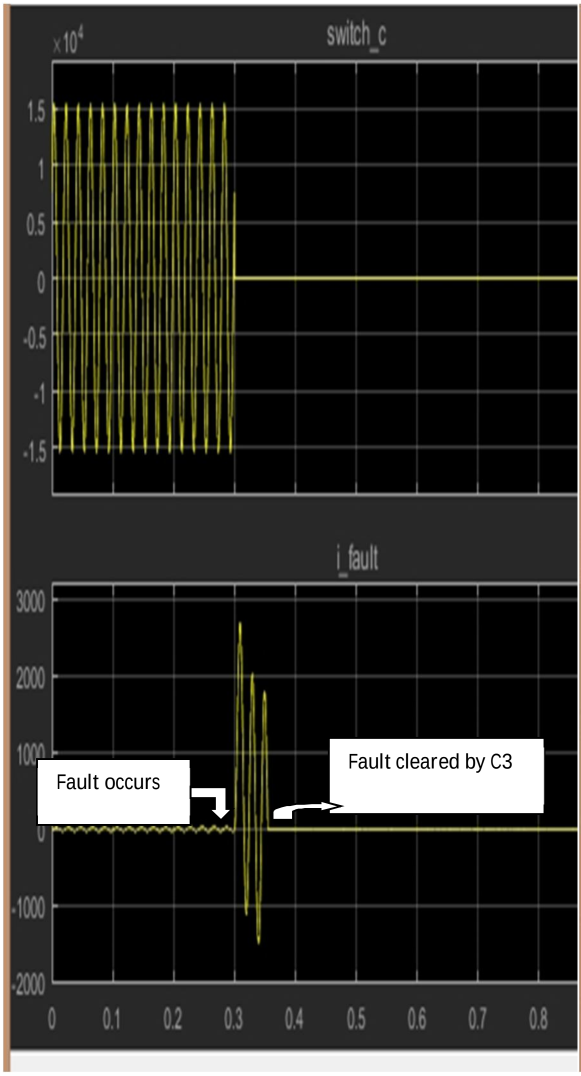

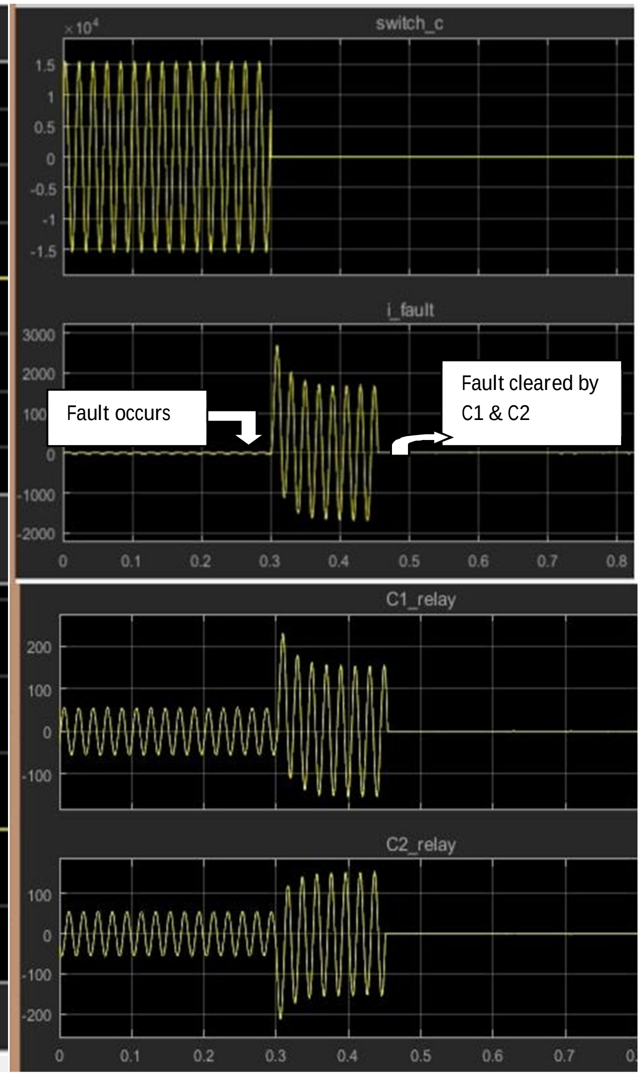

Figure 7. Simulation results when fault cleared by load way PD Fig. 8 simulation result when fault is cleared by backup protection provide by loop PDs.

B. Loop Fault

In this case how the permissive overreach transfer trip(POTT) scheme and its backup protection scheme clears a loop level fault in case of grid-connected mode. In this case microgrid is connected to main grid with the help of PCC. A single-phase to ground fault located at t = 0.3s in the loop X between Vista C and Vista D from figure 2. Figure 9 showing that the fault is removed by the POTT scheme with the help of several PDs in this section. Since fault is located at the middle , both B2 and C1 will detect about 250A rms fault current, so the fault will be cleared in less than 0.10 s without interrupting the electricity supply of the load buildings. Now figure 10 showing that when the POTT scheme failed, the back protection will come into picture and isolate the fault. From this figure, B2 has operated successfully but C1 failed to operate and its backup protective device C2 has been triggered to clear the fault. One side of the loop is the only one which is providing the fault current from time t=0.40 to time t=0.50. In this period current through relay C2 will increase while the current through relay D1 will reduced to zero. At time t=0.50 the fault is cleared by D1 and C2, and building connected to switch C will be removed from the microgrid.

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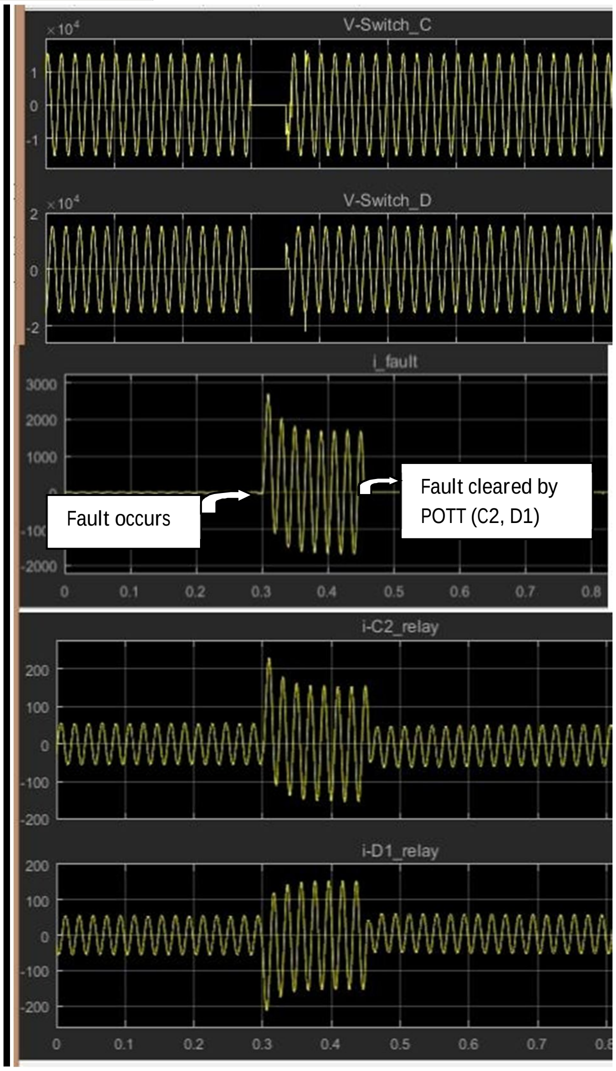

Figure 9. Fault cleared by POTT scheme

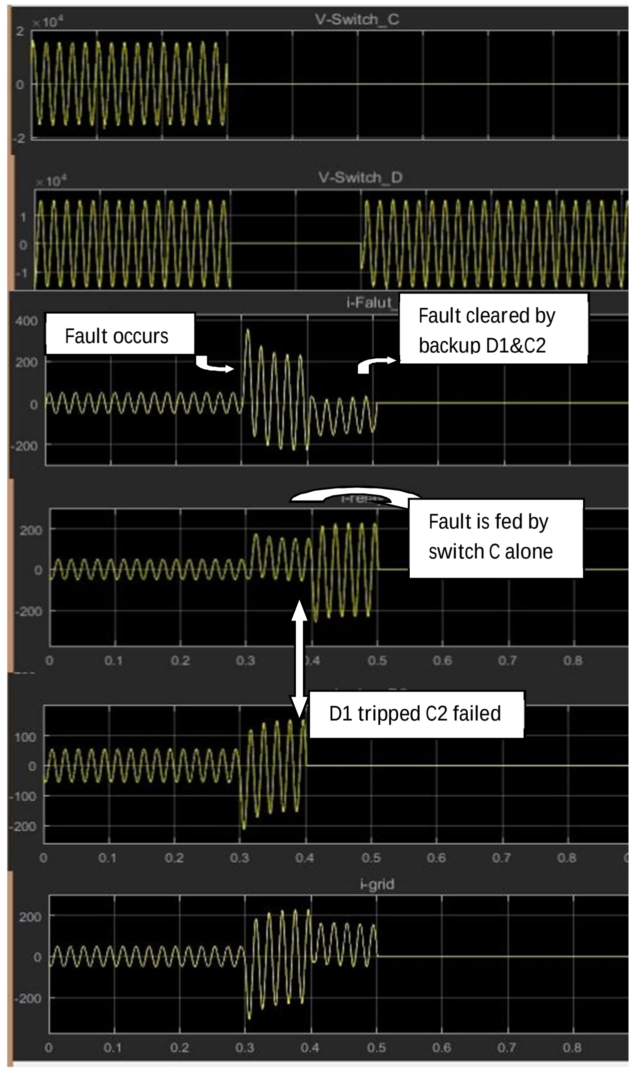

Figure 10. Fault cleared by backup loop PD when POTT scheme is failed

VII. CONCLUSION

From the given simulation result it is clear that the adaptive protection of the microgrid is very important to increase the reliability of the system also to identify the types of the modes and fault levels so that fault can be cleared without affecting or removing the whole load buildings. Since the distance and directional relay is not able to perform very well in both grid connected and islanded mode it become very compulsory to design a system which can adapt to the relay current setting according to requirement since in both grid connected and islanded mode current level is different. Adaptive differential protection system which has been discussed in this paper is able to give a better result than distance and directional protection scheme. As shown in the simulation result load way fault and loop fault can be cleared easily with this scheme but if the fault occurs near the substation PD then one of the relay will experience the more current than the other one and sometimes this condition differential relay failed to clear.

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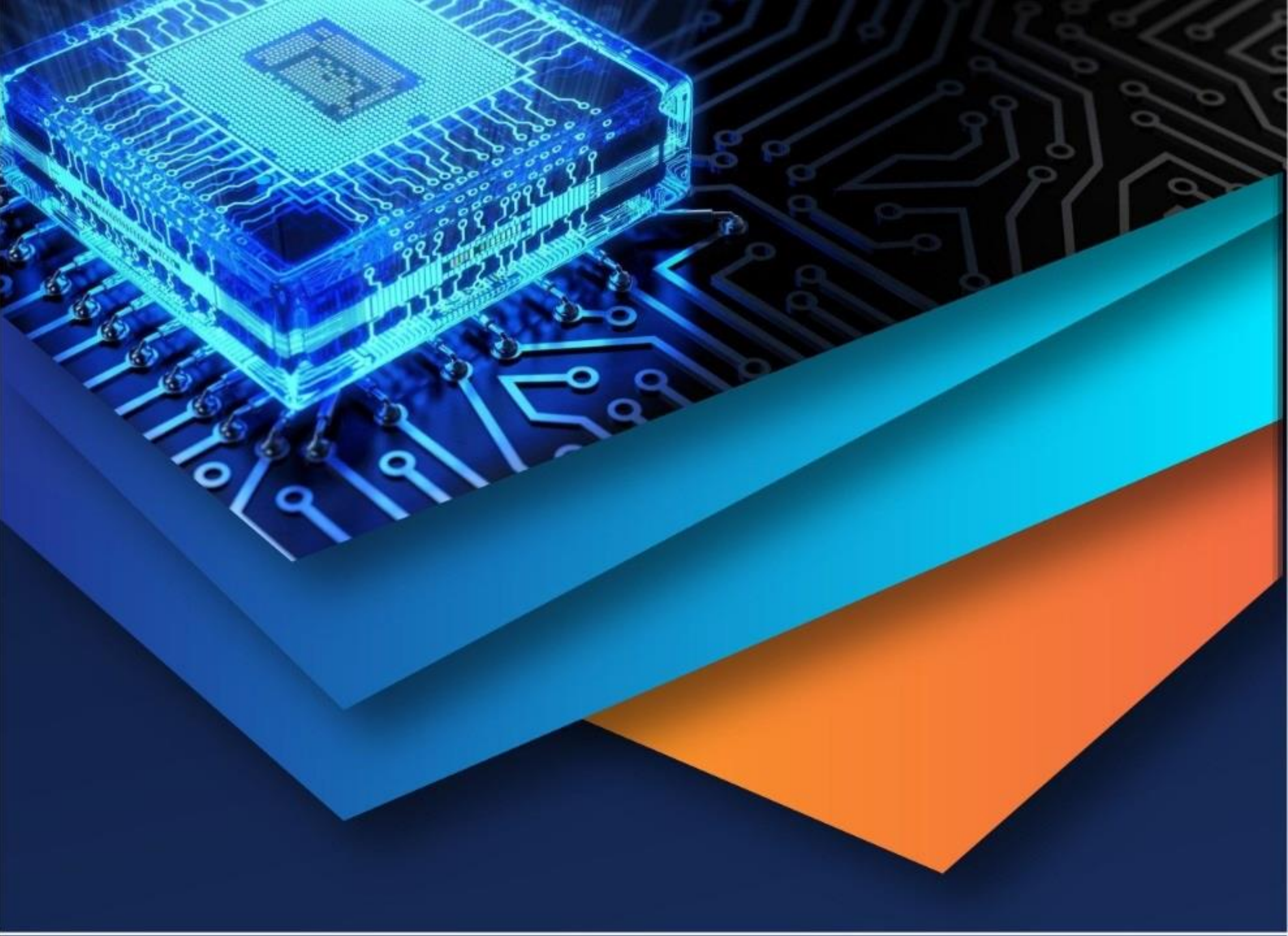

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