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Adaptive Central Control Scheme and Investigation of Fault Current Contribution for Protection of Microgrid

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Adaptive Central Control Scheme and Investigation of Fault Current Contribution for Protection of Microgrid

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Abstract. Microgrids suffer from issues namely protection blinding, sympathetic tripping. Microgrids operate in which differs from the conventional power system. Micro-grids operate in grid-connected mode or islanded mode of operation. In islanded mode microgrids utilize distributed energy resources that are renewable such as solar, wind, along with energy storage systems. In both, the modes of the system undergo various challenges such as protection blinding, sympathetic tripping, or short circuit current in power electronic interfaced generation. This work focuses on the analysis of fault in both modes of operation as well as the issues that are specific to a microgrid. Hence adaptive settings of the relay are required to switch over under the different modes of operation. This work utilizes an adaptive central controller for MG protection. Hence the sensed data from the system is fed to the controller and managing the relay operation which is the IDMT relay. This work focuses on the relay setting and plug set for the relays under modes of operation. The detailed analysis is carried out in IEEE 13 bus system and adaptive relay setting calculation for adaptive centralized MG protection is carried out.

1. Introduction

Distributed Generation (DG), particularly photovoltaic (PV) systems wind turbine (WT) have become much more widely used at the distribution level. The regulation of a number of (DGs) creates difficulty for network operators and controllers. Micro-grids (MGs), which are structures that co-ordinate distributed energy resources in a decentralized way, can help to address this problem.MG's are utilizing an application that includes DGs, energy storage systems (ESS), and other loads at the distribution voltage level. From a network perspective, the key benefit is that MGs are recognized as a controlled entity and can be considered an aggregated load. B Patnaik,et al., [1] proposed a model which improves efficiency while minimizing blackouts. Despite the benefits of MGs in today's power systems, their adoption is still limited due to technical hurdles including protection,system stability, energy management, and plug-and-play operation. Protection, as one of the aforementioned problems, has the critical responsibility of isolating any part of the system as rapidly as possible when it is exposed to a short-circuit or anomalous action that can damage the rest of the system. Traditional schemes, on the other hand, may fail to protect MG due to concerns such as presence of DGs; changes in fault current; their dynamic behaviour; topologic changes in the power grid due to the intermittent nature of DGs; bidirectional power flow. Given the necessity of reliable protection in enabling widespread adoption of MGs, various researches have focused on studies that addressing the aforementioned challenges. Annu Dagar et al.,[2] discussed the various frameworks of microgrid emphasis on the protection issues of AC and DC microgrid. Furthermore, their research work entailed developing a suitable microgrid protection mechanism, which is difficult as it is dynamic because of the uncertainty of renewable generation. Adam H et al.,[3] also reviews on various key issues that occur in the MGs. Vegunta et al.,[4] also discussed the benefits and techniques to switch between protection setting groups automatically as part of adaptive-protection schemes, to provide microgrid transitions between grid-tied and island modes.

Shahzad.U,et al., [5] discussed on various types of protection issues and also solutions to some of them in the paper. Alasali et al.,[6] which focussed on an optimal coordination scheme to minimize the total tripping time. Bhaskar Patnaik et al.,[7] addressed the AC microgrid protection issues, which focussed on the direction of providing a smooth relaying system under different operating conditions. Thus a control strategy is discussed in detail for various networks along with their market participation is provided by Palizban O , et al., [8].Ward Bower, et al.,[9] discussed the related standards and codes for microgrid protection and DG'S integration which is more helpful for selecting the appropriate protection scheme according to the operating modes of micro-grid Hany F. Habib et al.,[10].

The proposed model relay on a centralized control algorithm for monitoring the Microgrid's modes and assisting relays in defining fault locations and clearing the fault. Vaibhav Nougain, et al., [11] developed a centralized protection arrangement with a localized backup for a medium voltage network. The proportion differential current technique is used in the centralized scheme, which is backed up by a localized scheme. Ankan Chandra,et al., [12]proposed in which instantaneous and inverse time relay is used through main protection and backup protection are achieved. V. Vinod et al., [13] proposed a relaying scheme based on curve fitting adaptive technique for microgrids and performs well without using any extensive communication facility. This type of relaying scheme can be used to detect faults under different microgrid modes. Haneen Bawayan et al., [14] suggested a novel adaptive system and two-phase a directional overcurrent relay coordination mechanism address the impact of fault current changes and allow the MG to contionue operation. Daniel Gutierrez- Rojas et al., [15] explained the communication technologies and adaptive devices for large networks of microgrids. This article reviews future communication technologies deployments in microgrid indicating the viability of 5G wireless systems and multi-connectivity to enable adaptive protection. Henghwei Lin ,et al., [16] further proposed an adaptive protection that has been in collaborative effort with the machine learning techniques designed especially for microgrids. Arunan,et al.,[17] developed a adaptive protection scheme based on a self-organizing map clustering algorithm with digital overcurrent relays equipped with several settings groups. This proposed strategy aims at solving this mis-coordination between main and backup relay pairs. The relay utilized in this research is of IDMT type which means that the relay operates co-ordinately like inverse as well as definite time based on the fault current T. Kosaleswara Reddy et al, [18] provide further information that relay utilizes current contributions from a current transformer. The logic operation is provided to be of AND gate and thereby it compares the values present to that of the fault current values present in the system. Jain,Rishabh,et al., [19] & Naveen Kumar,et al.,[20] provides the overcurrent relay IDMT starts to operate after a certain time delay which might also be termed as operating time becoming definite after a certain time delay which might also be termed as operating time of that particular relay. The reason for the operating time becomes definite after certain high values of current is because electromagnetic relays the flux saturates at higher values of current.

The main contribution of this paper is to provide a centralized controller for micro-grid protection. The purpose is concerned with the topology under which the system is operated and the system ratings including voltage, current, and power due to the influence of DG's within the system and any abnormal condition sensed across the system. This centralized controller is also on the other side with relays or to be considered the field of the system thereby providing signals and directly controlling the system based on the information. This test system makes use of the IDMT relay for the operation. The overall system consists of three major levels are Field Level, Real-time measurement level, and also management level. The field level senses the topology with the sensed voltages and currents, the field level has been connected to the relays present in the system. In between the two is the management level which consists of the central controller. Thereby this novel method of adaptive protection enables the system to operate in both modes as well as enables us to control the system entirely at the management level with the presence of a micro-grid central controller.

The paper is organized as follows: Proposed methodology is explained for two modes of microgrid operation: grid-connected mode and islanded mode and corresponding relay selection along with its setting are provided in section 2. The description and simulation results of the test system and simulation results are provided in section 3. The conclusion and future scope of the work are provided in section 4.

2. Proposed Methodology

The proposed work is depicted in Figure 1.

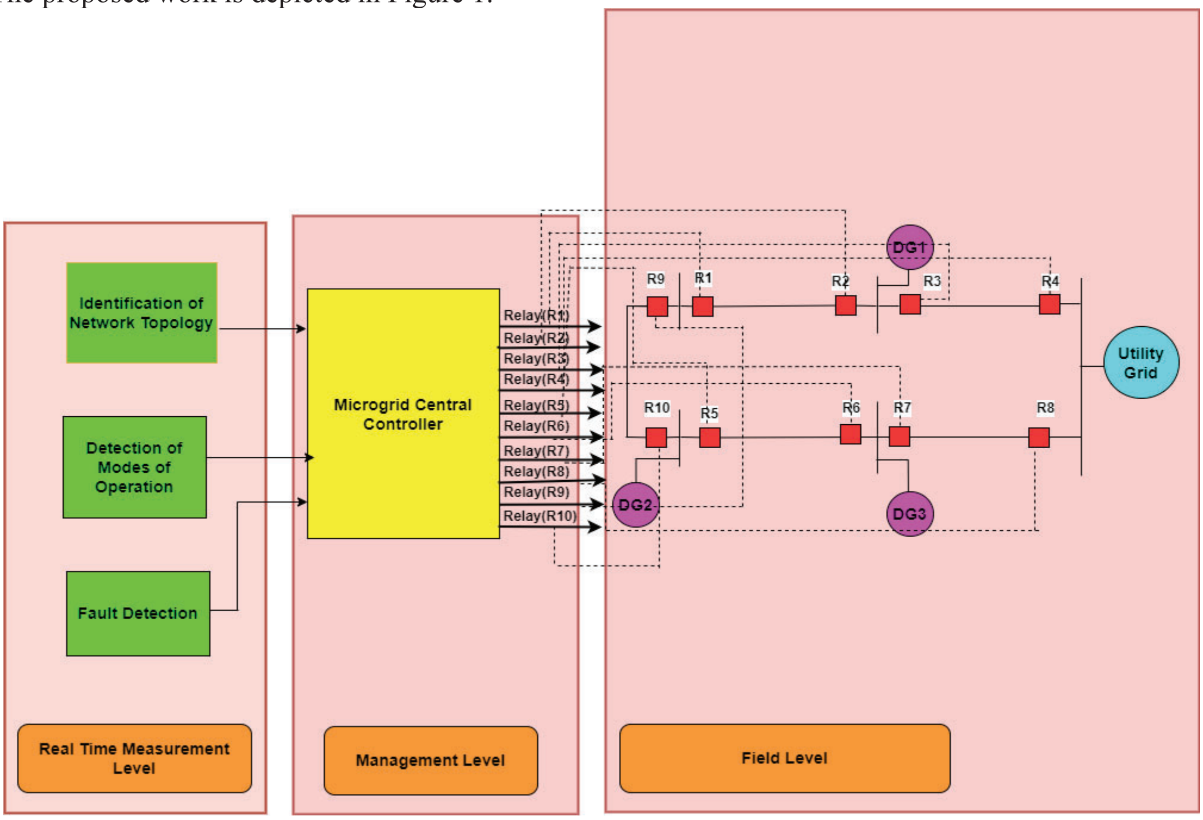

Figure 1. Centralized Adaptive Protection scheme under three levels of MG

The MG system is operated in three levels of operation. Real-time measurement level, Management level and Field level. Real-Time Measurement collects the real-time data from the system and provides them to the microgrids Central controller. The central controller is used at the management level that basically collects all the information and manages the relays by sending command signals based on timely information from the system. The entire system along with the relays is considered to be the field level which provides information to the other two levels and also relays operate according to the command signals obtained from the central controller. The proposed strategy must assure that the microgrid is operated in islanded and grid-connected modes. In a grid-connected manner, the current at fault is substantial because of the contribution provided by the utility grid. This provides a situation for use of standard overcurrent relay, although the inclusion of distributed resources (DR's), may impair or even eliminate the protection coordination in some instances.

The proposed protection system employs a micro-grid central controller (MGCC) unit that communicates with all of the network's relays as well as the renewable and other sources. The MGCC adjusts the relay's current settings, detects the current at the fault, and sends a signal for the circuit breaker, which facilitates an efficient protection system.

2.1 Proposed Strategy under Grid-connected and Islanded mode of operation

Figure 2 depicts the flowchart of a different mode of operation

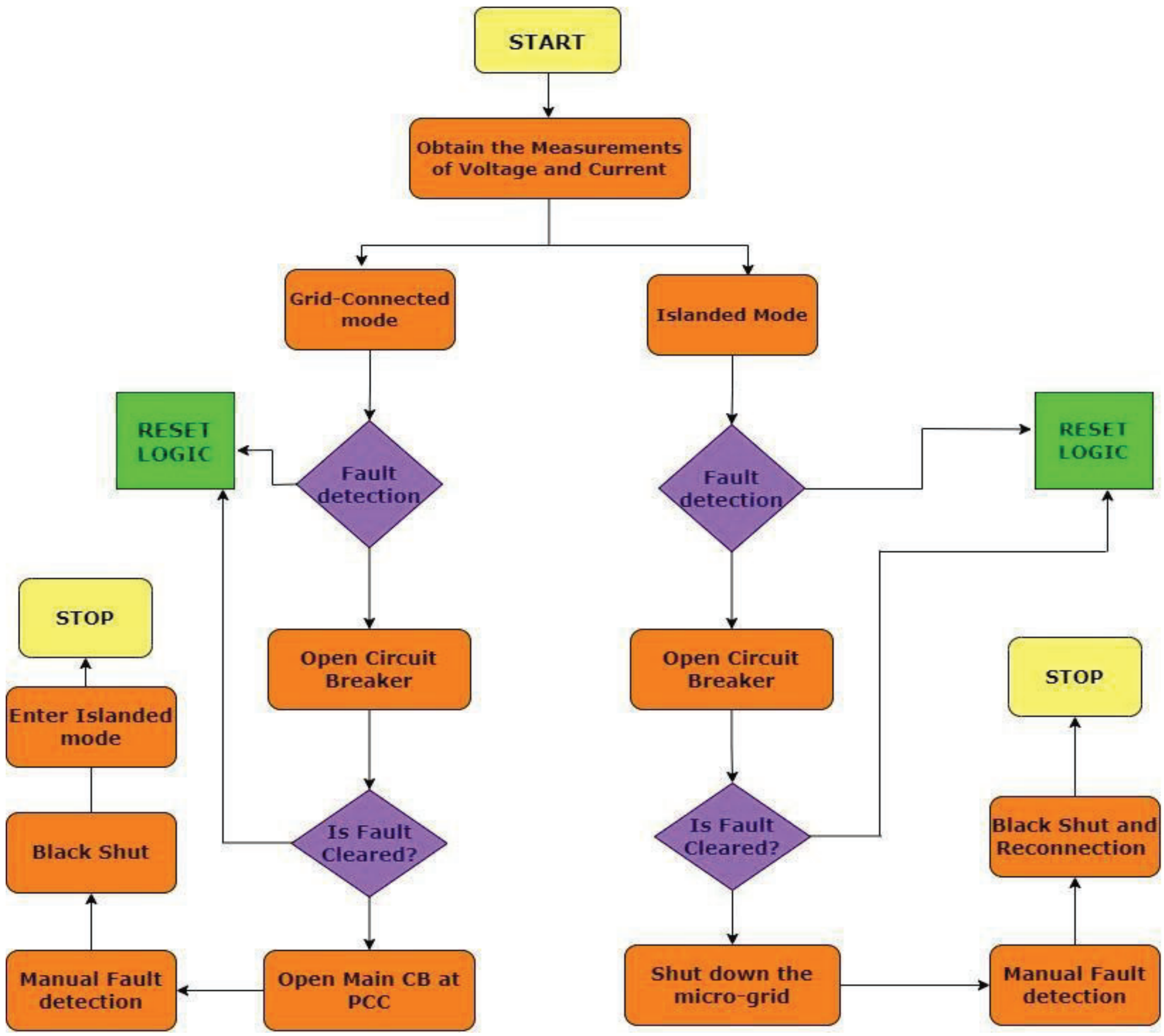

Figure 2: Flow chart for protection in Grid-connected mode and Islanded modes of operation

The MGCC receives the measured quantities and detects sequence components during the occurrence of a fault. The method is set up so that positive sequence components are recognized for three-phase faults, while negative and zero sequence components have been sensed for single-phase and ground faults. In addition to detecting the fault, MGCC stimulates algorithm to update the tripping time in accordance with variables like fault range, mode of the operation, and DG operation.

If the fault is cleared, the central controller of micro- grid resets the protection procedure by sending a tripping signal to circuit-breaker, which causes the circuit-breaker to trip out and clear fault within a predetermined amount of the time. After the fault has been cleared, the micro-grid has been switched to stand-alone mode, and also the reconnection process begins, allowing the microgrid to resume normal operation. MGCC directs the microgrid to be blacked out in the event of anomalous frequency and voltage profiles, and faults are physically eliminated. After the problems have been resolved, the microgrid is restarted and the re-connection procedure begins, allowing it to return to its conventional grid-connected working state.

Under islanded condition MGCC performs continuous tracking of electrical quantities on each bus and the feeder. During the occurrence of faults, the MGCC detects sequence components. The pickup value of the relay in stand-alone mode is lower than in grid mode of operation. If a positive sequence component is retained when a fault is detected, the MGCC will restart the protection algorithm and continue to monitor the electrical quantities. If negative as well as zero sequence components are encountered, the MGCC utilizes IDMT characteristics to compute the relay's operational time. After that, the MGCC sends a tripping command given to a specific feeder circuit-breaker, and the problem is cleared. When micro-grid's feeder circuit-breaker trips stand-alone mode, the other feeders must be able to feed the load condition at islanded micro-grid; in other conditions, the micro-grid's functioning could become unstable.

2.2 Selection of Relay settings

In this work, Inverse Definite Mean Time relay is used for microgrid protection. It exhibits the characteristics of both definite as well as inverse type of relay. The relation between the operating time and current is inversely related in this type of relay till the value reaches pick-up current rating, this means that the relay operates fast for a higher value of current. After reaching the pick-up value of current the relay seems to operate in definite time for all current values that are present above pick-up value of current set for the relay.

The IDMT has an advantage of providing high speed protection over a considerably large portion of the power-system. They are used in systems to avoid certain short-comings of using a definite time over-current relay. These types of relays are advantageous much more comparatively as they could be utilized in current as well as voltage protection. In this proposed system standard type of IDMT relay is used, for determining the relay settings, fault-current and load- current in each feeder separately in grid-connected manner and stand-alone approach. The two imperative settings of the IDMT relay are pick up the value of current, and Time Dial setting [TDS]. As the sensitivity and tripping time of the relay is exaggerated by the above two parameters. The operating time (t) is calculated as in equation (1)

$$t = TDS * \frac{0.14}{\{\frac{I_f}{I_{set}}\}^{0.02} - 1} \ seconds \qquad (1)$$

Where

TDS = Time Dial setting

I_{set} = Current setting

I_f= Actual current

The plug setting of the relay is generally calculated by the ratio between fault current rating to that of pick-up current. The operating time is used to calculate time setting for the standard inverse as in equation (2)

$$TMS = \frac{operating\ time\ of\ relay\ (sec) * (PSM^{0.02} - 1)}{0.14}\ (seconds) \qquad (2)$$

The characteristics curve of the IDMT relay is shown in the Figure 3 and it is much visible that the characteristics is inverse till certain range of fault current after which the relay tends to operate with definite time rating

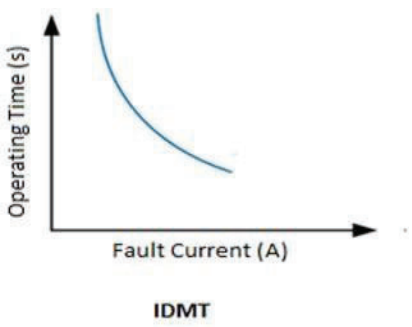

Figure 3: Characteristics curve of IDMT relay

3. Results & Discussions

The single line representation of the proposed IEEE 13 Node Test system is provided in Figure 4 and is developed in Digsilent- Powerfactory software tool 15.7 version. Figure 4 demonstrates the IEEE 13 node test system with PV system comprised of 5 DG's are connected to different bus bars. The main CB is closed during the grid-connected mode, and is opened in standalone manner. The relays connected in all lines are in adaptive nature. Thus, mode sensing of micro-grid is based on the status of the PCC circuit breaker. Load current and also the fault current at different modes of operation is analysed and provided in Table 1 and Table 2 respectively.

Table 1: Line current under grid-connected mode and islanded mode

Lines	Grid-Connected mode Line Current[A]	Islanded mode Line Current[A]
Line 4.0	137.863	137.391
Line 4.1	105.385	101.516
Line 4.2	309.466	309.200
Line 4.3	295.779	377.360
Line 5.0	125.868	124.118
Line 5.1	119.709	107.648
Line 5.5	98.788	98.220
Line 5.6	280.471	288.370

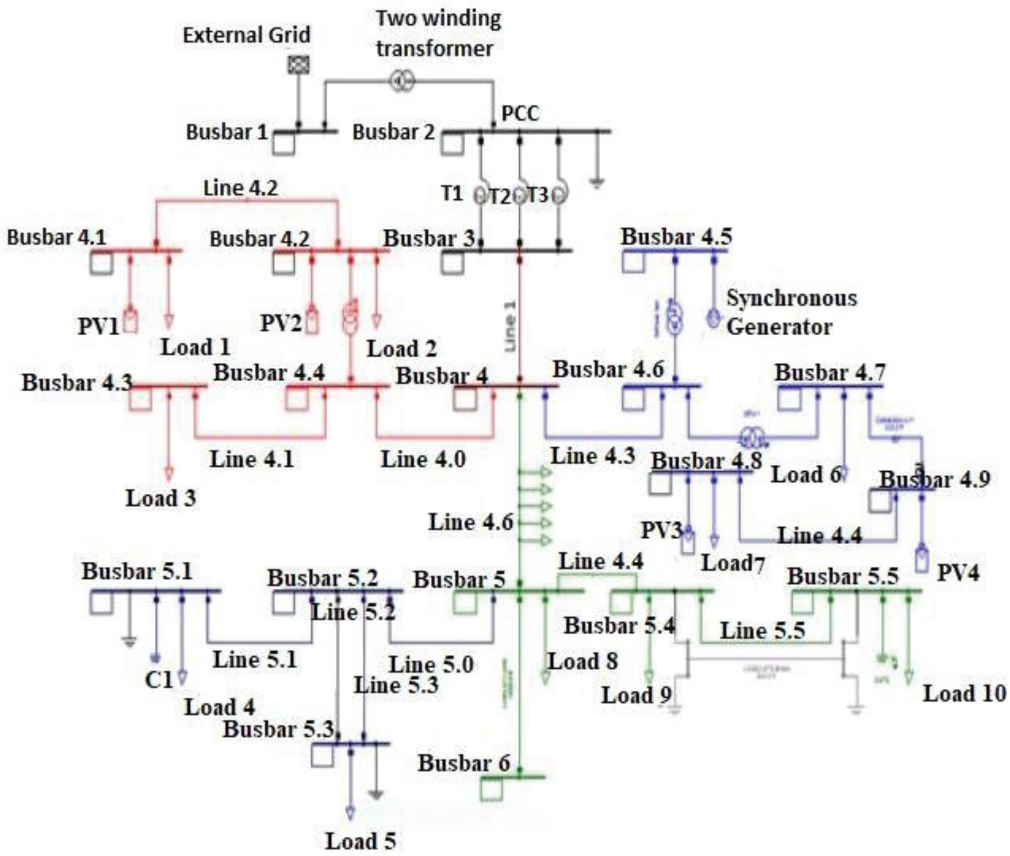

Figure 4: IEEE 13 Node Test system.

From the above table, it is cleared that line current values are slightly higher in grid connected when compared to islanded mode because of the contribution of the utility grid and DG's sources connected to the system. In stand-alone mode the utility grid is disconnected, therefore the effect of line current is lower.

Table 2 describes the fault current for two operating modes of the micro-grid. It shows the fault current values of different lines connected to the test system. The fault current values are slightly higher in stand-alone mode when compared to the grid-connected mode in certain lines because the stand-alone mode is separated from the utility grid. It has the effect of DG's connected to the system. Whenever the fault occurs at the DG's connected line, the fault current value of that line could be higher compared to the other lines connected to the system.

Table 2: Fault current under grid-connected mode and islanded mode

Lines	Grid-Connected mode Fault Current[kA]	Islanded mode Fault Current[kA]
Line 4.0	**0.152**	**0.151**
Line 4.1	**0.105**	**0.102**
Line 4.2	**0.243**	**0.309**
Line 4.3	**0.305**	**0.346**
Line 5.0	**0.180**	**0.177**
Line 5.1	**0.120**	**0.180**
Line 5.5	**0.118**	**0.120**
Line 5.6	**0.333**	**0.346**

Table 3 describes the pickup up of the relay, Plug Setting Multiplier [PSM], Time Dial Setting TDS for both modes of operation.

Table 3: Adaptive Relay settings under Grid-connected mode and Islanded mode

Lines	Pick up of the relay [kA]		PSM		TDS [sec]	
	Grid-connected mode	Islanded mode	Grid-connected Mode	Islanded mode	Grid-Connected mode	Islanded Mode
Line 4.0	**17**	**17**	**8.94**	**8.88**	**0.16**	**0.15**
Line 4.1	**13**	**12**	**8.07**	**8.54**	**0.15**	**0.16**
Line 4.2	**37**	**34**	**6.56**	**8.35**	**0.14**	**0.15**
Line 4.3	**36**	**45**	**8.47**	**7.69**	**0.15**	**0.14**
Line 5.0	**15**	**15**	**12**	**11.8**	**0.18**	**0.18**
Line 5.1	**15**	**13**	**8**	**8.31**	**0.15**	**0.15**
Line 5.5	**12**	**12**	**9.83**	**10**	**0.16**	**0.17**
Line 5.6	**34**	**35**	**9.79**	**9.88**	**0.17**	**0.16**

According tables, TDS value for IDMT relay is calculated for both modes of operation. With the help of pick-up value as well as fault currents the plug setting and time settings for operating the relays are calculated.

Case1: Grid-connected mode

Under grid-connected mode, when the fault occurs in line 4.2, the fault current is subsidized by the locally distributed generators and the main grid itself. Figure 5 and 6 demonstrates the time- overcurrent plot for line 4.1 and line 5.1 with fault clearing time. The maximum load and fault current observed at line 4.1 is 105.385 A of load current and the fault current is 0.105 kA. The TDS and PMS values are calculated based on the values of load current and fault current of the corresponding line.

Similarly, all the relays of the 13 node system are calculated based on the load current values. From this value of line 4.1, the TDS value is 0.15seconds and PSM is 8.07. The fault clearing time is 0.621 seconds in the grid-connected mode of operation.

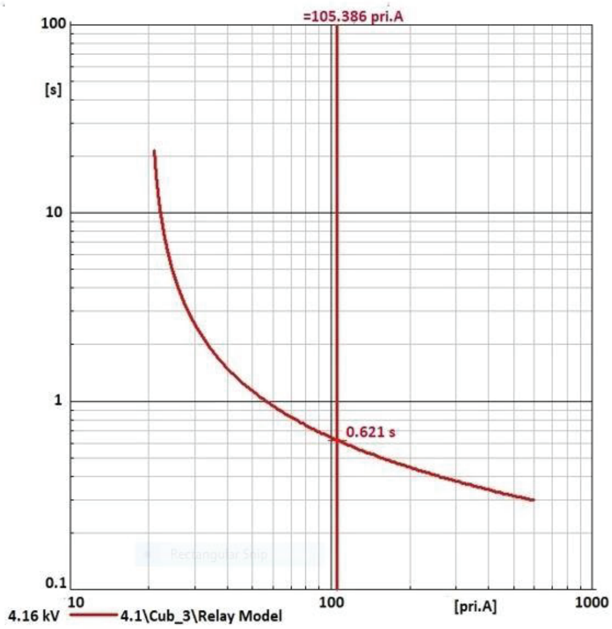

Figure 5..Time overcurrent graph for relay line 4.1

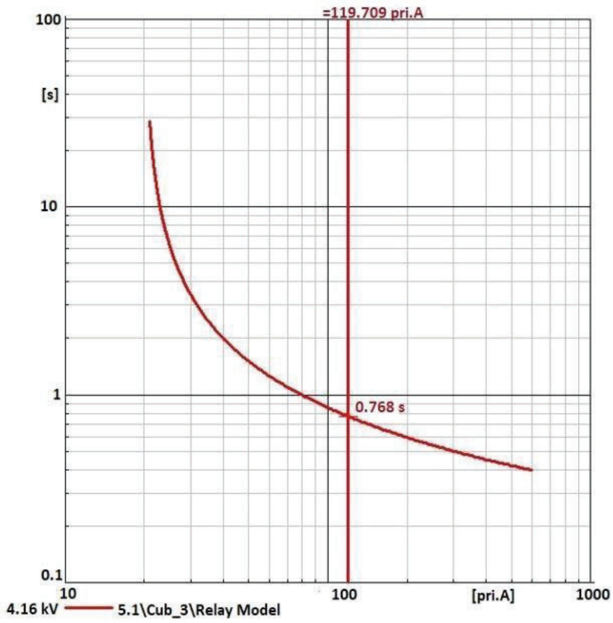

Figure 6. Time overcurrent graph for relay line 5.1

Case2: Islanded mode

Synchronous generators and PV have a high contribution of feeding the fault current. The maximum load and fault current experienced at line 4.1 is 105.516 amps of load current and 0.102 kilo ampere of fault current respectively. The TDS and PMS values are calculated based on the values of load current and fault current values and is provided in the table 1 and 2. Similarly, all the relays of the 13 Node system are calculated based on the load current and fault current values. From these values of lines 4.1, the TDS value is 0.15 seconds and PSM is 8.07. The fault clearing time is 0.636 seconds in the islanded mode of operation. The MGCC changes this line the relay setting from grid connected approach to stand alone mode. Figure 7 demonstrates the time- overcurrent plot for line 4.1with fault clearing time.

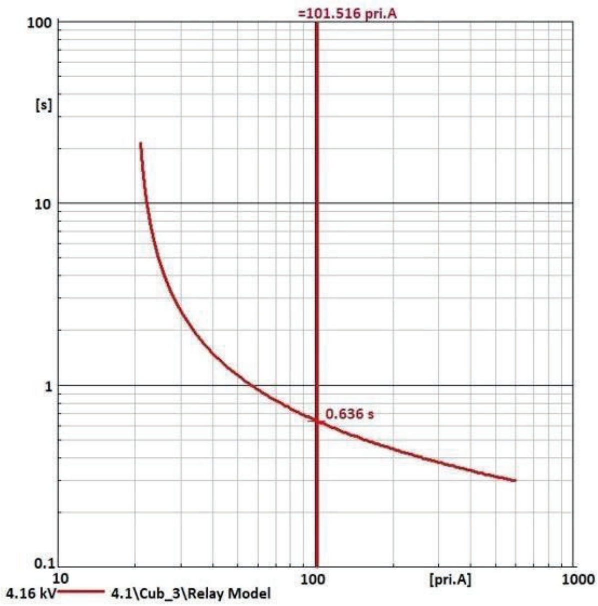

Figure 7.Time overcurrent graph for relay line 4.1

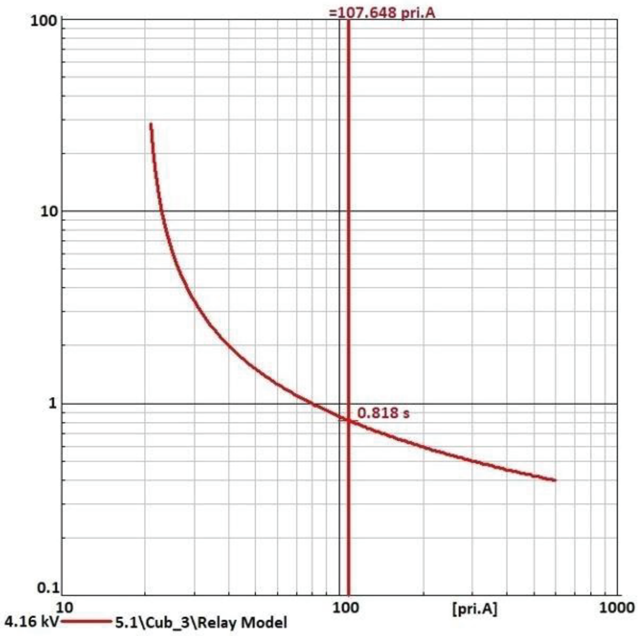

Figure 8. Time overcurrent graph for relay line 5.1

Table 4: Fault clearing time under Grid- connected and Islanded mode

Lines	Fault Clearing Time for Grid connected[sec]	Fault Clearing Time for Islanded mode[sec]
Line 4.1	0.621	0.636
Line 4.2	0.249	0.231
Line 4.3	0.375	0.330
Line 5.0	0.623	0.628
Line 5.1	0.768	0.818
Line 5.5	0.774	0.766
Line 5.6	0.484	0.477

4. Conclusion

The proposed system leads to the calculation of relay settings under different modes of operation based on the detection of fault and analysis of fault current. The relay parameters are adaptive to the microgrid status such as grid-connected or stand-alone mode. This relay setting is controlled by a central micro-grid controller which in turn adjusts the settings of all the relays in different lines. The parameters of relays are automatically updated when the microgrid enters into the islanded operation. The adaptive controller calculates and updates various relay settings dependent on the mode of operation. A 13-node distributed system of micro-grid is selected for the implementation of the proposed concept. When the microgrid transitions from grid-connected to stand-alone mode, the fault current switches from a higher to a lower value. In many case studies, the relays appear to trip at around the identical time in both modes. Designed for improved co-ordinations, the relays should have adaptive protection parameters or various groups of settings. In the future backup protection can be involved with the proposed controller for the most reliable and secured operation of MG.

APPENDIX

DETAILS OF IEEE 13-BUS STUDY SYSTEM

Table A 1.1 Load Demand

Node	Conn	Behaviour constant	Ph-1 / A-B kW	Ph-1 / A-B kVar	Ph-2 / B-C kW	Ph-2 / B-C kVar	Ph-3 / C-A kW	Ph-3 / C-A kVar	ΣP kW	ΣQ kVar
632-671	Y	PQ	17	10	66	38	117	68	200	116
634	Y	PQ	160	110	120	90	120	90	400	290
645	Y	PQ	0	0	170	125	0	0	170	125
646	D	Z	0	0	230	132	0	0	230	132
652	Y	Z	128	86	0	0	0	0	128	86
671	D	PQ	385	220	385	220	385	220	1155	660
675	Y	PQ	485	190	68	60	290	212	843	462
692	D	I	0	0	0	0	170	151	170	151
611	Y	I	0	0	0	0	170	80	170	80
		Σ	1175	616	1039	665	1252	821	3466	2102
	S	kVA	1327		1234		1497		4054	

Table A 1.2 Conductor data for Overhead lines

Conductor AWG	Material	R Ω/mi	Diameter in	GMR^s ft	Ampacity A
556.5	ACSR	0.186	0.927	0.0311	730
4/0	ACSR	0.592	0.563	0.00814	340
1/0	ACSR	1.12	0.398	0.00446	230

Table A 1.3 Impedance matrix for line configuration

Results in [2]			***Power Factory***		
R in Ω/mi			R in Ω/mi		
0,3465	0,1560	0,1580	0,3491	0,1573	0,1594
0,1560	0,3375	0,1535	0,1573	0,3399	0,1548
0,1580	0,1535	0,3414	0,1594	0,1548	0,3439
X in Ω/mi			X in Ω/mi		
1,0179	0,5017	0,4236	1,0198	0,5036	0,4256
0,5017	1,0478	0,3849	0,5036	1,0496	0,3868
0,4236	0,3849	1,0348	0,4256	0,3868	1,0367
B in μS/mi			B in μS/mi		
6,2998	-1,9958	-1,2595	6,3041	-1,9971	-1,2603
-1,9958	5,9597	-0,7417	-1,9971	5,9638	-0,7422
-1,2595	-0,7417	5,6386	-1,2603	-0,7422	5,6425

Table A 1.4 Voltage for line configuration

Voltage magnitude

	U A in p.u.			U B in p.u.			U C in p.u.		
Node	**Pub. [2]**	**SC1[s]**	**SC2[†]**	**Pub. [2]**	**SC1**	**SC2**	**Pub. [2]**	**SC1**	**SC2**
611							0.9738	0.9753	0.9753
632	1.0210	1.0218	1.0220	1.0420	1.0434	1.0424	1.0174	1.0176	1.0185
633	1.0180	1.0189	1.0189	1.0401	1.0404	1.0405	1.0148	1.0159	1.0159
634	0.9940	0.9950	0.9950	1.0218	1.0220	1.0221	0.9960	0.9971	0.9971
645				1.0329	1.0357	1.0332	1.0155	1.0141	1.0165
646				1.0311	1.0340	1.0315	1.0134	1.0121	1.0144
650	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
652	0.9825	0.9848	0.9835						
671	0.9900	0.9914	0.9915	1.0529	1.0536	1.0536	0.9778	0.9793	0.9793
675	0.9835	0.9847	0.9847	1.0553	1.0579	1.0579	0.9758	0.9770	0.9770
680	0.9900	0.9914	0.9915	1.0529	1.0536	1.0536	0.9778	0.9793	0.9793
684	0.9881	0.9896	0.9895				0.9758	0.9772	0.9773
692	0.9900	0.9914	0.9915	1.0529	1.0536	1.0536	0.9777	0.9793	0.9793
RG60	1.0625	1.0625	1.0625	1.0500	1.0500	1.0500	1.0687	1.0687	1.0687

Voltage angle

	PHI A in deg			PHI B in deg			PHI C in deg		
Node	**Pub. [2]**	**SC1[s]**	**SC2[†]**	**Pub. [2]**	**SC1**	**SC2**	**Pub. [2]**	**SC1**	**SC2**
611							115.78	115.95	115.95
632	-2.49	-2.46	-2.40	-121.72	-121.63	-121.65	117.83	117.95	117.91
633	-2.56	-2.46	-2.46	-121.77	-121.70	-121.70	117.82	117.91	117.91
634	-3.23	-3.13	-3.13	-122.22	-122.16	-122.15	117.34	117.43	117.42
645				-121.90	-121.76	-121.83	117.86	118.03	117.94
646				-121.98	-121.84	-121.91	117.90	118.07	117.99
650	0.00	0.00	0.00	-120.00	-120.00	-120.00	120.00	120.00	120.00
652	-5.25	-5.07	-5.06						
671	-5.30	-5.13	-5.13	-122.34	-122.24	-122.24	116.02	116.19	116.19
675	-5.56	-5.48	-5.48	-122.52	-122.42	-122.41	116.03	116.29	116.29
680	-5.30	-5.13	-5.13	-122.34	-122.24	-122.24	116.02	116.19	116.19
684	-5.32	-5.15	-5.15	-122.34	-122.24	-122.24	115.92	116.09	116.09

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