APPLICATION OF WIDE-AREA PROTECTION CONCEPTS IN MICROGRIDS

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ABSTRACT

In this paper wide-area protection is discussed in microgrids. Firstly, the opportunities that the microgrids propose for the enhancement of protection of the lines are presented. The main focus is on the communication capabilities that the microgrids inherently propose. The paper discusses the smart distribution microgrids, as this would refer to a communication infrastructure within microgrids that promotes the performance of the protection decisions. It is supposed that the sample microgrid has the required communication links to make a decision based on the local measurements and also the status of the adjacent relays. In this case logic-based protection is considered for the sample network. It is proposed instead of giving the authority of tripping the circuit breakers to different individual relays, the protection to be performed semi-centrally by collecting the situational data in a wider area, identifying the fault location based on the wide-area collected data and then intelligently make the trip decision. The contributions are presented on a sample microgrid.

INTRODUCTION

Protection schemes for transmission lines and distribution feeders can be classified into unit protection like differential protection and non-unit protection. In unit protection (pilot protection) the current measurements data from the remote end of the line is needed, while in non-unit schemes such as distance and overcurrent protection, the decision of the relay is only based on local measurements. In pilot protection concept, each relay at one end of the line receives the data of the remote-end relay with the systems communicating through pilot channels in end-to-end pairs. At the present time, the pilot protection schemes use only data transmitted between the two ends of a given line. This concept could conceivably be expanded further to provide a center with more global information from the relays of the adjacent lines, from parallel lines, or from other relays and locations. Such an expansion needs the availability of communication channels and the ease of receiving data from different points of the grid [1].
"Microgrid" is a cluster of loads and microsources along with some local storage. It appears just like a net load or a generator to the grid with well-behaved characteristics and a very dynamic behavior, as at any given time, a DG or load connection and disconnection might take place in the microgrid [2]. Whenever such a change occurs, the prior-assigned strategies like power generation, load sharing, control, and especially protection settings become trivial or even erroneous [3]-[4]. It is worth noting that two fundamental concepts of traditional distribution systems, i.e., "radial" structure of the grid and passive nature of the network, might jeopardize the existing conventional protection schemes in a microgrid [5]–[10]. Hence, some kind of adaptability to the conditions should be adopted by the parameters of the microgrid for a proper operation [4]- [5].
In [9], a microgrid protection scheme is proposed that optimally determines the sizing of the fault current limiters and setting of directional overcurrent relays. The optimally-designed protection scheme takes into account both modes of operation (grid-connected and islanded). The problem is formulated as a constrained nonlinear programming and is solved by using the genetic algorithm. In [4], the authors proposed a new protection scheme utilizing extensive communication to monitor the microgrid and update relay fault currents according to the dynamic changes in the microgrid like connection/disconnection of DGs. Modeling of the microgrid protection system is performed by using IEC61850 communication standards.
Microgrids inherently establish a sophisticated communication infrastructure that could be optimally used to implement a centralized management system to operate the system in a most economically manner and provide the protection hierarchy at all points of the network. More global protection designs may be applied in future microgrids by using high-bandwidth communications in order to achieve the required speed [3]-[5].
Differential protection can be well exploited for protecting underground distribution lines using a communication media such as pilot wires, fiber optics, radio or microwave, etc. between the line terminals. Differential protection with its highest selectivity requires a reliable communication media for instantaneous data transfer between terminals of the protected element. Advancements in communication infrastructure have made possible the wide-area monitoring, protection, and control.
In this paper wide-area protection is discussed in microgrids. It is supposed that the sample microgrid has the required communication links to make decisions based on local measurements and also the status of the adjacent relays. In this case logic-based protection is considered for the sample network. It is proposed instead of giving the authority of tripping the circuit breakers to different individual relays, the protection could be performed semi-centrally by collecting the situational data in a wider area, identifying the fault location based on the wide-area collected data, and then intelligently deciding on the trip.

DISTRIBUTION FEEDER PROTECTION

Generally, feeders are protected by overcurrent protection schemes, in which the fault is detected through a high value of the fault current passing downwards. Although the scheme is simple and efficient in traditional distribution systems, it has some drawbacks in a microgrid.
Figure 1 shows a sample microgrid used for simulation. It is composed of two feeders with different combinations of loads (sensitive, industrial, commercial, residential, etc.) and different energy resources. The microgrid is connected to the utility-grid (macrogrid) through a transformer. Circuit breakers (CBs) are equipped with protective relays to deal with the faults on the feeders.

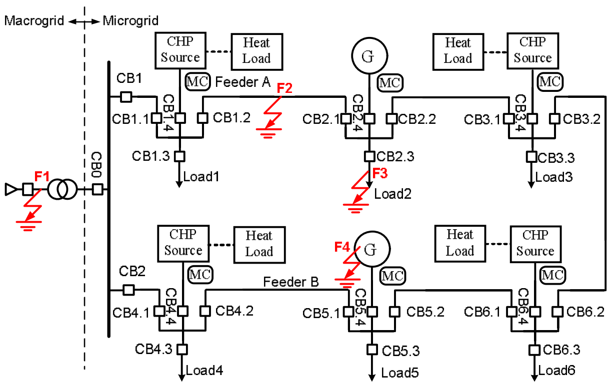

Figure 1: Sample microgrid

Table 1 shows the challenges that are associated with the overcurrent protection of the microgrid. The CBs with * may have sensitivity problems due to the low fault contribution from the microsources, especially with power electronic interfaces. The most important singularity lays in the time coordination of overcurrent devices in the microgrid.

Table 1: Problems associated with microgrid protection

Operating Mode	External Fault (F1)	Faults Inside Microgrid		
		Feeder (F1)	DG (F2)	Load (F3)
Grid-connected	CB0*	CB1.2 & CB2.1*	CB5.4	CB2.3
Autonomous	------	CB1.2* & CB2.1*	CB5.4	CB2.3

PROPOSED METHOD

Central Protection Using Overall Communication

The proposed method is based on determination of power flows at each end of the line by a protective device and transmitting the direction of the power flow to the control center. This scheme uses high-speed distance elements that are set to overreach the remote terminal. The overreach elements act as transfer direction devices and, on fault detection, keying of the frequency transmitting the direction. The algorithm implemented in the control center is based on checking the direction of power flows of both ends of the lines; if the algorithm finds a line with opposite power flow directions, then the conclusion is existence of a fault on that line, so the trip signal is issued for the two ends' CBs. The proposed method is fast, robust with full selectivity. This method does not need local protective decisions; the decision is made centrally at the higher level. The proposed method is illustrated in Figure 2. As can be seen from this figure, the central controller manages the operation of the generating units based on unit commitment and economic dispatch subject to the most economical scenario. In addition, the devices associated with the CBs of the interconnecting lines send the direction of the fault preferably whenever a fault occurs to alleviate the burden of the communication media. The protection algorithm checks the direction of the two ends of each line to find the one with opposite directions. CBs nominated as CB*.3 and CB*.4 (* would be a number 1 to 6) would operate locally, as Table 1 states, there is no challenge for these protecting devices; their status is a requirement for economical operation of the microgrid, so their status (closed or open) is transmitted to the central controller.

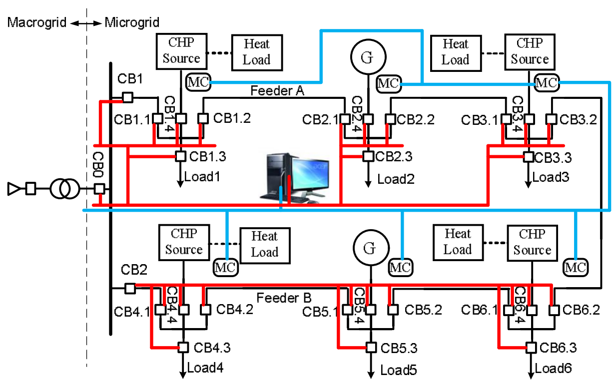

Figure 2: Sample microgrid with central controller for power dispatch of DGs and protection of the system

Back-up Protection Using Peer-to-Peer Communication

Because of a vulnerability to possible communication failures, the differential protection concept using central decision making requires a separate back-up protection scheme. In this regard, an auxiliary logic is proposed that is used as a backup protection system using peer-to-peer communication links. In this regard, the relays incorporated in each line end provide the directional device used in central protection and directional comparison blocking (DCB) protection scheme. Directional device monitors the direction of over-current relays on both sides of the line to confirm that there is a fault. DCB acts as a backup protection system which tends to isolate the fault once the short circuit current is sensed by directional overcurrent devices; however, directional device sends blocking signals if a fault is not occurred between the line ends' CBs. As a backup protection scheme, DCB is always active in the microgrid even if the distribution system is open-looped. Fiber optics is used as a communication medium between relays and CBs. The fiber optic communication system is capable of transferring the information in less than 2 msec which enables the main protection system to clear the fault in less than 6 cycles. The backup non-directional over current protection will operate if the primary protection scheme or the communication system fails.

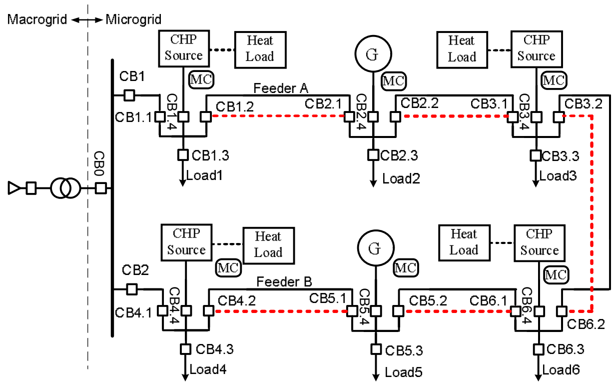

Figure 3: Sample microgrid with peer-to-peer communication links used for back-up protection

Figure 4 shows the logic diagram used for back-up protection. For an internal fault at point F1, both directional devices see the fault in forward directions, hence the transmitter does not send blocking signal to the other end, thereby the trip command would be initiated, while for an external fault at point F2, the blocking signal is transmitted and inhibits the tripping of the CBs.

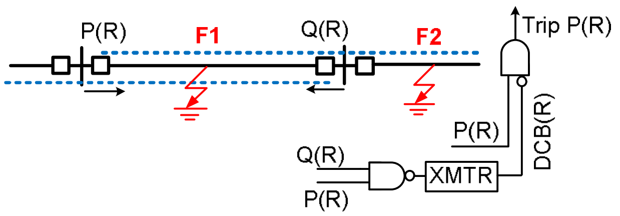

Figure 4: Logic diagram used for back-up protection

SIMULATION RESULTS

Different fault scenarios and microgrid structure is used to analyze the behavior of the proposed method.

Scenario 1: Microgrid connected to the grid and with DGs switched off

Figure 5 shows a fault on feeder A at point F1 between CB1.2 and CB2.1. A high-value fault current passes from the grid to the fault point. CB1.2 sees the fault and reports forward direction to the central controller. The algorithm checks the direction, and see that there is no confirmation from CB2.1, so reaches to this conclusion that the fault is on the related line and trips CB1.2 and also CB2.1, a sophisticated task from the proposed method, as the conventional protection ignores tripping CB2.1, hence avoiding the connection of the fault to the DGs, once they are connected.

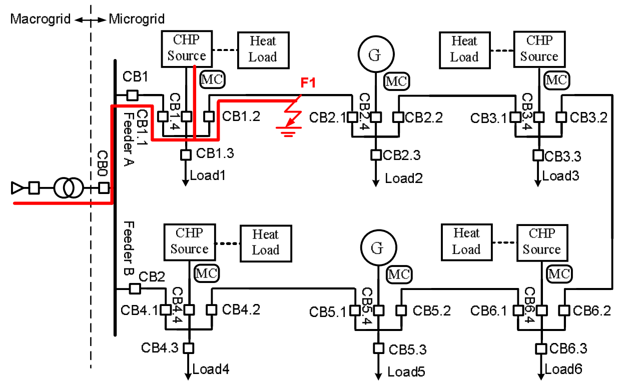

Figure 5: Scenario 1, Microgrid connected to the grid with DGs switched off

Scenario 2: Scenario 2, Microgrid connected to the grid with DGs switched on and feeders disconnected.

Figure 6 shows the sample microgrid connected to the grid and DGs in service and the feeders are disconnected by opening CB3.2 and CB6.2. The fault current is passes from both sides, but the fault contribution from the DGs in right side of F1 is limited and may not operate the overcurrent relay conventionally used to protect the line. However, the proposed method does not need a high fault current contribution, as it is only necessary to determine the power flow which is possible even by low current values. In case of communication failure of the central controller, a logic is foreseen to trip CB2.1 following the trip of CB1.2.

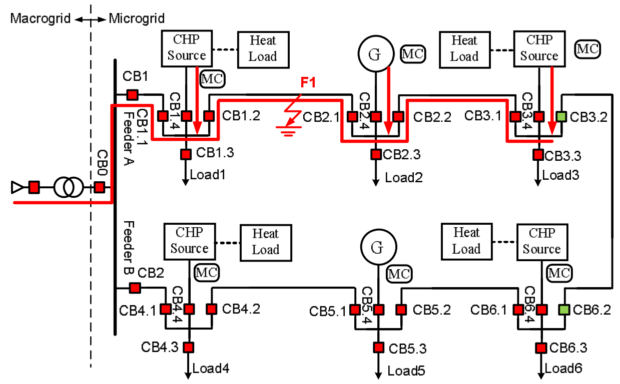

Figure 6: Scenario 2, Microgrid connected to the grid with DGs switched on and feeders disconnected.

Scenario 3: Microgrid in islanded operation mode

Figure 7 shows the microgrid in autonomous operation mode. As the figure shows the fault current is supplied by the microsources, if the DGs are interfaced by power electronic devices, then the fault contribution is normally limited to 1.1 times the rated current, so the sensitivity problems would be with the conventional overcurrent devices, while the proposed method successfully isolate the fault by opening CB2.1 and even CB1.2 without any fault current passing through it in order to refrain connection of the fault to the grid when the related CBs are closed.

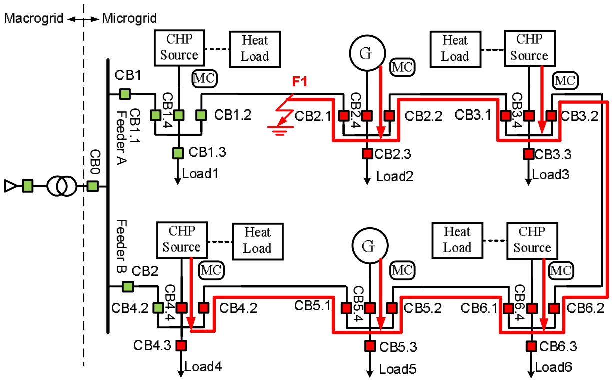

Figure 7: Scenario 3, microgrid in autonomous mode.

Figure 8 shows the microgrid in autonomous mode when a fault occurs at F2 on the line connecting CB2.2 and CB3.1. The fault current is indicated in the figure in addition to the communication links between the directional devices and the control centre. The algorithm receives all the power flow directions reported by the directional devices associated to each CB at the line ends and then reaches to this conclusion that the only line with opposite directions is the line with CB2.2 and CB3.1, hence the fault is successfully removed by sending trip signals through communication links by central controller.

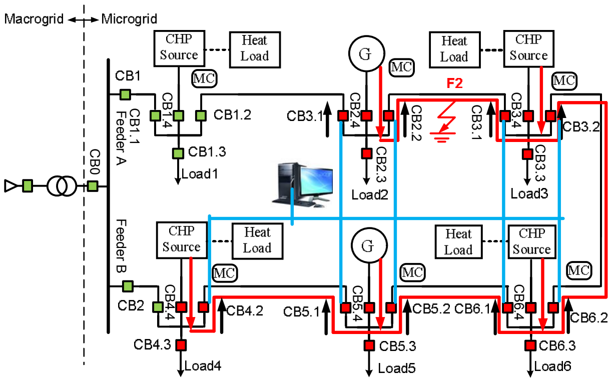

Figure 8: Fault current and communication links for a fault in the sample microgrid in autonomous mode.

CONCLUSION

In this paper a new methodology for detecting the faults in a microgrid is proposed that relies on the communication infrastructure of the microgrid. The decision to trip is based on analyzing the power flow directions of different devices installed on the line ends. The protection is performed in a central controller by checking the power flows of each line ends. The trip decision is made for any line with opposite directions. The healthy lines have the same directions, either in clockwise or anti-clockwise directions. The directional device is simple and does not necessarily depend on the fault magnitude. As the communication infrastructure is vulnerable to possible failures, the proposed approach using central decision making requires a separate back-up protection scheme. An auxiliary logic is proposed as a backup protection system using peer-to-peer communication links and directional comparison blocking (DCB) protection scheme. Directional device monitors the direction of over-current relays on both sides of the line to confirm that there is a fault. DCB acts as a backup protection system which tends to isolate the fault once the short circuit current is sensed by directional overcurrent devices; however, directional device sends blocking signals if a fault is not occurred between the line ends' CBs. The backup non-directional over current protection will operate if the primary protection scheme or the communication system fails. Voltage level of the microgrid affects the protection philosophy, as surveys show less than 2 faults per 5 years (overhead lines) and 1 fault per 20 years (underground cables) will take place inside a typical microgrid spanning over 1 km. However, more faults happen in MV grid and microgrid is needed to be isolated from the fault.

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