A Review on Protection Issues in Microgrid

Jayeshkumar G. Priolkar and Vinayak N. Shet

Abstract— Microgrid is cluster of distributed generation sources, storage systems and controllable loads. Microgrid can provide quality and reliable supply of energy to consumer. Microgrid can operate in both modes of operations that is grid connected mode and islanded mode. This implementation poses technical challenge of protecting the microgrid. Power quality, energy management, stability, power flow control, protection system and integration of various distributed generators are the major issues in the microgrid operation. This paper reviews various protection issues in microgrid, various protection schemes to overcome the protection issues are also discussed. Implementation of adaptive protection system using digital relaying and advanced communication is most successful method of the protection of microgrid.

***Index Terms*— Distributed generators, Inverter, Microgrid, Power flow control, Power quality Stability, Protection.**

I. INTRODUCTION

Microgrid is one of the solutions to present energy crisis. It is basically network comprising of distributed generation sources, storage system and controllable loads, which can operate in grid connected mode or incase of fault in isolated mode. Microgrid provides various advantages to end consumer's utilities and society. Various advantages include improvement in energy efficiency, minimisation of overall energy consumption and improvement in service quality and reliability of power supply [1]. The coexistence of multiple energy sources which have versatile dynamic properties and electrical characteristics have impact on safety, efficiency, control and stability of microgrid.

Technical issues associated with operation of microgrid are interconnection and the islanding mode. Interconnection of microgrid with maingrid is complex; complexity in interconnection is affected by the types of power generation number of generating sources, location of points of interconnection and level of penetration of microgrid system with maingrid [2].

Jayeshkumar G. Priolkar is working as Assistant Professor and Vinyak N. Shet is working as Professor in department of electrical & electronics engineering at Goa college of engineering, Farmagudi, Ponda Goa, 403404. (emails are 1. jayeshpriolkar@gmail.com 2. vns@gec.ac.in)

The increased penetration of distributed generation in microgrid system poses several technical problems in the operation of the grid such as steady state and transient over & under voltages at point of connection, protection malfunctions, increase in short circuit levels and power quality problems [3].The major challenge in microgrid is the protection system. Protection system must respond to both maingrid and microgrid faults. Protection system should isolate the microgrid from the maingrid as fast as possible to protect the microgrid. When Distributed generators (DG) are integrated to form the microgrid it is essential to assure that the loads, lines and DG on island are protected. The fast operation of protection improves the ability to maintain synchronism after transition to islanded operation, which is crucial from viewpoint of stability [4].

The various protection issues arises when the integration of DG is done with distribution level network, there is change in faults current level of network, possibility of sympathetic tripping, reduction in reach of distance relays, loss of relay coordination and unintentional islanding [5]. Protection problem arises in island operation with inverter based sources as inverter based sources are limited by ratings of silicon devices [6]. When microgrid is used to improve service continuity, distributed network protections are need to be modified. Automatic and fast operative devices are used to detect faulty portion of network, which disconnects it rapidly and automatically it will also reconfigure the network depending upon requirement [7].

To overcome problems arising due to bidirectional power flows, low fault current levels in microgrid with inverter based sources a new portion system is required with advanced communication system, with real measurements where settings parameters and relay are checked and updated periodically giving safe and reliable operation[2].

II. LITERATURE REVIEW

The various technical issues associated with the integration of the grid, protection challenges and possible solutions are discussed in [1]. Novel adaptive microgrid protection scheme with advanced communication system is also proposed in [1]. For proper integration of microgrid conventional power system protection cannot be used. In Paper [2] authors have reviewed the traditional power system protection concepts and strategies, protection challenges arising from integration of DG into the grid, alternate protection strategies, their merits and demerits are also discussed. The analysis of physical and electrical characteristics of the microgrid, numerical simulations and their influence on design of suitable protection schemes are discussed in [5]. The application of local induction generators on protection selectivity of the system with parallel distribution feeders and defect on fault detection is discussed in [6].Design and implementation of control scheme for microgrid is discussed in [7].Major protection issues arises in islanded operation with inverter based sources, this is mentioned in paper [8].For effective protection, the parameters of the protective devices are to be updated, and how the effective coordination is achieved is discussed in detail in [9].Various technical issues of the protection system with emphasis on protection coordination problem is discussed in [10] .Innovative protection schemes for multiphase and phase to ground faults in MV microgrid are mentioned in [11]. In paper [12] coordinated method to manage both network protection and DG interface protection is proposed. Authors have proposed a protection scheme using digital relays with communicated network for the microgrid [14]. In order to provide an effective network protection to meshed microgrid multilevel approach is adopted in paper [15].The application of admittance relay for protection of the converters used for distributed generator sources is discussed in [16].Paper [17] proposes use of microprocessor based relays for low voltage protection of microgrid. Communication network to monitor the microgrid and update the relay fault currents according to dynamic changes in system such as connection/disconnection of distributed generation sources is mentioned in [18].In [19] various issues related to protection of microgrid are discussed ,authors have used protection strategy, which adaptively selects different fault detection methods in grid connected mode and islanded mode, which improves the selectivity and reliability in protecting the microgrid. Design of microgrid protection system which makes use of current limiters in fault current estimation and uses communication network to monitor and update the relay fault currents according to variations in the system is proposed in [20].Paper [21] discusses about the protection issues related to inverter interfaced distributed generators and various protection schemes available. In [22] for a particular microgrid, protection scheme is developed which makes use of abc-dq transformation of system voltage to detect presence of short circuit fault and by comparing measurements at different locations provides discrimination between faults in different zones of protection. For protection of synchronous based distributed generators, scheme based on directional overcurrent relay is proposed in [23]. Various protection techniques and control strategies have been proposed to ensure a stable operation and to protect the distributed generation sources [24 - 26].

III. Protection Issues

Fault currents for grid connected and islanded operation of microgrid are different. The short circuit power varies significantly. Faults also causes loss of sensitivity, overcurrent, earth leakage, disconnection of generators, islanding, reducing reach of overcurrent relays , single phase connections and loss of stability[2].Depending upon location of faults with respect to distributed generators and existing protection equipment, problems like bidirectional power flow and change in voltage profile occurs. The power output of distributed generators like synchronous generators, induction generators and inverter interfaced protection units is unpredictable due to which whenever there is a fault, power output of these DG sources changes [5].Modification in fault current level, device discrimination, reduction in reach of impedance relays, reverse power flow, sympathetic tripping, islanding, single phase connection, selectivity are the key protection issues.

A. *Modification in fault current level*

When large number of small distributed generation units that uses synchronous or induction generator units are connected to distribution network or grid it changes fault current level as both types of generators contribute towards fault currents. When inverter interfaced DG units are used, fault current is limited to a lower value [7,20]. As fault current is not high as compared to load current, some of the relays do not trip, others that respond to fault operate with the time delay. The undetected fault spreads out in the system and can damage the equipment [2]. Fault impedence also decreases when DG is connected into network in parallel with the other devices. When faults occurs downstream of the point of common coupling, both the main source and DG contributes fault current. Relay placed at upstream of DG measure fault current supplied by upstream source. In Fig. 1 the relay placed at the upstream of DG measure the fault current supplied by upstream source. Actual fault current is different, relays will not function properly and there will be coordination problems. If there is short circuit fault, when DG is integrated with the main grid it will affect the amplitude, direction and duration of fault currents.

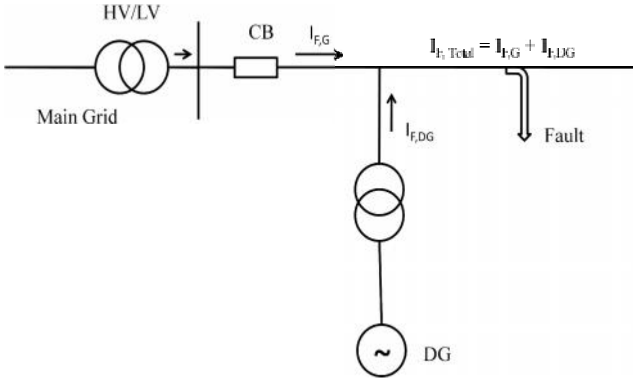

Fig. 1.Fault current contribution from DG and grid

B. *Device discrimination*

In the power system network that has generation sources at the end of network , fault current decreases with increase in distance as the impedance increases. The variation in magnitude of fault current is used for discrimination. Incase of islanded microgrid with inverter interfaced distributed generation units , fault is limited to a lower value ,fault level at the locations of feeder will be almost constant [9].The traditional current protection scheme which uses the variation in magnitude of fault current for discrimination does not work properly. New protection system for device protection is required.

C. Reduction in reach of Impedance relays

The reach of impedance relay depends upon the distance between the relay location and fault point , maximum distance means minimum fault current that is detected [2]. When DG is present in the system, distance relay may not operate according to defined zone settings. When faults occurs downstream of the bus DG connected to utility network, impedence measured by relay located in upstream is higher than real fault impedence. This affects grading of relays and causes delayed operation or sometimes relay does not operate at all**.**

D. Reverse Power flow

Main challenge for protecting the microgrid arises because power can flow in both the directions in each feeder of microgrid. Sources are located in both sides of load due to which power flows in opposite direction from two sources towards the load. Power flow also changes its direction incase of distribution network with embedded generation when local generation exceeds local consumption [2]. The reverse power flow can also cause power quality problems resulting in variation of voltage.

E. Sympathetic Tripping

This occurs when protective device operates for faults in an outside protective zone. DG contributes towards the fault; relay operates alongwith another relay which actually sees the fault resulting in malfunctioning of protective scheme. Relay on line 2 will unnecessarily operate for fault F_1 at line L_1 as a result of infeed from DG to fault current as shown in Fig.2

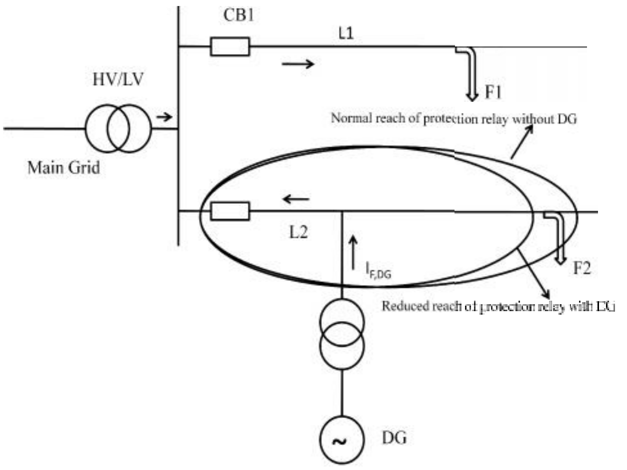

Fig. 3. Underreaching of relay and sympathetic tripping due to DG connection

F. Islanding

The DG creates a problem when part of distributed network with DG unit is islanded. Islanding is due to fault in the network. If generator continues to supply power despite the disconnection of utility, fault might persist as fault is fed by DG [2, 4]. If the control for the voltage is not provided, it results in unexpected rise in voltage levels incase of islanded operation.

G. Single phase connection

Some DG sources inject single phase power into the distribution grid, for example PV systems. This affects balance of three phase currents, due to unbalance current in the neutral conductor increases which also results in flow of stray currents to earth. This current should be limited to prevent overloading.

H. Selectivity

Protection system is said to be selective if the protection device closest to the fault operates to remove the faulty section. Without DG, there is power flow in only one direction, during normal operation as well as when there is fault, by using time graded overcurrent relays selectivity can be obtained .When DG is integrated with the grid ,this systems becomes inadequate. There is possibility of disconnection of healthy feeder by its own protective relay because it contributes to the short circuit current flowing through fault in the neighboring feeder. The tripping current for electrical protective device is between maximum load current and minimum fault current. Fault current and load current depends upon the state of grid, state of distributed generators and whether microgrid is operating in islanded mode [9].

.

The main challenge for protecting the microgrid arises from the fact that power can flow in both the directions in each feeder of the microgrid. Close to each local load, there may exist two or more sources that contribute to the loaded power. The sources are located in both sides of load due to which power flows in opposite direction from two sources towards the load

IV. CASE STUDY ON STUDIED MICROGRID

Particular case for the microgrid is considered for study as shown in the Fig. 4. Different fault scenarios in microgrid are considered to see the operation of circuit breaker and coordination between circuit breakers as listed in Table I

TABLE I

MAJOR CLASSES OF MICROGRID PROTECTION [1]

Operating mode	External Faults (Main grid)		Internal Faults (Microgrid)	
	MV feeder,(F1)	Distribution Transformer (F2)	LV feeder (F3)	LV Consumer (F4)
Grid connected (CB1) closed	Fault is managed by MV system Microgrid isolation by CB1 incase no MV protection tripping. Possible fault sensitivity problems for CB1	Fault is managed by MV system (CB0) .CB1 is open by follow me function of CB0. Incase of communication failure ,sensitivity problem for CB1	Disconnect smallest portion of microgrid (CB 1.2 and CB 2.1).CB 1.2 is opened by fault current from the grid (high level). Low level of reversed fault current causes sensitivity problems.	Faulty load is isolated by CB 2.4 or fuse. Incase of no tripping the SWB is isolated by CB 2.5 & local DG is cut off.
Isolated (CB1 open)			Disconnect smallest portion of microgrid (CB	Faulty load is isolated by CB 2.4

			1.2 and CB 2.1). Low level of fault currents causes sensitivity problems for both CB	or fuse. Incase of no tripping the SWB is isolated by CB 2.5 and local DG is cut off

A. Fault Analysis

Scope of fault analysis in this paper is to estimate the magnitude of current under short circuit condition. Fault level indicates strength of system; selection of circuit breaker and design of coordination system for protective relaying is done based on fault analysis. Fault analysis in this paper done for the typical microgrid as shown in Fig.4. The ratings and parameters of the equipments considered for typical microgrid for analysis is given in appendix. For fault analysis base kVA selected is 630 kVA, base voltage is 400V and fault location is at F3. Table II indicates comparison of fault currents for different faults, Table III shows the comparison of fault currents in different modes.

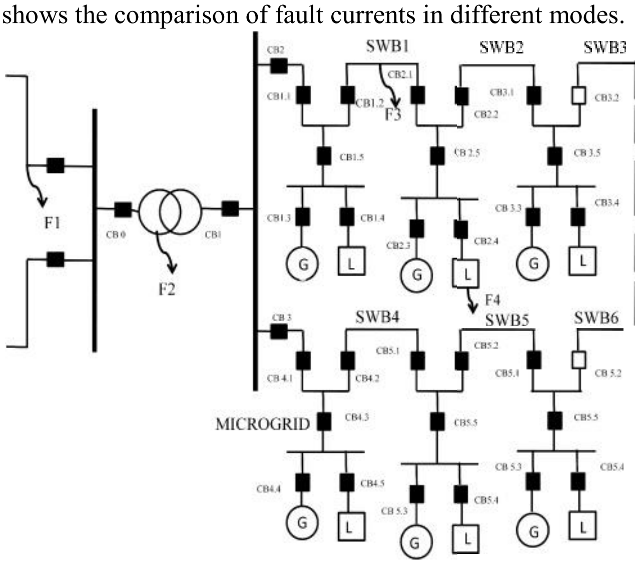

Fig. 4. Different Fault scenarios of Microgrid [1]

TABLE II
COMPARISON OF FAULT CURRENT FOR DIFFERENT FAULTS

Type of Fault	Location	Fault current
Three Phase	F_3	14.57 kA
Single Line to Ground	F_3	8.02 kA
Double line to Ground	F_3	8.0 kA

TABLE III
COMPARISON OF FAULT CURRENT IN DIFFERENT MODES

Type of operating mode	Fault Location	Magnitude of fault current
Grid Connected with DG	F_3	14.57 kA
Islanded mode	F_3	5.857 kA
Grid Connected Mode without DG	F_3	7.913 kA

From the fault analysis done it can be concluded that there is change in fault current level during different modes of operation in microgrid, which makes protection system design for entire network complex.

V. POSSIBLE SOLUTIONS FOR PROTECTION ISSUES

There are various solutions available to overcome protection challenges in the microgrid network. Whenever there is reverse power flow or bidirectional power flow, main relays of feeders which are fed from the substation can be interlocked [11]. The use of directional over current relays can also solve this problem. The other solution is main feeder relay adjustment in terms of time settings. Feeder without DG can have faster relay settings as compared to feeder with DG.

A. Protection of inverter interfaced DG units

Conventional protection systems cannot give reliable protection for inverter interfaced units, because there is limited fault current. The solution can be achieved by using inverters which have high fault current capability that is uprating the inverter, using faster communication system between Inverter and protective relays, and introduction of energy storage devices that are capable of supplying large current incase of faults [2].

B. Differential protection scheme

The conventional differential protection cannot give the reliable protection. The protection scheme for microgrid with Inverter interfaced DG units cannot differentiate between fault current and an overload current, which results in nuisance tripping when system is overloaded, in some instances traditional protection scheme. For proper clearing of fault in an islanded microgrid and to ensure selectivity ,it is important that different distributed generators should effectively communicate with each other. Use of evolving distribution system version of pilot wire line differential scheme is required for protection [2].

C. Balanced combination of different types of DG units

To obtain the protection of an isolated microgrid is to use DG units with synchronous generators or to use inverters having high fault current capability or to use combination of both types of DG units so the conventional protection schemes can be properly used.

D. Inverter Controller design

Protection scheme for islanded microgrid is dependent on type of inverter controller, controller can actively limit the available fault current from inverter interfaced distributed generator units.

E. Protection based on symmetrical components and differential components of currents.

Microgrid can be protected against unsymmetrical faults based on symmetrical components. As per the studies carried out for differential and symmetrical component of currents , a symmetric protecting the microgrid against all single line to ground and line to line fault is developed[8,23].

F. Adaptive protection for microgrid

Adaptive protection scheme solves the problem both in grid connected as well as islanded mode [1,19]. In adaptive protection system there is automatic readjustment of relay settings when microgrid changes from grid connected mode to islanded mode and from islanded mode to grid connected mode. Adaptive protection is an online system that modifies preferred protective response to change in system conditions or requirements in timely manner by means of external generated signals or control actions. Technical requirements and suggestions for practical implementation of an adaptive protection system make use of numerical directional overcurrent relays. Numerical directional overcurrent relays should have possibility of using tripping characteristics (several settings groups) that can be parameterized locally or locally. For effective protection make use of communication system and standard communication protocol such that individual relays can communicate and exchange information with a central computer or between different individual relays. Main components of centralized adaptive protection system are microgrid central controller and communication system. Main goal of adaptive protection is to maintain settings of each relay with regard to current state of microgrid. Microgrid central controller has module which is responsible for periodic checking and updating relay settings. Microgrid Central controller will monitor the state of microgrid by polling all individual directional overcurrent relays. Module basically consists of two components one of which has information about the precalculated values of fault parameters which is done during offline fault analysis of given microgrid, second one is online operating block. Adaptive directional interlock is used in avoiding the nonselective operation of relays in the microgrid. Adaptive protection is used to send the blocking signals in the right direction so that relays on both sides of faulty element trips and fault is isolated.

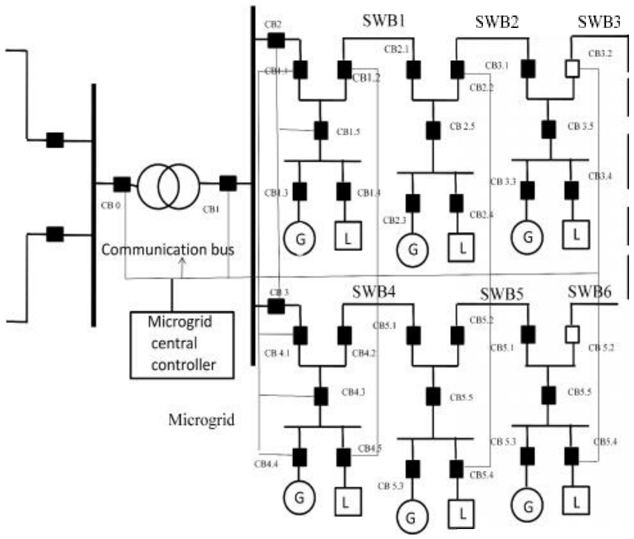

Fig. 5. Centralised Adaptive Protection System [1]

VI. CONCLUSION

Various protection issues that arise when microgrid is integrated to main grid are discussed and analysed in this paper. Technical challenges like change in fault current level of the network, possibility of sympathetic tripping, reduction in reach of distance relays, loss of relay coordination, unintentional islanding are briefly discussed. From the fault analysis carried out on the particular case of microgrid it is observed that fault current level changes depending upon modes of operation which poses the challenge while designing protection system. Adaptive microgrid protection system is the best solution to overcome all the problems associated with all issues in microgrid.

APPENDIX

Distribution Transformer Parameters: - Rated apparent power: 630 kVA, Rated voltage primary/secondary: - 6000/400 V Z_{1t}=j0.1, Z_{2t}=j0.1,Z_{0t}=j0.1.
Synchronous generator parameters: - Rated voltage: - 400V, Rated power :- 160 kVA, Z_{1G}=j0.235, Z_{2G}=j0.098,Z_{0G}=j0.027
XLPE Cable:- Nominal current :- 750 Amps, Length of cable :- 150 meters, cable impedence ;- 0.321 ohms.
Source Impedance =j0.0126 (assumed).

REFERENCES

[1] A.Oudalov and A. Fidigatti, "Adaptive network protection in microgrids," *International Journal of Distributed Energy Source*, vol. 4, pp. 201–205, 2009.

[2] B.Hussain, S.Sharkh, S.Hussain, and M.Abusara,"Integration of distributed generation into the grid: protection challenges and solutions," 10th IET *International Conference on Developments in Power System Protection,* pp. 1-5, March/April 2010.

[3] N.D.Hatziagyriou and A.P.Sakis,"Distributed energy sources: Technical challenges," *IEEE Power Engineering Society General meeting,* 2002.

[4] H .Laaksonem and K. Kauhaneimi, "Voltage and frequency control of low voltage microgrid with converter based DG units," International J*ournal of Integrated Energy Systems Integrated Energy Systems*, vol. 1, no. 1, pp. 47–60, June 2009.

[5] C.Stefinia, R. Lorenzo, and V. Umberto, "Analysis of protection issues in autonomous MV microgrids," in *Proc.of Power conversion conference ,Nagoya*, 20th *International Conference on Electricity Distribution* , pp. 1-5, June 2009.

[6] J.Driesen, P. Vermeyen, and R. Belmans, "Protection issues in microgrid with multiple distribution generation units," in *Proc.of Power Conversion Conference,Nagoya*, pp. 646-653,October 2010.

[7] Z.Wang, X.Huang ,and J. Jiang , "Design and implementation of a control system for microgrid ," in *Proc. IEEE Electrical power conference* , pp.25–26, October 2007.

[8] H. Nikkhajoei and R. Lassester, "Microgrid Protection," in *Proc.of IEEE power engineering society general meeting,* pp. 1-6, June 2007.

[9] B.Kin , K. Jung , M. Choi , S. Lee ,S. Huyan , S. Kang, "Agent based adaptive protective coordination in power distribution system ," in *Proc.CIERD, 17th International Conference on Electricity Distribution* pp. 1–7, May. 2003.

[10] B.Hussain, S.Sharkh, S.Hussain, M.Abusara , "Impact studies of distributed generation on power quality and protection set up of an existing network*," International symposium on Power Electronics, Electrical drives ,Automation and Motion,* pp. 1243-1246, March 2010.

[11] S. Conti, L. Raffa and U.Vagliasindi, "Innovative solution for protection schemes in autonomous MV microgrids," *International Conference on Clean Electrical Power,* pp. 647–654, 2009.

[12] S.Conti and S.Raiti, “Integrated protection scheme to coordinate MV distribution network devices,” *International Conference on Clean Electrical Power*, Nov. 2008, pp. 640–646, 2009.

[13] E.Sortomme, S.SVenkata and J. Mitra , “Microgrid Protection using communication assisted digital relay,” *IEEE Transactions on Power Delievery,* Vol. 25 , No. 4, pp. 2789-2795,October 2010.

[14] A. Parsai, T.Du, A.Paqette, E.Buck, R. Harley, and D. Divan, “Protection of meshed microgrids with communication overlay”, Energy Conversion Congress and Exposition, pp 64-71,2010.

[15] M. Dewadasa , R. Mazumdar ,A. Ghosh and G. Ledwich , “Control and protection of a microgrid with converter interfaced micro sources*”, 3rd International Conference on Power Systems,* 2009.

[16] M. A. Zamani , T.S. Sidhu, and A. Yazdani "A protection strategy and microprocessor based relay for low voltage microgrids," *IEEE Transactions on Power Delivery,* Vol. 26, No.3, pp. 1873-1883,July 2011.

[17] T.S.Ustum, C. Ozansoy and A. Zayegh, “A Microgrid protection system with central protection unit and extensive communication” 10th IET *International Conference on Environment and Electrical Engineering, 2011.*

[18] K.Dang, X. He,D. Bi, and C. Feng “An adaptive protection for Inverter dominated microgrid ,”*International Conference on Electrical Machines and systems*, pp. 1-5, 2011.

[19] S.Ustun,C.Ozansoy,and A.Zaygeth, “A centralised microgrid protection System for network with fault current limiters,” *10th International Conference on Environment and Electrical Engineering,* 2011.

[20] S. Conti, “Protection issues and state of art microgrids with inverter interfaced distributed generators,” *International Conference on Clean electrical power, pp. 643-647, June* 2011.

[21] H. Al-Nasseeri, M Redifern, and R.Gorman, “Protecting microgrid systems containing solid state converter generation”, *International Conference on Future Power System, pp.1-5,* 2005.

[22] H.Zeineldin,E.Saadany,and M.Salama, “Protective relay coordination for microgrid operation using particle swarm optimization”, *IEEE Transactions on Power Delivery,* pp. 152-157,2006.

[23] W. E .Ferro , D.C. Dawson and J. Steavans, “White Paper on Protection Issues of Microgrid Concept”, March 2006.

[24] F. Katiarei,M.R Iravani,and P.W.Lehn, “Microgrid autonomous operation during and subsequent to islanding process” *IEEE Transactions on Power Delivery,* pp. 248-257,2005.

[25] N.Poaku,M.Prodanovic,andT.C.Green, “Modelling,analysisand testing of autonomous operation of an inverter based microgrid” *IEEE Transactions on Power Electronics p*p. 613-625,2007.

[26] J.A.Pecas,C.Moreira,and A.Madureira, “Defining Control strategies for microgrids islanded operation” *IEEE Transactions on Power Electronics p*p. 916-924,2006.