A Review on Protection Issues in Micro-Grids Embedded with Distribution Generations

Ali Khademlahashy, Li Li, Jeremy Every, Jianguo Zhu

School of Electrical, Mechanical and Mechatronic Systems, University of Technology Sydney, Australia
Ali.khademlahashy@student.uts.edu.au, Li.Li@uts.edu.au, Jeremy.every@student.uts.edu.au, Jianguo.Zhu@uts.edu.au

***Abstract*—According to recent developments, the application of distributed generations (DGs) has become popular especially in distribution systems. The high utilization of distributed generating resources in modern power systems can cause new challenges from protection coordination perspectives. Changing the distribution system structure from single-supply radial system to multi-source ring network, leads to the bidirectional power flow and also has a vital impact on protection coordination issues. In addition, micro-grids can be operated under grid-connected as well as islanded mode, and fault current is extensively different for these two operation modes. Therefore, traditional protection algorithms cannot be used in the advancement of power systems. In recent years, several research studies have been conducted to investigate the improvement of protection schemes in micro-grids. This paper presents a comprehensive review on protection problems resulting from micro-grids embedded with DGs, and discusses some alternate protection strategies.**

Keywords—Micro-grid Protection; Islanding; Distribution system; Multi-function relays

I. Introduction

Recently, the application of renewable energy sources in the competitive electricity markets has gained significant attention due to the economic and environmental concerns associated with fossil fuel-based energy resources as well as depletion of such resources [1]. Micro-grid is the combined energy resources which can consistof distributed energy resources, multiple electrical loads and energy storage devices. It can be connected to the utility and has the capability of operating in parallel to or islandedly from the distribution network [2]. One of the tremendous benefits of micro-grid on the distribution system is having dynamic responses to a wide range of local demands. Using micro-grid has some critical challenges in distribution networks such as energy management, control and protection [3], [8]. In a traditional distribution system, protection devices operate based on fault current magnitude and unidirectional power flow [4]. That's why, overcurrent relays, fuses and reclosers are the main equipment for protection of traditional distribution networks [9], [10].

In the normal condition, micro-grid works in the grid connected mode. In case of any faults, it has to disconnect itself from the network, working on the islanded mode, and operate in this mode until the normal condition in the grid. One of the most important benefits of micro-grids is providing more reliable supply to consumers by the capability of changing mode from grid connected to islanded in the event of any faults [13]. One of the main protection issues in micro-grid is the capability of islanding during the contingency and having the reliable operation under abnormalities [2], [12].

II. Problems of Conventional Protection in Micro-Grids Embedded with Distribution Generations

Overcurrent relays, fuses and reclosers are used as the protection of distribution system without DGs in conventional protection schemes at the low voltage level [14]. But with connecting DGs to the distribution system, conventional protection system cannot operate correctly. Part of these challenges can be addressed with the aid of micro-grids. Some problems of traditional protection schemes in micro-grids embedded with DGs are as follows:

A. Bidirectionality

Changing from single supply to multi-source network leads to having power flow in any directions in the network. Also, it has had a significant effect on protection schemes. The unidirectional relays in conventional systems cannot detect any faults from the reverse power flow. Tap changer of transformers for regulating of voltage can be influenced with using DGs in distribution networks by reducing the load on the transformer [5]. Using directional overcurrent relay is proposed for solving the bidirectionality problem [17]. Also, using an interlocking system with the relay of the feeder that is connected to the DG can solve the problem of bidirectionality too [5]. In this case, when a fault occurs in the zone out of the feeder having DG, a relay that detects a fault sends a locking command to the relay that protects the DG for avoiding maloperation [5]. Being complicated and impractical is the major disadvantage of this method. Most relays in distribution level are adjusted as definite time. With readjustment of main feeder's relay to critical clearing time on the point of common coupling (PCC) can recognize faults in the reverse power flow [5], [6]. But all of them have some disadvantages such as the complicated locking signal [7], fault current limitation for directional overcurrent and being careful about this readjustment so that it can overlap with downstream protection coordination [5], [11].

B. Fault Current Limitation

Using the static switches in the micro-grid has had a direct effect on protection systems [15]. The conventional protection system is designed based on maximum fault current and single supply network. Since the fault current is limited in an islanded MG with inverter-interfaced DGs, the protection relays cannot operate properly [16]. The maximum fault is limited about two times of the rated output current in these types of DGs. As a result, fault current levels are different in the grid-connected and islanded modes. Because of this difference, using fixed settings for micro-grid relays is not suggested and leads to relay maloperation and reduced network reliability [15].

Besides, as a different scenario using DGs in distribution systems can result in an increase of the fault current levels in the grid-connected mode because they can contribute to the network fault current too [5]. The increase of short circuit level of the system can affect the core saturation of instrument devices such as current transformers and operation of protection relays and fuses.

C. Blinding of Protection

Because of the contribution of DGs in the fault current in grid connected mode, if the fault occurs somewhere supplied with both the DG and distribution network, the relay that is located at the PCC beginning of the feeder measures the fault current which magnitude is less than the actual value; see Fig. 1. This incident may result in having a delay in relay operation or no operation because of current reduction, thus leading to malfunction of relays [18], [19].

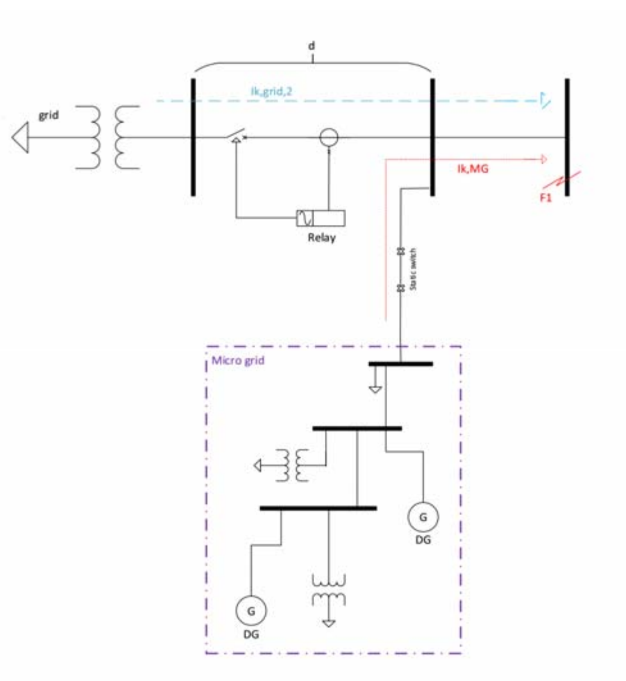

Fig. 1. Blinding of protection in grid connected mode

D. Sympathetic / False Tripping

This is one type of relay maloperation and it may happen when faults occur at another feeder and the healthy feeder may be isolated because of its relay maloperation [5]. It happens when the connected DG of a feeder provides the fault current with the fault occurring in an adjacent feeder [18]; see Fig. 2. The increased fault current level can increase the possibility of sympathetic tripping in the network [2], [20].

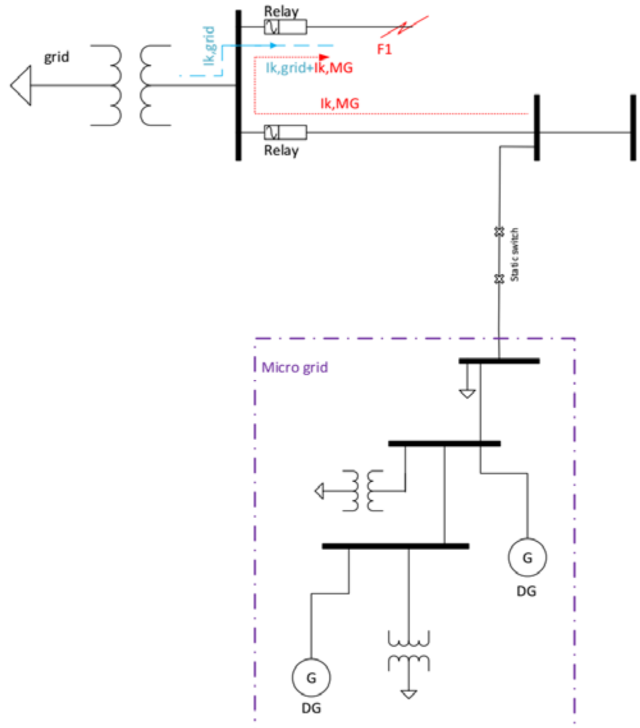

Fig. 2. Sympathetic tripping

E. Device Discrimination

Since the traditional network is radial and has single supply, the fault current has an inverse relationship with the distance of the point of fault from the network supply. It means the more distance between the point of fault and the source, the less fault current [5]. It is considered in protection coordination of the conventional system, and the protection scheme is designed based on the magnitude of fault current. Because of fault current limitation in an islanded micro-grid with inverter-interfaced DG units, the fault current is independent of fault location and it has almost constant value in all parts of the feeder. As a result, conventional protection coordination based on fault current magnitude cannot work correctly, and new strategies should be considered in a distribution network with embedded DGs [5].

F. Single Phase Connection

Some DGs are connected to the distribution network using a single phase connection. It can have an effect on the current balance of the system. As a result, current may flow in the neutral wire and it can lead to overloading and an unbalance between the currents in the live and neutral wire. Also, the public safety may be threatened by having a current in the neutral [19].

G. Reduction in Reach of Impedance Relay

The reach of an impedance relay signifies the accuracy and coordination setting of the relay, and it depends on the location of relay and fault point. The maximum distance is equivalent to the minimum fault current that can be detected by the relay. DGs have an impact on impedance relay. For example, if the faults happen downstream of the feeder with DG, in this case, the measured impedance by the upstream relay is higher than the actual fault impedance because of the increased voltage due to feeding the feeder with both grid and DG. Therefore, the upstream relay may have a delay in its real operation or even do not operate when the fault occurs in the downstream [5].

H. Recloser Problems

A recloser is very useful for temporary faults because the fuse is used for the permanent fault on the system. Reclosers have two types of curves, fast and slow curves. For having a stable network, recloser-fuse coordination is very important. For example, in the case of temporary faults, reclosers should be coordinated with its fast curves and if the fault becomes clear, it gives permission to the system to work normally. Recloser should be set in the slow curve if the system confronts a fuse failure. Also, relay operation should be set after the fuse failure and recloser. This coordination is used for a traditional network with the radial system [2]. But the presence of micro-grids will cause two basic problems in distribution feeders with recloser. Firstly, DGs can have an impact on the fault current magnitude that is measured by the recloser. That's why its performance is reduced. Secondly, because of having reverse power flow the coordination between recloser and fuse should be changed [18].

I. Islanding

DGs can create severe problems when part of a distribution network with DG units is islanded. In this case, power grid can not control the voltage and frequency of the disconnected part. Having the fault is the cause of islanding in most cases if the DG continues supplying power. Thus, the magnitude of voltage may not be controlled if the system is not equipped with voltage control. This problem may occur in the micro-grid with small embedded DGs. In this case, voltage level is increased and frequency is not stable. As a result, the power quality is not suitable for the consumers [5].

III. Possible Solutions for Protection Issues

Micro-grid can operate in both grid-connected and islanded modes with different short circuit levels and bidirectional power flow. Some conventional protection system problems are mentioned in Section II. Thus the new protection system should cover all the problems in both modes and be reliable and accurate. Some proposed possible solutions for protection issues are as follows:

A. Using Directional OverCurrent

Directional overcurrent can detect the fault current flow whether in the reverse or forward direction. Although the problem of bidirectionality and reverse power flow can be solved with using directional overcurrent, it cannot cover blinding of protection and sympathetic tripping. Also, having different short circuit level in the grid-connected and islanded mode can have an impact on the operation of directional relay. Using multi-settings in the numerical relay and designing an interlocking system are proposed [5], [19], but being complicated and impractical because of the size and number of feeders in the distribution network is the major disadvantage of this method.

B. Using Differential Protection Schemes

Since the fault current is limited in an islanded MG with inverter-interfaced DGs, the overcurrent relays cannot operate correctly because they operate based on the fault current magnitude. Hence the use of the differential relays for micro-grid protection is proposed for solving fault current limitation issues [15], [16]. However, not capable of distinguishing overload from fault current in the conventional differential protection, it will cause nuisance trip from overload current caused. For having a reliable protection system in the islanded micro-grid, the pilot wire differential relay is suggested. This relay is used for transmission line protection and there is an interconnecting channel between the ends of the terminals that can communicate with each other with telephone line [19]. Since micro-grid has recently gained a lot of momentum in power distribution systems and industry, the budget study should be considered top priority in the study. Differential relay, especially the wire pilot type, is more expensive than overcurrent relay (about nine times according to General Electric products). Not being cost effective and having a normal operation in some cases are some cons of the differential relay.

C. Using Fault Current Limiter

MGs can increase the fault current level of distribution networks in the grid-connected mode. Some factors can have an impact on the increase of short circuit level. The type of DGs and its interface are two of the main factors. If transformers are used as an interface, it can contribute to fault current and increase the short circuit level. If power electronics are used as an interface, it can limit the fault current in the islanded mode and does not have a significant impact in the grid-connected mode. The distance between DG and fault point and the arrangement type of network between fault point and DG are other factors [22]. When the main grid confronts faults, DGs should be disconnected from the main grid [23]. Also, as mentioned in the previous section, relays of the feeder with DG may have maloperation when a fault occurs outside their zone and may not operate because of the contribution of main grid in fault current when a fault occurs in their zone [24]. Thus, fault current limiter (FCL) is proposed to reduce the effect of MGs on the existing protection schemes during the fault conditions. FCLs allow free power flow under normal condition, while limiting fault current magnitude under the fault condition. Also, as the resistance of FCLs is very small, they do not affect a lot the power system efficiency [22]. The locations for installing FCLs are proposed for the distribution network with embedded DG at the busbar of PCC, feeders with DG and load feeders. Using series reactor as the FCL is very common at the distribution and transmission levels. FCL can handle different short circuit levels in the grid-connected and islanded modes. Also, it is very useful for avoiding sympathetic tripping too. Using FCL has some disadvantages too. For example, when the fault occurs upstream, the protection scheme can detect it without any problems; on the other hand, if the fault occurs downstream, FCL cannot limit the fault current magnitude properly, which may affect the system reliability and flexibility downstream. Loss of coordination between the upstream and downstream overcurrent relays and power quality disturbances downstream are some problems of using FCL in this situation. As a result, using unidirectional FCL is proposed for solving this problem [24], [25].

Also, using FCL can affect the system reliability of the main grid. Because transient recovery voltage (TRV) and rate of rise recovery voltage (RRRV) are mainly influenced by installing series reactor as an FCL. The voltage appearing across the terminals of a pole of a circuit breaker after the interruption is called the recovery voltage. The TRV is directly related to being resistive, inductive or resistive of the network [26], [27]. Also, the possibility of resonance phenomenon is increased with using series reactor in the network. Thus complicated transient stability studies should be required for choosing suitable FCL [36]; see Fig. 3.

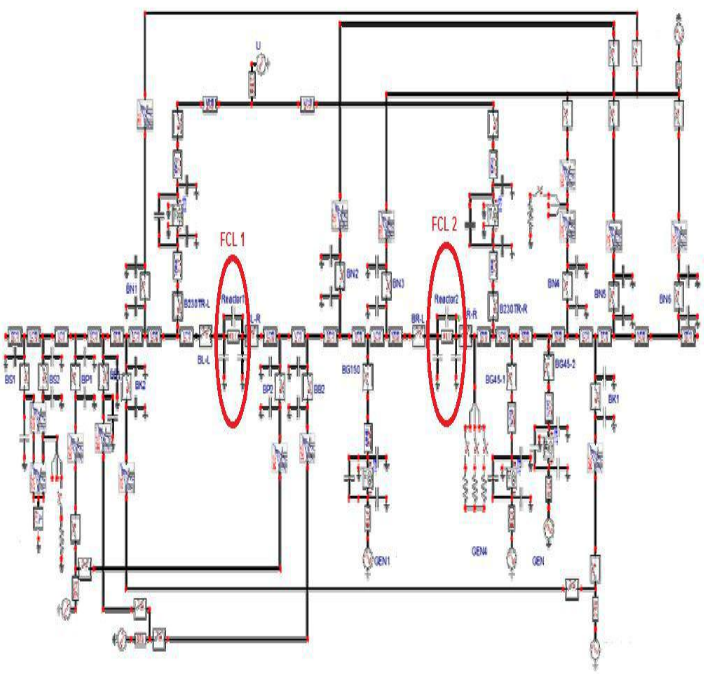

Fig. 3. Modeling of FCL for Transient Stability Study

D. *Wide Area Monitoring, Protection and Control*

Wide area monitoring, protection and control (WAMPAC) was introduced as a new strategy with more accuracy and reliability in comparison with other technologies in past decades. Phasor measurement unit (PMU) plays the main implementation of this scheme. PMUs are sampling devices with high accuracy and speed in the power system that can measure synchronized phasors of current and voltage in the real time [28]; see Fig. 4. PMUs communicate with global positioning system (GPS) and can record dynamic data of power system with high sampling rate [29]. They can provide the magnitude of current and voltage, real and reactive power and phase angles for control and protection purposes. The procedure of PMU system is similar to SCADA system except not being synchronized and low sampling rate in the SCADA system. Also, using PMU system can solve the time skewness problem that may occur in the SCADA system [28]. WAMPAC system has two types of topologies, centralized and distributed. In the centralized strategy, there is a protection center station with protection devices, which are installed separately from all the networks; center station has the responsibility of decision making and finding fault location for protection devices. In the distributed strategy, the distribution network is divided into some regions and each region is responsible for fault detection, operation, judgment and fault location. Each region should collect the information of intelligent electronic devices (IEDs) individually. Regions are linked together with communication interfaces [30], [2].

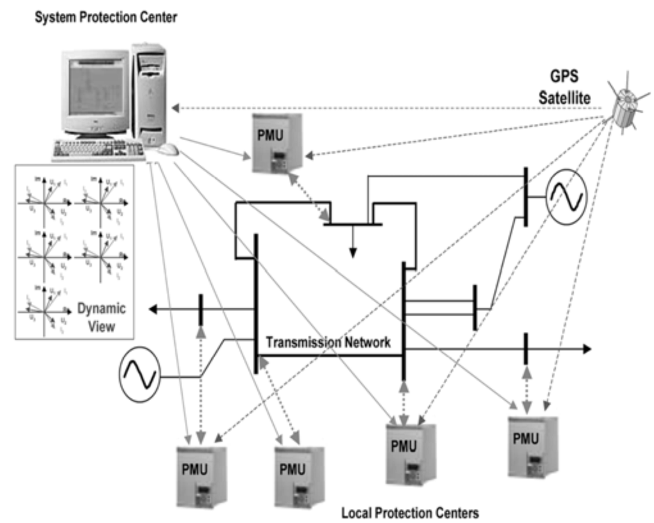

Fig. 4. Wide Area Protection Architecture [31]

For achieving the smart grid, using WAMPAC seems compulsory in distribution networks. PMUs can provide some benefits to meet the minimum requirements of smart grids, for example, control and monitoring of the system in real time, power system estimation, congestion management, power system estimation, post power system disturbance analysis, power system restoration and protection, and control of distribution network with embedded DGs [28].

Using PMUs was started after a widespread blackout in the northeast part of USA in 2003, and only 1126 PMUs were operated in the power grid of USA at both the transmission and distribution levels until 2013. Monitoring and observation are the main focus of most researchers. Using the synchro-phasors for automatic feedback control and developing matrix algorithm of fault location can be other challenges of this strategy [28], [29], [32].

E. *Other Protection Schemes*

Since conventional protection cannot meet all the protection requirements of distribution networks with embedded DGs, some strategies are proposed for optimizing the protection system. For example, protection based on negative and zero sequences is one of these strategies; in this model single line to ground and line to line faults can be detected. Being simple to use is one of its benefits, while not recognizing unbalance faults is one of its major disadvantages, because some types of DGs such as PV in the small capacity range are connected to the main grid as a single phase device[19]. Using symmetrical components and differential components current is another strategy so that phase angle and positive sequence component current is evaluated for detecting the fault [24].

Another strategy is using inverter controller design as a protection system [15]. This method can be used only for the islanded mode, and having different short circuit level in the grid-connected mode is one of the main disadvantages of this method.

Another solution is using adaptive protection scheme [33], [34]. Adaptive protection is served as an online activity that modifies the preferred protective response to a change in system conditions or requirements promptly using externally generated signals or control action. There is a main controller in adaptive protection schemes that updates protection settings according to the operation modes of micro-grids periodically. The main controller makes decisions based on information that is put in the server beforehand. It means it cannot work in the real time. Directional overcurrent relays have the capability of several setting groups and using communication infrastructure and standard protocols such as IEC 61850. They are the basic requirements for adaptive protection system implementation [34], [35]. An adaptive protection system is very costly in comparison with the traditional protection which is based on overcurrent relay and fuses [34]. Also, one of the problems of this method is that when a fault occurs in different parts of the grid, the load level of micro-grid, running mode of every section and whether part of the micro-grid is still connected to the grid need to be considered [24].

IV. Conclusion

Renewable and distributed energy resources are expected to play an important role in the power supply industry and low carbon economy of near future. Various protection issues associated with embedded DGs are discussed in this paper. It is shown that most of them have some benefits and disadvantages which makes it hard to say one specific method greatly outweighs the others. Thus, studies for unique protection scheme are highly required. There are two main challenges for this. Firstly, in the case of existing distribution networks with embedded micro-grids, studies should be focused on the existing equipment and optimizing the network to defer costly upgrades of existing distribution networks. Secondly, for future networks, having functional smart distribution grids will largely depend on the development and implementation of synchronized phasor measurement and on the continuous improvement of the required communication infrastructures. WAMPAC is mostly used or studied at the transmission level. To adopt this method for distribution grids, the specification of distribution grids in terms of size and number of loads should be considered.

References

[1] M. Tanrioven, "Reliability and cost–benefits of adding alternate power sources to an independent micro-grid community", J Power Sources. 150 (2005) 136–149

[2] Niraj Kumar Chaudhary, Saumya Ranjan Mahantj, Ravindra Kumar Singh, "A Review on Microgrid Protection", Proceedings of the International Electrical Engineering Congress 2014 IEEE

[3] Waleed K. A. Najy, H. H. Zeineldin, Wei Lee Woon, "Optimal Protection Coordination for Microgrids With Grid-Connected and Islanded Capability", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, vol.60 , no.4, 2013 1668-1677

[4] Dae-Geun Jin, Jong-Chan Choi, Dong-Jun Won, Hak-Ju Lee, Woo-Kyu Chae, Jung-Sung Park, "A Practical Protection Coordination Strategy Applied to Secondary and Facility Microgrids", Energies 2012

[5] Suleiman M. Sharkh, Mohammad A. Abusara, Georgios I. Orfanoudakis , Babar Hussain, "Power Electronic Converters for Microgrids", First Edition, chapter10, 2014

[6] S. J. Mirazimi, B. Salehi, M. Tadayon, H. R. Karshenas, "Optimal Relay Placement in Microgrids Considering Critical Clearing Time", IEEE 7th International Power Engineering and Optimization Conference (PEOCO2013), Malaysia 2013 691-696

[7] H. M. Sharaf, H. H. Zeineldin, E. El-Saadany, "Protection Coordination for Microgrids with Grid-Connected and slanded Capabilities using Communication Assisted Dual Setting Directional Overcurrent Relays", IEEE Transactions on Smart Grid 2016

[8] Ming Sun, Juan Y, DENG B, "Analysis of impact of DGs on Line Protection of Distribution network", Power System Technology, vol 33 (S), 2009, pp-104-107

[9] P. P. Barker and R. W. de Mello, "Determining the impact of distributed generation on power systems: part I-radial distribution systems", in Proc. IEEE Power Engineering Soc.Summer Meeting, pp. 1645-1656, Jul. 2000

[10] Cooper Power Systems, Electrical Distribution-System Protection, Cooper Industries, 3rd Edition, 1990

[11] J.-H. Teng, C.-N. Lu, "Feeder-switch relocation for customer interruption cost minimization", IEEE Transactions on Power Delivery. 17 (1) (2002) 254–259

[12] Yuan Chao, Wu Gang, Zeng Xiangjun, Qiao Hui, "Protection Technology of Distributed Power Generation System",Protection and Control of Power System, vol.37, no.2, 2009, pp.99-105.

[13] M.R. Miveh, M.Gandomkar, S.Mirsaeidi, M.Nuri, "Analysis of Single Line to Ground Fault Based on Zero Sequence Current in Microgrids", ISCEE conference, Kermanshah, Iran, 2011.

[14] P. P. Barker and R. W. de Mello, "Determining the impact of distributed generation on power systems: part I-radial distribution systems", in Proc. IEEE Power Engineering Soc. Summer Meeting, pp. 1645-1656, Jul. 2000

[15] G.Nayak, S. Nath, " Effect of Power Electronic Protections of Inverters on Protection of Micro-Grids", 978-1-5090-0128-6/16 IEEE, 2016

[16] X.Wang, J.Qi, Y.Hou, Y.Wang, W.Xu, D.Wang, Z.Jiao, " Studies on Fault Analysis and Protection Configuration Schemes in an Isolated Micro-grid", 978-1-4799-6415-4/14 IEEE ,2014

[17] Z.LI, Y. LI, G.FU, B.LI , "Directional Protection Based on Fault Component Energy Function in Micro-grid", IEEE PES ISGT ASIA 2012

[18] M.R. Miveh, M.Gandomkar, S.Mirsaeidi, M.Nuri, "A Review on Protection Challenges in Microgrid", dgr_3704, IEEE conference

[19] P.Anil Kumar, J.Shankar, Y.Nagaraju, "PROTECTION ISSUES IN MICRO GRID ", (IJACEEE) Volume 1, Number 1,May 2013

[20] D. Q. Hung and N. Mithulananthan, "Multiple distributed generators placement in primary distribution networks for loss reduction," IEEE Trans. Ind. Electron. , vol. 60, no. 4, pp. 1700-170S, Apr. 2013

[21] 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 p1– 7,May. 2003

[22] T.Ghanbari, E.Farjah, " Unidirectional Fault Current Limiter: An Efficient Interface Between the Microgrid and Main Network" , IEEE Transactions on Power System, 0885-8950, 2012

[23] IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE Std. 1547, 2003

[24] C.Jian, H.Zheng-you, " The overview of protection schemes for distribution systems containing micro-grid", 978-1-4244-6255-1/11 IEEE, 2014.

[25] R. M. C. Abyaneh, H. A. Agheli, and A. H. Rastegar, "Overcurrent relays coordination considering transient behavior of fault current limiter and distributed generation in distribution power network," Proc. Inst. Elect. Eng., Gen., Transm., Distrib., vol. 5, no. 9, pp. 903–911, 2011.

[26] IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers, IEEE Std C37.011, 2005

[27] Cigre Guide Line, "Transient Recovery Voltages in Medium Voltage Networks" , Cigre group CC03 of study Committee 13, 1998.

[28] M.Penshanwar, M.Gavande, M. F. A. R Satarkar, " Phasor Measurement Unit Technology and its Applications – A Review ", International Conference on Energy Systems and Applications (ICESA 2015)

[29] A.Chakrabortty, P.Khargonekar, " Introduction to Wide-Area Control of Power Systems ", American Control Conference (ACC), 978-1-4799-0178-4 AACC, 2013.

[30] Ning W, Yang X, Yu-ping L, "New Fault Section Location Algorithm for Distribution Network with DG", Automation of Electric Power Systems, vol. 33(14),Jul. 2009, pp. 77-S2.

[31] J.Bertsch, D.Karlson, J.Mc Daniel, K.Vu," Wide-Area Protection and Power System Utilization", Proceedings of the IEEE, Vol. 93, No. 5, May 2005.

[32] C.W. Taylor, D.C. Erickson, K.E. Martin, R.W. Wilson, Y.Venkatasubramanian, "WACS Wide-Area Stability and Voltage Control System: R & D and Online Demonstration", Prceedings of the IEEE, vol. 93(5), pp 892-906, May 2005.

[33] L.Che, M E.Khodayar, M.Shahidehpour, " Adaptive Protection System for Microgrids: Protection practices of a functional microgrid system", IEEE Electrification Magazine, Vol. 2, Issue. 1, March 2014, pp. 66-80.

[34] ABB group, " Adaptive Protection Schemes for Microgrids ", Presented at 2012 3rd IEEE PES ISGT Europe, Berlin, Germany, October 14 -17, 2012.

[35] N.Hatziargyriou, V.Kleftakis, V.Papaspiliotopoulos, G.Korres, " Adaptive Protection for Microgrids", IEEE PES, July 2012.

[36] R.Koushmand, G.Isazadeh, " TRV Transient study and Analyse with using FCL in Islamabad Substation", 24th International Power System Conference, Iran, 2009.