A Novel Approach for Distributed Generation in Hybrid Power Systems using PMU Control Networks

R.Kamalakar[1], J. Siva Prasad[2]

[1]Student, PG Scholar, CBIT Proddutur

[2]Assistant Professor, CBIT Proddutur

Abstract: ***Distribution Generation (DG) is a renewable energy in small scale near to the load in a distribution system. Installation of DG in power system can reduce the power loss and improve the voltage profile. Thus the DG will serve as an interconnecting network between the Generation and Distribution Units of an Off-Grid Power system. In this project we introduced a novel approach for DG design, modeling and implementation using a widely accepted, universally trusted and highly efficient Phasor Measurement Techniques. The proposed algorithm constructs the PMU Control Network to act as a DG Unit between the generation and the distribution units of the Distributed Generation Off-Grid Hybrid Power System(DG-HPS)s. The PMU Control Network not only serves as DG Unit, but also detects, locates and isolates all types of faults that cause heavy power loss and severe damage to the circuitry in both generation and distribution units of the Off-Grid Power System(OGPS)s. These PMU based DG Units will bridge the generation and distribution units and test on several cases, to find the optimal sizing and location of DG in distributed network to decrease the power loss and to improve the voltage profile. This method has been tested on the standard IEEE-9 bus distribution network using MATLAB R2012a software. The result shows that the proposed DG Units are working well and their performance is well sufficient to meet present application demands of the Off-Grid power systems.***

Keywords: DG-HPS,Distribution Generation(DG),PMU Control Network and OGPS etc.

1. Introduction

The energy cycle consists of generating the energy, its transmission, and delivering to the consumers where the distribution feeders are the last elements of this cycle. The significance of the latter part is not less than the former parts in the electrical power system if not higher. The growth of any power system grid in the world is always has been on an accelerating pace, feeding the almost insatiable demand for electrical power for the past century or so [1, 2]. This in turn forces a certain level of intricacy on the power system, which compounds with time; to the point where the power systems face the inability to progress with ease due to introductions of new transmission systems and construction of generating plants near load centers. As the system grows more complex and burdened with increasing load; various issues regarding cost, pollution, power quality and voltage stability takes centre stage [2].

Distributed Generation (DG) is an electrical power generation unit that is directly connected to a distribution network or placed as nearly as possible to its consumer. The technologies adopted in distributed generation vary in methods of generation including small-scaled gas turbines, wind-farms, fuel cells, solar energy and hydro power plants, etc [1]. DG is both beneficial to the consumers and utilities, much so in places where centralized generations are unfeasible or where deficiencies can be found in transmission systems. One of the challenging and vital issues for the customer is the reliability of the provided electrical energy. At the same time electrical utilities wish to decrease the revenue loss caused by outage. For this reason, the DPS has to be more reliable and efficient under not only routine conditions but also under emergency conditions. Under the situation that DPS consisting of a number of radial feeders are normally subjected to the various types of faults caused by storm, lightening, snow, freezing, rain, insulation breakdown, and short circuit faults caused by birds and other exterior objects, desired reliability cannot be achieved easily. In order to improve the reliability of the DPS, utility should be able to detect and recognize the fault location and type immediately after the fault is occurred. The faster the fault location is identified or at least estimated with reasonable accuracy, the more accelerated the maintenance time to restore normal power supply.

Optimally allocated DG units may address all the issues stated before, resulting in reduced power system losses, improved voltage profile, enhances power transfer capability, reduces pollution and cut generation and transmission cost [3,4].

Benefit-wise, DG unit may offer solutions to the majority of power systems crave. However, installation of a DG unit at a non-optimal place may have the reverse effect instead to the system; such as increases in system losses followed by an increase in cost [5-8]. With that in mind, selecting the most appropriate place for installation paired with the ideal size of a DG unit is of utmost importance in a large power system. Nevertheless, the optimum choice and allocation of DG is a complex integrative optimization method for which common or older optimization method falls short in implementing such a concept in the system [9].In optimization, many techniques are used to solve the problem in power distribution systems. This project aims to find the optimum sizing and location of DG in power system by using PMU Control Network based Distribution Generation. PMU Control Network based Distribution Generation is a population-based optimization method first proposed by

Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling [10].

The PMU-DG as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PMU-DG system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called Pbest), and according to the experience of a neighboring particle (This value is called Gbest), made use of the best position encountered by itself and its neighbor.

2. Proposed Work

In this project we designed ,developed and implemented a Novel DG unit using the most efficient and widely accepted technique called the Phasor Measurement Units and constructed a PMU Control Network to employ as a DG unit in the emerging DG-HPS systems to ensure the real time fault protected and power quality enhanced operation of DG-HPS.We constructed a PMU Control Network to act as an efficient DG unit for fault free operation of DG-HPS.The schematic block overview of the proposed DG- HPS system is shown in figure(1).

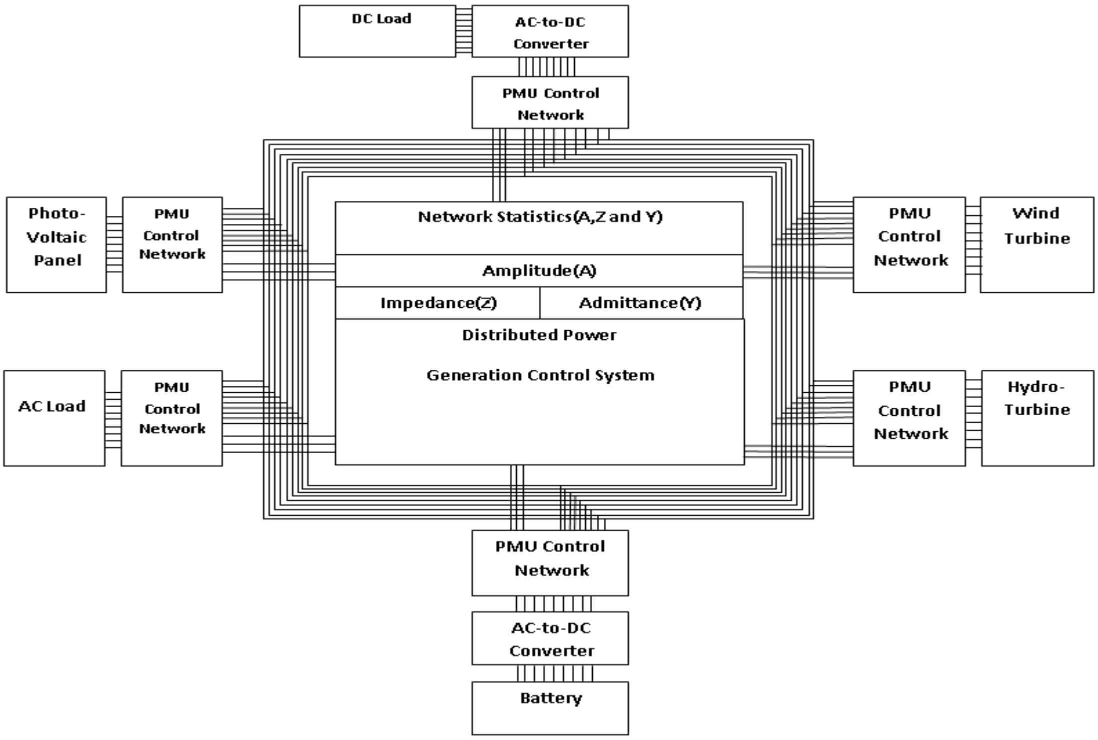

Figure 1: Schematic block diagram of the proposed DG-HPS System

The proposed system consists of a Distributed Generation Hybrid Power System(DG-HPS) which is implemented using a ring bus architecture as shown in figure(1).The ring bus architecture enables the DG-HPS to serve the regions surrounding it with its power. DG-HPS supplies the power to all regions or zones around it .One identical bus branch is drawn to each and every region or zone. Each power distribution bus branch is put under the control of an unique PMU Control Network as shown in the figure(1).Each PMU Control Network will control and monitors the assigned bus branch for faults and acts accordingly to detect and isolate the faults without showing any impact on the operational effectiveness of the DG-HPS.The DG-HPS maintains the data base of rated line parameters values of individual lines of Power Distribution Bus(PDB) and Power Generation Bus(PGB) of the DG-HPS.The rated line parameter values are used as the basis for fault detection and isolation in a DG-HPS.DG-HPS also consists of a Distributed Power Generation Control System(DPGCS),which will control and regulates all operational activities of DG-HPS.DPGCS simply serves as a control system for DG-HPS.All the PMU Control Networks are put under the control and direction of DPGCS.The DPGCS controls all the PMU Control Networks through three control signals. The internal architecture of the PMU Control Network based DG unit is shown in figure (2).The PMU Control Network based DG unit will consists of a PMU Module and its associated bi-directional breakers. An identical set of breakers are used on both distribution and generation sides. The breakers on distribution side are identified with a prefix ‘D’ in their terminology to indicate the distribution side, where as the breakers on the power generation side are added with a prefix ‘G’ in their terminology to indicate the power generation side. The internal architecture of the PMU Module consists of a ROM unit, two dedicated RAM units one for each side (i.e., one for generation side and one for distribution side) ,two mini processes(Line Parameter Calculation Circuit(LPCC)s,each for both PDB and PGB) and a Time Switched Comparator and Decision Making Device(TSC-DMD) units. The time switched checking and comparing operations are adopted so as to check the line faults in both PDB and PGB.A fixed time slot is set to switch the operational status check between the power generation and distribution buses. Required time duration is provided by the Astable multi-vibrator circuit as shown in below figure (2).

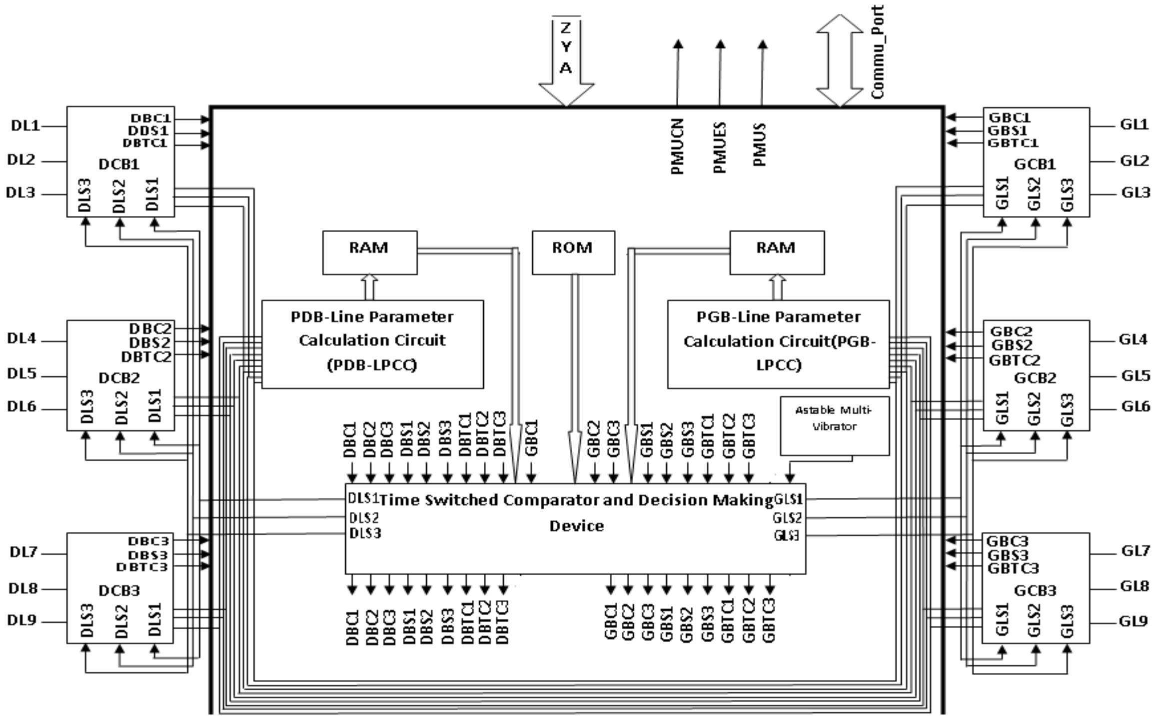

Figure 2: Schematic block diagram of the proposed DG unit.

A devoted mini-processor (Line Parameter Calculation Circuit) is assigned for both Power Generation and Distribution Bus units to calculate the instantaneous line parameter values of PDB and PGB.The objective of ROM unit is to store the rated parameter values from data base unit of DG-HPS.The TSC-DMD unit accepts the instantaneous line parameter values and rated line parameter values along with the control, status and trip signals of the individual breakers as input and processes them accordingly to issue the necessary control signals to all breakers to ensure the fault free and regulated operation of the DG-HPS.A single PMU Module inside the DG unit controls all the breakers on both power generation and distribution sides. Each DG unit is put under the control of the DPGCS unit which will control them with a specialized set of three control signals they are: PMUCN(PMU Control),PMUS(PMU Status) and PMU Error Status(PMUES). The Control signal logical definitions are given as

PMUCN→PMU based DG unit control signal; If PMUCN=1; DG unit is enabled, otherwise disabled.
PMUS→ PMU based DG unit Operational Status. If PMUS=1; All the internal components of DG unit are working perfectly and the DG unit is active at this instance of operation, otherwise there is an error in the operational condition of internal components of the DG unit.

PMUES-PMU based Dg unit Error Status. If PMUES=1; there is a fault in the lines of the bus branch being monitored by this DG unit. Otherwise there is no fault in the lines of the bus branch being monitored by this PMU based DG unit.

At every instant of its operation, the instantaneous operational status of the DG unit is informed in terms of a detailed text message format to the DPGCS unit. The DPGCS unit receives the operational status messages from all the DG units to examine their operation condition and to act accordingly. If the DPGCS unit receives a message stating an error in the operational condition of a particular DG unit, the DPGCS unit passes the messages received from the corresponding DG unit which is monitoring the faulted bus branch for faults to the technical department. Since this message from the DG unit consists of a detailed information about the operational conditions of the region to which it is assigned as an independent region monitoring device, if any line fault is occurred in a region, then that fault condition is precisely identified by its type, location and number of the line suffering from the fault and the same information is informed to the technical department so as enable faster recovery of faults with negligible amount of delay and man power. The internal architecture of the breaker circuit is shown in below figure(3),which consists of three relay circuits to control three lines i.e., 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 will get discharged. When LS1=0, then first line of the breaker will faulty and hence isolated from the network. Similarly, if LS2=0, second line of the breaker will be isolated and if LS3=0 then the third line of the breaker will be isolated.

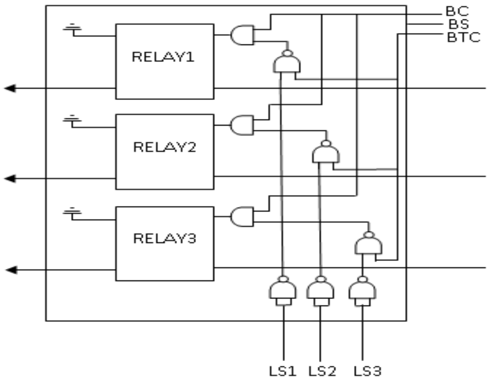

Figure 3: Internal architecture of the breaker circuit

3. Results and Discussion

To verify the operational effectiveness of the proposed DG-HPS, the computer simulations have been performed using MATLAB.The algorithm is designed, programmed with six operational zones or branches and simulated using Matlab.As a first task after starting its operation the DG-HPS initializes all its PMU based DG Units for rated fault free operation. This initialization includes loading the rated parameter values of line voltage, line currents and associated phase deviations by individual DG Units from the DG-HPS. The operational results of the proposed algorithm under fault free conditions of the DG-HPS are presented primarily as follows. Under fault free condition the operational status of the PMU based DG unit on both Generation and Distribution sides are given in table (1) and table (2).

Table 1: PMU Based DG Unit Operational Summary on Generation Side

PMU2 GENERATION UNIT 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	Untrip
11	BTC2 Status	Untrip
12	BTC3 Status	Untrip

Table 2: PMU Based DG Unit Operational Summary on Distribution Side.

PMU DISTRIBUTION UNIT 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 DG Unit of a particular branch, then its control, status and error status are in enabled, active and no error conditions respectively. Ultimately all the breakers will work perfectly and doesn't cause any line trip problem. The DG Unit's performance summary on both generation and distribution sides are given in table (3) and table (4).

Table 3: DG Unit's performance summary on Generation side under fault free conditions.

PMU GENERATION UNIT 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

Table 4: DG Unit's performance summary on Distribution side under fault free conditions.

PMU DISTRIBUTION UNIT 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 DG Unit breakers with respect to the operational conditions for fault free operation on both generation and distribution sides are illustrated in figure (4) and figure (5) respectively. When a particular breaker of the DG Unit is working according to the normal fault free operational condition, then its current variation is also normal and is logic high, otherwise it is logic low.

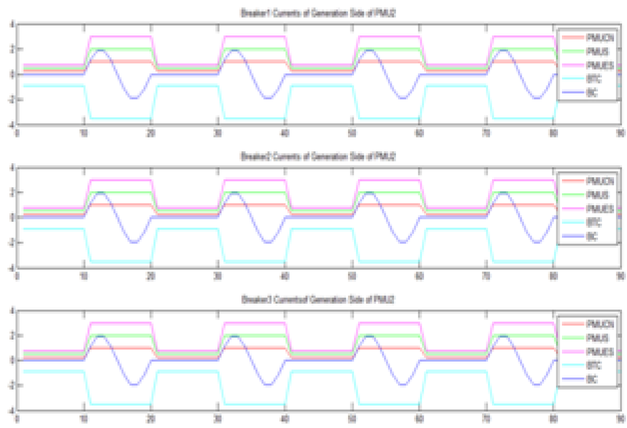

Figure 4: Breaker currents of the DG Unit breakers on Generation unit under fault free condition

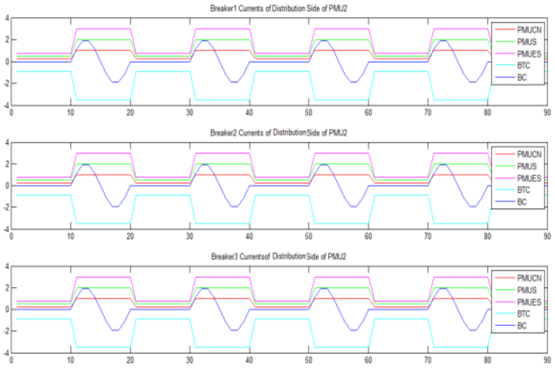

Figure 5: Breaker currents of the DG Unit breakers on Distribution side under fault free condition

The operational results of the proposed algorithm under faulty operational conditions of the DG-HPS are presented primarily as follows. Under faulted condition the operational status of the PMU based DG unit on both generation and distribution sides are given in table (5) and table(6).

Table 5: DG Unit Operational Summary on Generation Side

PMU1 GENERATION UNIT 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	Untrip
11	BTC2 Status	Untrip
12	BTC3 Status	Trip

Table 6: DG Unit1 Operational Summary on Distribution Side.

PMU1 DISTRIBUTION UNIT 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	Untrip
11	BTC2 Status	Trip
12	BTC3 Status	Trip

The DG Unit's performance summary on both generation and distribution sides are given in table (7) and table (8).

Table 7: DG Unit1 Performance Summary on Generation Side.

PMU1 GENERATION UNIT 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	Opened	Change	Change	Change
9	LINE9	Closed	Rated	Rated	Rated

Table 8: DG Unit1 Performance Summary on Distribution Side.

PMU1 DISTRIBUTION UNIT 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	Opened	Change	Change	Change
5	LINE5	Opened	Change	Change	Change
6	LINE6	Opened	Change	Change	Change
7	LINE7	Closed	Rated	Rated	Rated
8	LINE8	Opened	Change	Change	Change
9	LINE9	Closed	Rated	Rated	Rated

The variation of breaker currents of the DG Unit breakers for faulty operation on both generation and distribution sides are illustrated in figure (6) and figure (7) respectively.

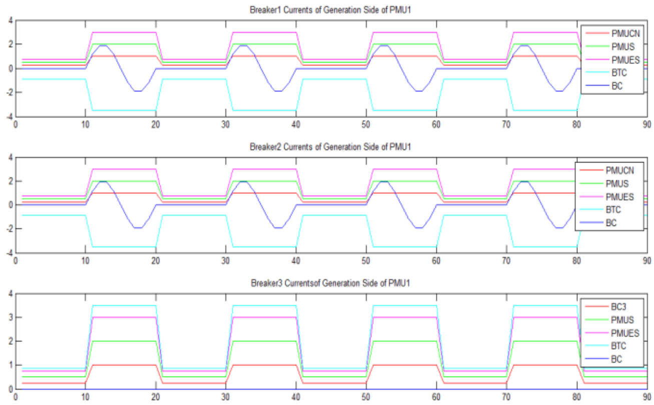

Figure 6: Breaker currents of the DG Unit1 breakers on Generation side.

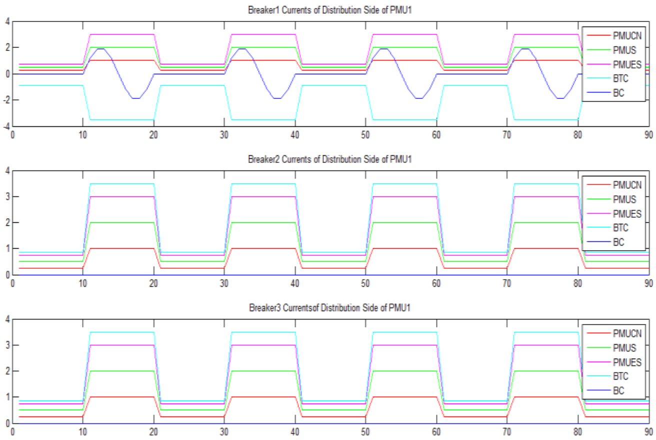

Figure 7: Breaker currents of the DG Unit1 breakers on Distribution side

4. Conclusion

The importance to maintain the reliable HPS operation demands an efficient fault detection and location algorithms on both power generation and distribution sides which reduces the time and cost of fault detection and isolation. As a result, several algorithms were proposed in the literature at an incremental stage 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 distributed power systems.In this effort in order to counteract to the current challenges in the adaptive security of the DG-HPS, we proposed this algorithm with the employment of PMU Control Network based DG units as the key security monitoring devices on both Power Generation and Distribution Sides. The proposed DG Unit 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 of PGB and PDB lines, 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 detection 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 no constraints on the size of the network and hence it can be extended to any large size DG-HPS with increased number of operational zones and any higher order bus. Increase in the physical size of the DG-HPS 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.

References

[1] Mirzai, M.A.; Afzalian, A.A., "A Novel Fault-Locator System; Algorithm, Principle and Practical Implementation," Power Delivery, IEEE Transactions on , vol.25, no.1, pp.35,46, Jan. 2010.

[2] Faradonbeh, M.A.; Bin Mokhlis, H., "Unbalance fault location in electrical distribution system," Electrical Power Distribution Networks (EPDC), 2011 16th Conference on , vol., no., pp.1,8, 19-20 April 2011.

[3] Thukaram, D.; Khincha, H. P.; Vijaynarasimha, H. P., "Artificial neural network and support vector Machine approach for locating faults in radial distribution systems," Power Delivery, IEEE Transactions on , vol.20, no.2, pp.710,721, April 2005.

[4] Javadian, S. A M; Nasrabadi, A.M.; Haghifam, M.-R.; Rezvantalab, J., "Determining fault's type and accurate location in distribution systems with DG using MLP Neural networks," Clean Electrical Power, 2009 International Conference on , vol., no., pp.284,289, 9-11 June 2009.

[5] Barker, P . P . ; de Mello, R . W. " Determining the impact of distributed generation on power systems: part1-radial distribution systems," IEEE Trans. Power Delivery, vol. 15,pp. 486–493, Apr. 2000.

[6] Dugan, R. C.; McDermott, T. E. "Operating conflicts for Distributed Generation interconnected with Utility Distribution Systems, " IEEE Industry Applications Magazines, 19-25, Mar/Apr. 2002.

[7] Yimai Dong; Kezunovic, M., "Fault location algorithm for radial distribution systems capable of handling insufficient and inaccurate field data," North American Power Symposium (NAPS), 2009 , vol., no., pp.1,6, 4-6 Oct. 2009.

[8] Senger, E.C.; Manassero, G.; Goldemberg, C.; Pellini, E.L., "Automated fault location system for primary distribution networks," Power Delivery, IEEE Transactions on , vol.20, no.2, pp.1332,1340, April 2005.

[9] Salim, R.H.; Resener, M.; Filomena, A.D.; Rezende Caino de Oliveira, K.; Bretas, A.S., "Extended Fault-Location Formulation for Power Distribution Systems," Power Delivery, IEEE Transactions on , vol.24, no.2, pp.508,516, April 2009.

[10] R.M. Cuzner and G. Venkataramanan. The status of dc micro-grid protection. pages 1 {8, oct. 2008.

[11] Fairley P. Edison vindicated. IEEE Spectrum, N/A:14{16, February 2011.

[12] X Fu, K Zhou, and M Cheng. Predictive current control of the VSC-HVDC system. International Conference on Electrical Machines and Systems, pages 3892{3896, 2008.

[13] H Chen. Research on the control strategy of VSC based HVDC systems supplying passive network. Power & Energy Society General Meeting, pages 1{4, October 2009.

[14] L Tang and B.T. Ooi. Protection of VSC-multi-terminal HVDC against DC faults. 33rd Annual IEEE Power Electronics Specialist Conference,2:719{724, November 2002.

[15] N Flourentzou, V Agelidis, and G Demetriades. VSC-based HVDC power transmission systems: An overview. Power Electronics Transaction, 24(3):592{602, April 2009.

[16] M.E. Baran and N.R. Mahajan. Overcurrent protection on voltage sourced converter based multiterminal DC distribution systems. IEEE Transactions on Power Delivery, 22(1):406{412, January 2007.

[17] J.L. Blackburn and T.J. Domin. Protective Relaying:Priniples and Applications. CRC Press, 2007.

[18] J Yang, J Zheng, G Tang, and Z He. Characteristics and recovery performance of VSC-HVDC DC transmission line fault. Power and Energy Engineering Conference (APPEEC), pages 1{4, April 2010.

[19] IEEE application guide for "ac high-voltage circuit breakers rated on a symmetrical current basis". 1999.

[20] P.M. Anderson. Power systems protection. 1998.

[21] N.R. Mahajan. Systems Protection for Power Electronic Building Block Based DC Distribution Systems. PhD thesis.

[22] G Ding, G Tang, Z He, and M Ding. New technologies of voltage sourced converter (VSC) for HVDC transmission system based on VSC. Power and Energy Society General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century, pages 1{8, July 2008.

[23] L Tang and B.T. Ooi. Locating and isolating DC faults in multi-terminal DC systems. IEEE Transactions on Power Delivery, 22(3):1877{1884, July 2007.