A Novel Approach for Fault Observability and Isolation in Distributed Micro-Grid System Using PMUs

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Abstract: ***In a Distributed Micro-Grid System (DMGS), the occurrence of line faults is very frequent due to natural threats to the lines and their ageing. In a big Micro-Grid network a fault is occurred at one corner part of the network shows a serious impact on the entire network by causing a severe deviation in its operation there by leading to shut-down of the entire network until or unless the fault was detected and isolated. In this project in order to resolve the above issues we proposed a novel algorithm for DMGS security by replacing IEDs in former algorithm with Phasor Measurement Units(PMUs)which determines the occurrence of the faults based on the analysis of voltage and current phasors of Power Distribution Bus (PDB) lines. The method exploits the nodal voltage and mesh current analysis where the phase voltage, impedance and admittance matrices of the network and its dual circuit are developed and utilized for smooth detection and isolation of faults without network malfunction. In addition, this method not only detects and isolates the faults but also informs the same to the technical department for immediate correction. The PMUs are organized as independent region monitoring devices controlled by the control unit of DMGS. The proposed algorithm is implemented and verified in MATLAB.***

Keywords: DMGS, PMU, Micro-Grid, Fault Observability, Line faults.

1. Introduction

Faults and device failures affect the power quality in power systems and cause losses for both electric utilities and customers [1]. In Distributed Generation (DG) [4], safety and secure operation of the system highly rely on the level of power system operating condition monitoring. In traditional approaches the measurements provided by the remote terminal units (RTU) at the substations are sent to the control center. This data include real/reactive power in different lines as well as bus voltages and branch currents. The unmeasured states of the system are then estimated by state estimators that reside in the control center. Normal observability in power system is defined as knowing the voltage phasors of all the buses. Fault observability [18], on the other hand, is defined such that a system becomes fault observable when the voltage at two ends of each line and the current at any end of the line are determinable. In general, a system, which is observable in the normal condition, may not be observable for the fault condition. In this project the application of PMUs in fault location [15] is investigated and a method is proposed to effectively reduce the number of required PMUs [16] while retaining the accuracy of fault location [15]. Thus, fault observability[18] is the main focus in this work. In a big distributed micro-grid network a fault is occurred at one corner part of the network shows a serious impact on the entire network by causing a severe deviation in its operation there by leading to shut-down of the entire network until or unless the fault was detected and isolated. This will lead to a heavy loss to the consumers and industries as it disturbs the production process. Unlike the traditional AC distribution systems, protection has been challenging for DC systems. Multi-terminal DC power systems do not have the years of practical experience and standards that AC power systems have. Also, the current power electronic devices cannot survive or sustain high magnitude faults. Converters will shut down to protect themselves under faulted conditions. This makes locating faults in DC system difficult, and causes the DC bus to de-energize. In order to counteract to these issues, a protection method using Intelligent Electrical Devices (IED)[11] was proposed by J candelaria, in which an algorithm is proposed using IED which monitors the assigned zone for faults, if occurred it will de-energizes the entire bus for a while and isolates the faulted zone from the bus and resumes the bus operation with the fault free zones. This algorithm does not inform the control centre about the type and location of the fault occurrence [12] and also it will keep the network unnecessarily in an idle state for a while.

In order to resolve the above issues we proposed a novel algorithm for DMGS security by replacing IEDs in former algorithm with PMUs[16] which determines the occurrence of faults based on the analysis of voltage and current phasors of PDB[9][10]. This method will make use of the nodal voltage and mesh current analysis for smooth detection and isolation of the faults without affecting the network's normal operation. The criterion of determining the number and the places of PMUs is that the fault location and impedance[4] can be obtained in a unique manner without multi estimation. The PMUs are organized as independent region monitoring devices, which not only detects and isolates the faults but also informs the same to the technical department for immediate correction.

2. Proposed Algorithm

In this project we intended centrally to develop an novel algorithm for an efficient and effective observability, detection and isolation of faults that occur frequently in the DMGS systems. Generally a DMGS is a huge network which distributes the power over a large areas surrounding it

.It becomes a gigantic power distribution source[12] for all the major regions surrounding the network. The most practical example of the distributed power system is the Power Grid which supplies the power over the large extent in the regions surrounding it. Some grids will supply the power to several districts surrounding it by treating them as their operational zones. Some big distributed micro-grid systems can have several states around it as their zones of operation. One of the challenging and important issues for the customer is the reliability [2] of the provided electrical energy. At the same time electric utilities wish to reduce the revenue loss caused by outage. For this purpose, the DMGS [5],[6] has to be highly reliable and efficient under not only normal condition but also emergency conditions. Under the situation that DMGS consisting of a number of radial feeders are always subject to the various types of fault caused by storms, lightning, snow, freezing, rain, insulation breakdown, and short circuits caused by birds and other external objects, desired reliability [2] cannot be achieved very easily. In order to improve the reliability, utility should be able to detect and recognize the fault location [15] and type immediately after fault occurs. The faster the fault location is identified or at least estimated with reasonable accuracy, the more accelerated the maintenance time to restore normal energy supply.

In traditional methods, customers' calls are the base of outage troubleshooting. That is, usually the utility starts to identify faults when they are informed by consumers about a fallen electric pole, broken cable, or when they receive complaints about the cut in power supply [3]. In order to specify the exact location of the fault there has to be a precise overlap between the geographic location of the caller and the connectivity of the DMGS network. In addition, if the fault occurs during the night-time, the utility might not receive any calls, which poses a problem for the operator in locating the fault. Also, the barriers such as practical difficulties to install the measurement devices at each distribution system [5],[6] bus or problems such as communication failures limit the possibility of measuring currents in the lines and voltages at the distribution transformers.

Also since the DMGS system is a huge and very complex network, which carries the power transmission [7] operation over large areas surrounding it. The quality and uninterrupted power distribution is achieved with the robust operation of the DMGS system. Reliability [2] of the DMGS system can be improved with its fault free operation. But in general in any DMGS system the faults and device failures are very frequent to occur. These faults can affect the power quality in DMGS and cause losses to both electric utilities and customers by causing an undesirable deviation in their operational condition there by leading to their malfunction[13]. Any unexpected deviation in the normal operational condition of the device is treated as a fault. The possible types of faults that have the probability to occur in the DMGS are discussed earlier in this paper. Naturally in a distributed network, safety and secure operation of the system highly rely on the level of power system operating condition monitoring.

Due to its huge and complex networking structure of the DMGS, a small fault occurred at one remote corner of the network, will cause a large deviation in the operational conditions of the network. For instance, let us consider that the DMGS system is being operated with a ring bus like architecture. The power from the generation stations will reach to the power distribution source from where it is given to excite the power distribution bus(ring bus)[8].From this bus the branches are derived in all directions to supply the power to all the regions surrounding it. For each region in one particular direction an unique branch will be derived. All the bus branches are supplied with power by the power distribution bus (which is of loop structure). A small fault in the corner part of the network due to environmental changes like snow ,rain fall, storms,thunders,birds and animals not only the associated remote branch of the network but also entire power distribution network will get disturbed and creates an essence to primarily shut-down the entire network until the fault and the faulted line is traced and isolated. It takes a huge time to test each and every line to detect the fault and the faulted line. During this time the network will be in an idle (shut-down) state. This will cause a remarkable loss to both production industries, business organizations and other consumers of electricity.

In order to counteract to these issues, a protection method using Intelligent Electrical Devices (IED) was proposed by J candelaria, in which an algorithm is proposed using IED which monitors the assigned zone for faults, if occurred it will de-energizes the entire bus for a while and isolates the faulted zone from the bus and resumes the bus operation with the fault free zones. This algorithm does not inform the control centre about the type and location of the fault occurrence and also it will keep the network unnecessarily in an idle state for a while.

In this project in order to resolve the above issues we proposed a novel algorithm for micro-grid security by replacing IEDs in former algorithm with Phasor Measurement Units(PMUs)[16]which determines the occurrence of the fault based on the analysis of voltage and current phasors of lines[8]. The method exploits the nodal voltage and mesh current analysis where the phase voltage, impedance and admittance matrices of the network [14] and its dual circuit are developed and utilized for smooth detection and isolation of the fault without affecting the network.

Consider a DMGS with 9-line ring bus like architecture as shown in figure (1).Schematically the DMGS consists of a Power Distribution Source (PDS), Rated Power Statistics (RPS) of the bus lines and Power Distribution Control Centre (PDCC).The network derives the bus branches along the perimeter of the ring bus to supply the power to various regions around the DMGS. Let us consider that the region around the 9-line ring bus of the DMGS is divided into nine operational zones. Each of these nine operational zones are assigned with one Phasor Measurement Unit (PMU) s.These PMUs will monitor the bus branch lines of the associated zone for faults [17]. The PMU will performs the comparative analysis of current and voltage phasor relationships on individual bus lines[8] and computes the instantaneous values of the line voltage, impedance and admittance parameter matrices[8] which will be compared with the rated line parameter matrices. PDS will energize the PDB, with the power from the generation units. The RPS unit of DMGS includes the fault free and rated statistics of the line voltage, impedance and admittance parameter matrices which may be used for comparison against their faulted counter parts. Faults in each zone are monitored, detected and isolated by an associated PMU[16] of that zone without disturbing the continuous operation of the DMGS network. The PDCC will have a complete control over the PMUs of all zones. If a fault is occurred in a particular zone, the PMU of that particular zone detects the fault by identifying an

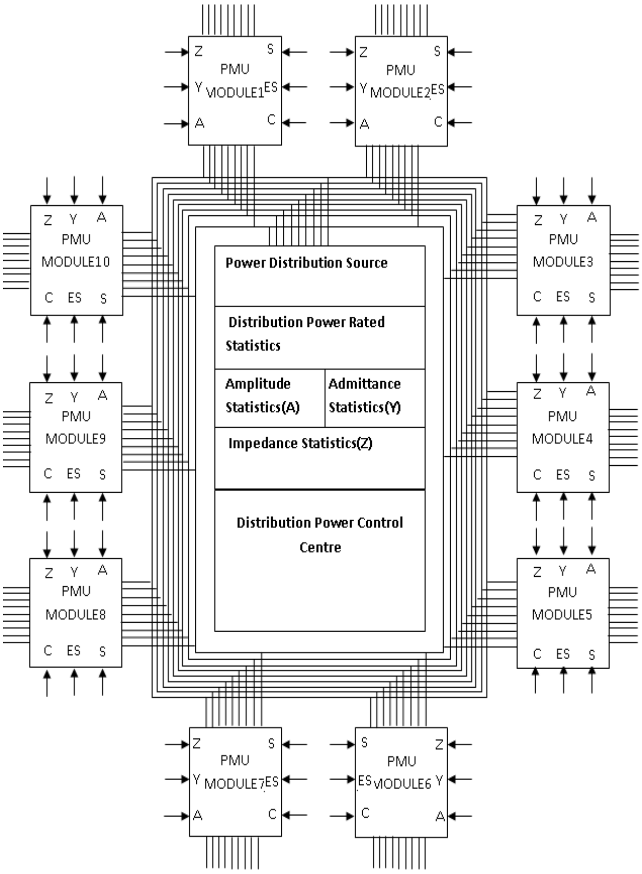

Figure 1: Schematic block diagram of the DMGS with 9-line ring-bus like architecture and PMU Modules.

undesirable deviation in the voltage and current phasor relationship and the mismatch between the rated and instantaneous line parameter matrices. The PMU informs the control centre about the occurrence of fault with the PMUES (PMU Error Status) pin and isolates the faulted line automatically by de-energizing the relay of the faulted line in the controlling breaker without disturbing rest of the network. Each PMU[16] is designed to be operated with the 9-line bus and uses dedicated set of three breakers to route and control the line connections. Each PMU has a complete operational command over the associated three breakers. All the three breakers of a particular PMU are controlled and monitored by it. Each breaker has three control lines such as BC,BS and BTC as shown in figure(2), which are connected to the associated PMU.BC stands for Breaker Control pin by which the PMU enable or disable the particular breaker.

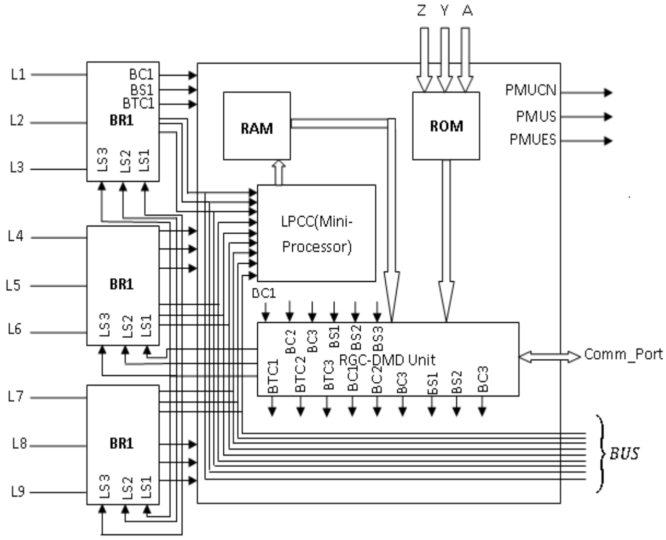

Figure 2: Internal Structure and construction of the Phasor Measurement Unit(PMU)Module.

If BC=1 then breaker is enabled, otherwise disabled by the PMU.BS meant for Breaker Status pin with the signal on which the PMU tests whether the breaker internal components are active or not. If BS=1 then breaker components are working properly and are active, otherwise inactive.BTC is used to represent the breaker trip status. Whenever a fault due to an accountable phasor deviation is occurred on the breaker lines then the PMU will detect this fault and trip the corresponding breaker by enabling the BTC (Breaker Trip Control) Pin of the particular breaker until the fault condition is removed and fault is corrected. If BTC=1 then the breaker will be trip, otherwise untrip by the PMU.At the time of operational initiation all the PMUs in the DMGS are initialized with the rated line parameters from the RPS unit of the DMGS. All the rated statistics of the bus lines are loaded into the ROM unit of PMU directly from the RPS unit of the DMGS

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The internal architecture of the PMU Module [16] is shown in figure (2), which consists of a primary RAM memory unit, a permanent ROM unit, a Line Parameter Calculation Circuit (LPCC), a Robust Giant Comparator and Decision Making Device (RGCDMD) and a serial communication port. The RAM unit is used to store the instantaneous values of line parameters calculated by the LPCC unit temporarily to compare with the rated parameter values from ROM unit in the RGCDMD unit and to act accordingly by the PMU.The ROM unit is used store the rated line parameter values permanently from the RPS unit.

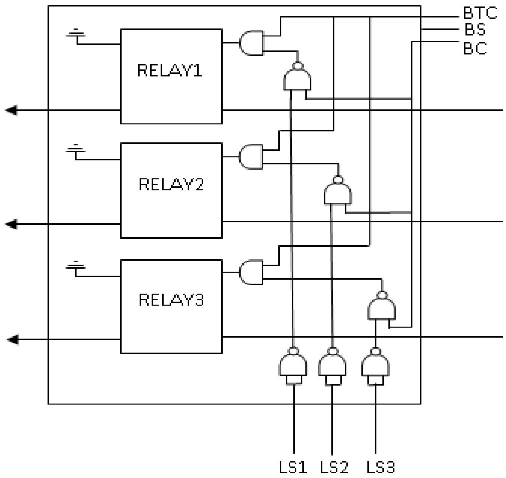

Figure 3: Internal architecture of the breaker circuit.

The LPCC unit is a mini-processor which will calculate the instantaneous values of line parameters of the PMU[16] output bus-line branch.PMU output branch is connected to the PMU through the corresponding breakers.PMU makes a conditional connection between the output bus-line branch with its input bus-line branch and extracts one sample branch from the output bus branch to LPCC Unit to calculate the instantaneous values of line parameters of output bus-line branch. The LPCC unit calculates the real time line parameters of output branch and stores them temporarily in RAM from where they will be routed to RGCDMD unit to compare with their rated counterparts from ROM unit. The RGCDMD unit accepts all the control and status signals of three breakers, instantaneous and rated line parameters as its inputs, compares them and acts accordingly to open and close the bus lines based on their detected fault status. At the same time the RGCDMD unit informs the control centre about the detected fault status through serial communication port. If $BC_{i,j} = 0$,then it informs to control centre that j^{th} breaker of i^{th} PMU is disabled. If $BS_{i,j} = 0$,then it displays that j^{th} breaker of i^{th} PMU is inactive. If $BC_{i,j} = 1$ and $BS_{i,j} = 1$ then the individual breaker lines are checked and if any mismatch is found, the corresponding breaker is tripped and the faulty line of the tripped breaker is isolated until the fault is corrected by the technical department and status is informed to control centre. After the faulted line is isolated, the tripped breaker is untripped to continue its operation with the remaining fault free lines. The faulted line is immediately reclosed by the PMU atonce after the detected fault is corrected by the technical department and informs about the same to the control centre.

The internal structure of the breaker circuit is shown in figure(3),which consists of three relay circuits to control three lines one for each line and the associated control circuitry. Each relay will control and monitor the close or open status of one particular line. Each breaker has three control pins such as BC,BS and BTC with access of which the associated PMU controls its operation..If a fault is occurred in a particular breaker lines, then it will get tripped by making its BTC=1 and based on the logic levels on Line Status(LS)pins such as LS1,LS2 and LS3,the relay of the particular faulted line. when LS1=1 ,then first line of the breaker will faulty and hence isolated from the network. Similarly, if LS2=1,second line of the breaker will be isolated and if LS3=1 then the third line of the breaker will be isolated.

3. Results and Discussion

To verify the proposed protection scheme, computer simulations have been performed using Matlab. The algorithm is designed, programmed and simulated using Matlab.The operational results of the proposed algorithm under fault free conditions of the DMGS system are presented primarily as follows. Under fault free condition the PMU operational status of the DMGS is given in below table (1).

Table 1: PMU Module's operational summary under fault free conditions

PMU OPERATIONAL SUMMARY

SNO	Control Variable	Operational Status
1	PMU Control	Enabled
2	PMU Status	Active
3	PMU Error Status	No Error
4	BR1 Control	Enabled
5	BR2 Control	Enabled
6	BR3 Control	Enabled
7	BR1 Status	Active
8	BR2 Status	Active
9	BR3 Status	Active
10	BTC1 Status	Untrip
11	BTC2 Status	Untrip
12	BTC3 Status	Untrip

If there is no error in the PMU Module of a particular branch, then its control, status and error status are in enabled, active and no error conditions. Ultimately all the breakers will work perfectly and doesn't cause any line trip problem. The PMU Module's operational performance summary is given in table(2).

Table 2: PMU Module's performance summary under fault free conditions.

PMU PERFORMANCE SUMMARY

SNO	PMU_BUS_LINE	LINE_STATUS	AMPLITUDE	IMPEDANCE	ADMITTANCE
1	LINE1	Closed	Rated	Rated	Rated
2	LINE2	Closed	Rated	Rated	Rated
3	LINE3	Closed	Rated	Rated	Rated
4	LINE4	Closed	Rated	Rated	Rated
5	LINE5	Closed	Rated	Rated	Rated
6	LINE6	Closed	Rated	Rated	Rated
7	LINE7	Closed	Rated	Rated	Rated
8	LINE8	Closed	Rated	Rated	Rated
9	LINE9	Closed	Rated	Rated	Rated

The status and variational characteristics of breaker currents of the PMU Module breakers with respect to the operational conditions for fault free operation is illustrated in figure(4).When a particular breaker of the PMU Module is working according to the normal fault free operational condition, then its current variation is also normal and is logic high, otherwise the current variation is abnormal and logic low.

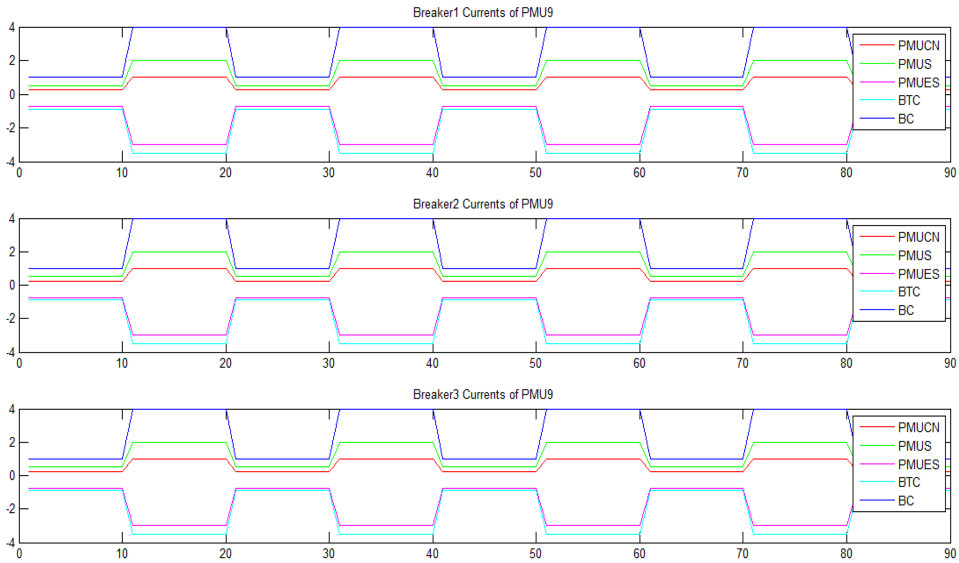

Figure 4: Breaker currents of the PMU Module breakers under fault free condition

Similarly now for faulted operation, the results of the proposed algorithm are presented as follows. Under faulted condition the PMU Module's operational status is given in table(3),and performance status is given in table(4).The variation and status of breaker currents of the PMU Module[16] breakers is shown in figure(5).If there is a deviation (fault) in the operation of PMU breaker lines ,its current will goes to logic low state until the fault is detected and isolated.

Table 3: PMU Module's operational summary under faulted conditions.

PMU OPERATIONAL SUMMARY

SNO	Control Variable	Operational Status
1	PMU Control	Enabled
2	PMU Status	Active
3	PMU Error Status	Error
4	BR1 Control	Enabled
5	BR2 Control	Enabled
6	BR3 Control	Enabled
7	BR1 Status	Active
8	BR2 Status	Active
9	BR3 Status	Active
10	BTC1 Status	Trip
11	BTC2 Status	Untrip
12	BTC3 Status	Trip

Table 4: PMU Module's performance summary under faulted conditions.

PMU1 PERFORMANCE SUMMARY

SNO	PMU_BUS_LINE	LINE_STATUS	AMPLITUDE	IMPEDANCE	ADMITTANCE
1	LINE1	Closed	Rated	Rated	Rated
2	LINE2	Opened	Change	Change	Change
3	LINE3	Closed	Rated	Rated	Rated
4	LINE4	Closed	Rated	Rated	Rated
5	LINE5	Closed	Rated	Rated	Rated
6	LINE6	Closed	Rated	Rated	Rated
7	LINE7	Closed	Rated	Rated	Rated
8	LINE8	Opened	Change	Change	Change
9	LINE9	Closed	Rated	Rated	Rated

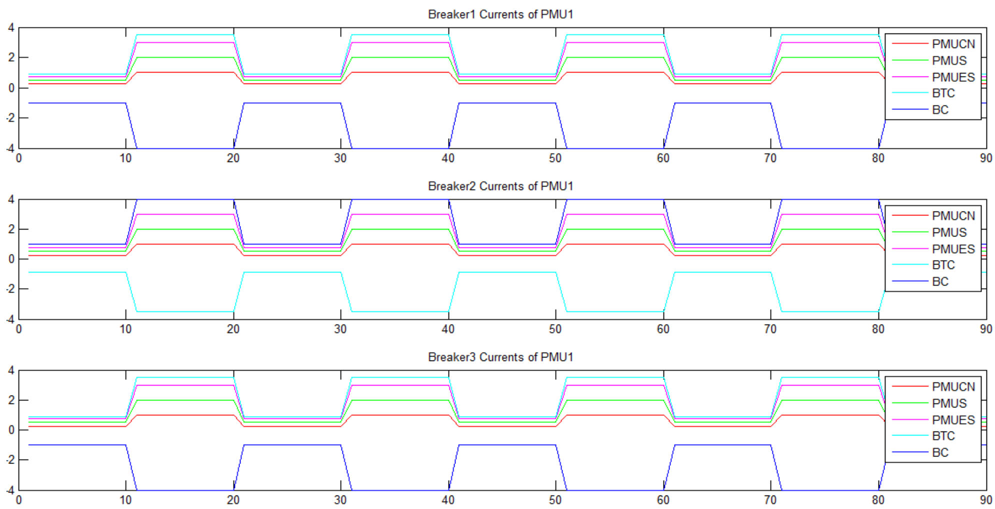

Figure 5: Breaker currents of the PMU Module breakers under faulted condition.

4. Conclusion

The importance to maintain the reliable power system operation demands an efficient fault observability[18] and location algorithms which reduces the time and cost of fault identification and isolation. Robust and fault free operation of a DMGS can benefit the power distribution company, network and also the consumers. Some years of research was dedicated to find an appropriate means for optimized security of the DMGS[5],[6] and Network. As a result, several algorithm were proposed in the literature at an incremental stages of research, but still a rapid improvement in the algorithm and techniques used for adaptive security is demanded by the today's huge, deeply routed and very complex DMGS.

In this effort in order to counteract to the challenges in the adaptive security of the DMGS, we proposed this algorithm with the employment of PMU Modules as the key security monitoring devices. The PMU Module monitors the faults in the associated zone or branch, by closely examining the line voltage and current phasor relationships and with an aid of the so constructed line amplitude, impedance and admittance parameter matrices PDB lines[9][10], it will detect the faults and isolates the faulted lines in very quicker span without disturbing the remaining network. The Proposed algorithm is practically implemented and tested in Matlab.The results of the implementation adjudged that the proposed algorithm is efficient in fault observability and isolation. A closer insight into the results produced by the proposed algorithm reveals the fact that the proposed algorithm outperforms all the existing methods and techniques.

5. Future Work

This algorithm is proven to be the best in performance in all aspects by its performance. In this project in order to reduce the complexity, the proposed algorithm is practically implemented with 9-line ring bus architecture. But there are practical constraints on the size of the network and hence it can be extended to any large size DMGS with increased number of operational zones and any higher order bus. Increase in the physical size of the DMGS network doesn't cause any performance dissimilarities and extra limitations. As a consequence the physical size and processing capability of the internal components has to justified with the proper selection of internal components of matched capacity and efficiency.

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