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DC RING-BUS MICROGRID FAULT PROTECTION& IDENTIFICATION OF FAULT LOCATION

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Abstract:* Unlike traditional AC distribution systems, protection has been challenging for DC systems. Multi-terminal DC power systems do not have the years of practical experience and standards that AC power systems have. Also, the current power electronic devices cannot survive or sustain high magnitude faults. Converters will shut down to protect themselves under faulted conditions. This makes locating faults in DC system difficult, and causes the DC bus to de-energize. The main goal of the protection method is to detect and isolate faults in the DC system without degenergizing the entire DC bus. In order to achieve this a ring bus was utilized for the main DC bus. The bus was then segmented into individual zones with solid state bi-directional switches used to isolate the zone in the event of a fault. Each zone is monitored and controlled by an individual Intelligent Electrical Device. This probe power can also be used for a pilot test before main CB reclosing to avoid system issues that can be expected when the reclosing fails due to a permanent fault. The proposed algorithm can be implemented and executed by an intelligent electrical device for individual node. The proposed concepts have been verified with hardware experiments.

I. INTRODUCTION

Recently, many distributed power systems have been researched and developed, especially to meet the demand for high penetration of renewable energy resources, such as wind turbines and photovoltaic systems. The distributed power systems have advantages, such as the capacity relief of transmission and distribution, better operational and economical generation efficiency, improved reliability, eco-friendliness, and higher power quality .The micro-grid system is a small-scale distributed power system consisting of distributed energy sources and loads, and it can be readily integrated with the renewable energy sources . Due to the distributed nature of the micro- grid approach, the connection to the central dispatch can be removed or minimized so that the power quality to sensitive loads can be enhanced. Generally, they have two operation modes: stand-alone (islanded) mode and grid-connected mode. Micro-grid systems can be divided into ac-bus and dc-bus systems, based on the bus to which the component systems are connected. The advantage of the ac-bus-based micro-grids is that the existing ac power grid technologies are readily applicable. However, problems with the ac grid issues, including synchronization, reactive power control, and bus stability, still persist. DC ring bus-based systems can become a feasible solution because micro-grids are small, localized systems where the transmission loss is negligible. While the advantages of dc micro-grids are considerable, the protection of dc distribution systems has posed many challenges, such as autonomously locating a fault within a micro-grid, breaking a dc arc, dc protective equipment, and certainly the lack of standards, guidelines, and experience. The main objectives of the proposed scheme are to detect the fault in a bus segment between devices and then to isolate the faulted section so that the system continues to operate without disabling the entire system. Also proposed is a non-iterative, deterministic fault location technique using a probe power unit. The information on fault location is extracted from the probe current.

II. EXISTING SYSTEM

AC distribution system is the existing system in most of the places. AC micro-grids have a clear advantage when it comes to system protection. AC power systems come with more than 100 years of experience and well-defined standards. (e.g., ANSI/IEEE and IEC standards). All of this can be easily translated into an ac micro-grid. Standards on the protection of dc systems currently do not exist. AC breakers rely on the natural zero crossings of the ac current hence, these breakers cannot be applied in dc systems due to the lack of zero crossing in the dc current. In case of DC protection system, the existing system requirement of phasor information, high sampling rate, limits the practicality of the method. AC systems suffer from skin effect, loss will me more in ac system.

A. Dc-Bus Microgrid

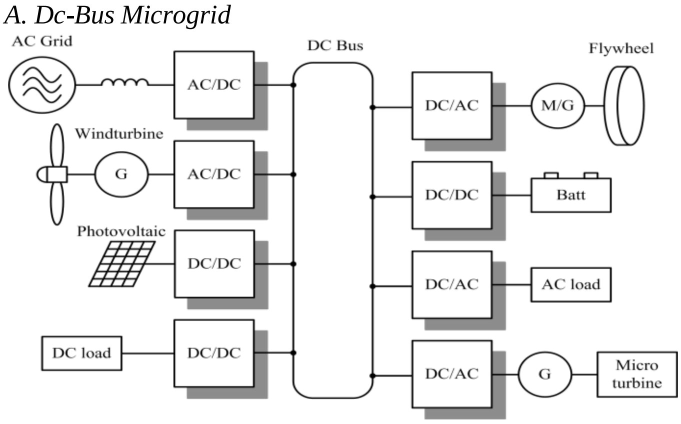

Fig. 1. Conceptual Diagram of a Dc-Bus Micro-Grid System

B. AC VS DC

Micro-grid systems can be divided into AC-bus and DC-bus systems, based on the bus that the component systems such as energy sources, loads and storages are connected to. AC-bus based micro-grids are advantageous because the existing AC power grid technologies can be readily applicable. However, AC grid issues including synchronization, reactive power control, and bus stability are inherited as well. DC-bus based systems can become a feasible solution because micro-grids are small, localized system that the transmission loss is negligible, unlike the traditional power systems that have a long line of transmission and distribution. Moreover, it does not need to consider the AC system issues and system cost and size can be reduced compared to the typical AC-DC-AC conversion configuration because DC power is generally used in the power electronics devices as a medium.

While the advantageous of DC micro-grids are great, protection of DC distribution systems has posed many challenges such as autonomously locating a fault within a micro-grid, effectively breaking a DC arc, DC protection devices, and certainly the lack of standards, guidelines and experience.

C. HVDC vs. LVDC

When it comes to power transmission systems HVDC is the most prominent. HVDC lines have been a part of the United States grid for over 40 years. HVDC lines help transmit bulk power over long distances and interconnecting the three grids in the in the United States. In traditional power systems there are three main components: generation, transmission and loads. Generally the generation is a large power plant (coal, nuclear, etc.) and is located outside large cities, while most of the loads lie within these large cities. The transmission component delivers energy from the generation sites to the loads. This is how the power systems around the world currently work. Attitudes and views on how the power system should operate have begun to shift and decentralization of the grid is beginning to gain attention. This would mean that traditional loads would install local generation often called independent power producers (IPP). The local generation can be used to supply the local loads, thus decreasing the transmission losses. When the IPP produces more electricity than the load consumes it can sell the power back to the utility, and when production falls short the grid is there to make up the difference. It is in this application that LVDC has started to gain attention. Although, the Electric grid is primarily AC many of the loads in our homes and businesses are DC. This means that each of these devices requires a small AC-to-DC converter, which increases losses. If local IPP's produce DC power that the loads are able to use directly it would decrease these conversion losses. This is especially advantageous for data centers where almost all of the equipment is DC. Recently, the European Telecommunications Standards Institute (ETSI) began drafting a standard on 380VDC wiring for building-wide power distribution

D. LCC vs. VSC

Currently line commutated converters (LCC) or classical thyristor-based DC systems hold the market in bulk power transmission. Recently voltage source converter based DC systems are becoming more of a competitor of classical thyristor-based DC systems. Not only is VSC a competitor for transmission but it can also be used in multi-terminal systems, which have become an attractive option for renewable energy applications or for distribution in large cities. As the converter power rating increases it may one day replace thyristor-based converters. VSC's are attractive because, unlike classical converters, no reactive power support is needed to operate the system. In fact VSC's can produce reactive power, and control active and reactive power independently .This controllability allows VSC converters to operate in systems with little or no AC support, something that classical converts cannot achieve without expensive support VSC's are also advantageous in multi-terminal systems. Multi-terminal systems consist of three or more converters to create a DC network. Applications of multi-terminal systems include distribution into large cities, micro-grids, and even ship power systems VSC's are better suited for multi-terminal systems as the power can be changed by changing the direction of the current. Classical DC converters require the DC voltage polarity to be changed, which can be difficult. VSC systems are, by design, vulnerable to faults on the DC systems. Classical HVDC systems are naturally able to withstand short circuit currents due the DC inductors limiting the current during fault conditions when a fault occurs on the DC side of a VSC system the IGBT's lose control and the freewheeling diodes act as a bridge rectifier and feed the fault. The types of faults possible on a HVDC system are as follows. A challenge associated with the protection of VSC systems is that the fault current must be detected and extinguished very quickly as the converters fault withstand rating is generally only twice the converter full load rating . Fault detection is also important, especially on multi-terminal systems, in order to isolate the fault and restore the system to working order.

III. PROPOSED SYSTEM

DC DISTRIBUTION system is one of important future power systems to save energy and to reduce CO2 emission because it can improve the efficiency of systems due to the reduction of the number of power conversion stages. Especially, the dc distribution system for a residential house using dc home appliances can allow the flexibility of merging many renewable energy sources because most of the output of renewable energy sources is dc. In Dc systems can deliver $\sqrt{2}$ times more power than ac system. This is because the usable power is based on the rms values in an ac system, while the dc power is based on constant current and voltage the main goal of the proposed scheme is to detect and isolate the faults in dc bus without de-energizing entire system. This system is implemented by using RING-BUS .The bus was segmented into overlapping nodes and links with circuit breakers to isolate the segment in the event of a fault. Backup protection is implemented for circuit breaker failures to improve system reliability; the solid-state circuit breaker is a bi-directional circuit breaker generally consists of two switches in series with one opposing other. Fault location technique using probe power unit is proposed.

A. Fault Protection of Dc-Bus Micro-Grid Systems
For DC system two types of faults exist, line-to-line and line-to-ground, as can be seen in Fig. A line-to-line fault occurs when a path between the positive and negative line is created, shorting the two together. A line-to-ground fault occurs when a path between either the positive or negative pole or ground is created. A line-to-ground fault is the most common type of fault. VSCs may experience internal switch faults that can cause line to line short fault. This is a terminal fault for device that can't be cleared and in most cases it requires replacement of the device.

B. Line to Ground
A line-to-ground fault (ground fault) occurs when the positive or negative line is shorted to ground. In overhead lines faults may occur when lightning strikes the line. This may cause the line to break, fall to the ground and create fault. In this situation the fault is always permanent and the line must be isolated for repair. Ground faults may also occur by objects falling onto the line, such as trees, providing a path to ground. In some cases when an object causes the ground fault it may fall away from the line and the system can be restored. If the fault persists the line would have to be taken out of service until the fault path can be cleared. Underground cable is almost completely immune to line-to-line faults, as insulation, conduit and the earth separate the cables. However, they can still occur. The insulation of the cable can fail due to improper installation, excessive voltage/current, and exposure to the environment (water, soil, etc) or cable aging. When this occurs, the broken insulation will allow a path for current to flow to ground. As the fault persists the integrity of the insulation is reduced causing the fault to worsen. A ground fault may also occur when a person in advertently cuts through one of the lines. This generally happens during construction projects. In either case the fault will always be permanent and will require a complete shutdown of the line as well as a costly repair. When a line-to-ground fault occurs, the faulted pole rapidly discharges capacitor to ground. This causes an imbalance of the DC link voltage between the positive and negative poles. As the fault voltage of the faulted line begins to fall, high currents flow from the capacitor as well as the AC grid. These high currents may damage the capacitors and the converter.

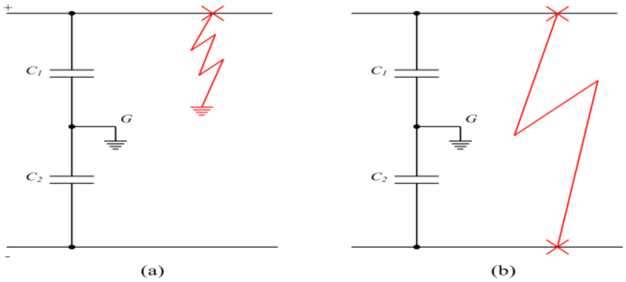

Fig. 2. a) Line-to-Ground Fault b)Line-to-Line Fault

C. Line to Line
As stated before, a line-to-line fault on a cable-connected system is less likely to occur on the cable. In an overhead system, line-to-line faults can be caused by an object falling across the positive and negative line, they may also occur in the event of the failure of a switching device causing the lines to short. A switching fault, which is independent of how the converter stations are connected together, causes the positive bus to short to the negative bus inside the converter. A line-to-line fault may be either temporary or permanent.

D. Over current
While over current protection is important during line-to-line and line-to- ground faults, it must also operate when the system is being overloaded. Over- load conditions may occur in two-terminal systems when the load increases past the rating of the converter or as a result of a fault on another part of the system. For example, if three VSC's are feeding a common load and one VSC is dropped due to a permanent fault, the remaining two must supply the load. This will result in elevated currents that may overload the converters. In this situation the over current protection would need to operate. Another option to avoid a wide spread blackout would be to shed non-critical loads.

IV. TECHNIQUES PROPOSED

A. Fault Protection Techniques
Protection of dc systems has been done with dc protective switchgear as well as conventional ac devices, such as CBs and fuses. Although ac devices have advantages, such as low cost, maturity of technology, and shorter lead time, dc devices are a better option whenever possible. DC protective devices can interrupt constant current faster than their ac counterparts to isolate faulted lines and maintain the operation of unfaulted lines. Although ac CBs result in the longest interruption time because of their mechanical restrictions, using ac CBs on the ac side of the VSC is the most economical way to protect the dc system. Currently, the best interruption time for an ac CB is two cycles .In conjunction with ac CBs, differential protection can be used for back-to-back or two-terminal transmission systems .One relay could monitor the ac current at the sending VSC as well as the receiving VSC or a communication link would be required for the current readings to be sent between relays at two terminals. If the current entering does not match the current leaving, the differential relay will trip the ac CB. However, it is problematic because this scheme shuts down the entire system. It is especially so in the case of ground faults where the faulted line could be separated and rest of the system could keep running in monopolar mode or in loop-type bus. AC CBs are also inconvenient in multi-terminal systems. Fuses on the ac side are generally not a good solution for dc system protection because a fuse is a slow thermal device that is generally not resettable. To overcome the limitations of fuses and traditional ac CBs in dc systems, solid-state CBs have been investigated. Power devices, such as gate turn-off thyristors (GTOs), IGBTs, and insulated-gate commutated thyristors (IGCTs) are used. Such

devices have different characteristics: GTOs have high blocking capability and a low conduction loss, but switching speed is slow. IGBTs are widely used in the low-voltage (LV) systems. IGBTs offer fast interruption time and an ability to withstand short-circuit currents, but have high conduction losses. IGCTs have relatively low conduction loss and high turnoff capability. The IGCT's switching speed is lower than IGBT, but it may not be a concern for a CB. The solid-state CBs needs to be bidirectional to allow power flow in either direction. The bidirectional CB generally consists of two switches in series with one opposing the other.

B. Fault -Location Techniques

Several methods have been investigated for locating faults in ac systems. Fault location can be determined using the computed reactance based on recorded fault current and voltage information at one terminal of a line. Fundamental phasor information, phasor measurement unit (PMU), and fault voltage sag can be used as well. The traveling- wave method computes the difference in time of arrival for a transient wavefront at two or more locations connected to a fault to locate the fault. The traveling-wave method has gained popularity due to the commoditization of global positioning system (GPS) receivers for accurate time synchronization. However, the requirement of phasor information, two-terminal measurements, high sampling rate, and training data limit the practicality of the method. Also, there is an inherent limitation for dc systems which lack frequency and phasor information. The existing dc fault-location techniques use rate of current rise, magnitude of current, current oscillation pattern, continuous wavelet transform, distributed parameter line model ,iterative estimation using reference voltages , and artificial neural networks .The accuracy of the a fore mentioned methods shows promise; however, the dependence on two-terminal measurements restricts the practical uses. The instrumental aspects, such as the impact of sensor error and communication delay, have been investigated in .Furthermore, because the dc fault current rises so quickly, it may have to be interrupted before some useful information for the fault location can be obtained. Also, it may be difficult to extract the necessary information for fault location at the time of the fault,because the fault current is determined by other bus segments and components as well as fault impedance.

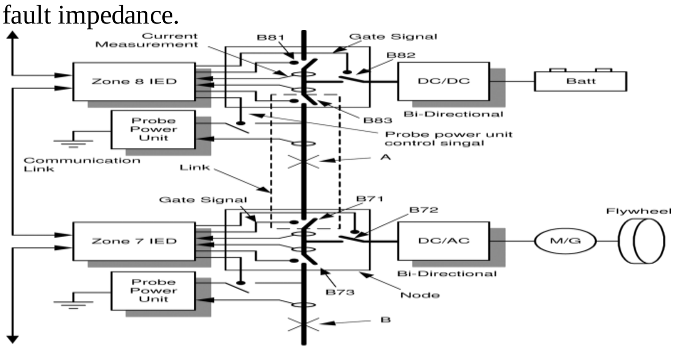

Fig. 3. Detailed diagram of the proposed protection system- each IED controls node/link CBS, communication links, and probe power unit

C. Proposed Fault Protection Method

Unlike other previously presented methods for dc systems, the proposed protection method does not require a complete shutdown of the microgrid. Rather, only the affected section is isolated and de-energized. This is demonstrated with a ring-bus configuration for the dc bus, creating several zones of protection that can be defined using overlapping nodes and links within the bus. Each node consists of three CBs, and two CBs at each end of a bus segment form a link. This can be implemented for the positive and negative pole in bipolar systems. At each node, a probe power unit will be installed to locate the fault and test the bus for reclosing.

D. Fault Detection and Isolation

An IED monitors and controls the node and links. The currents flowing through the assigned CBs are continually monitored for fault detection. Predefined thresholds and current readings from adjacent IEDs will be used for over current and differential current fault detection. The goal of the fault detection unit is to detect the abnormal current in the bus segment and isolate the fault as quickly as possible. Assuming a fault at the point A in Fig. 3, IEDs in Zone 7 and 8 will detect the abnormal currents, which can be seen in Fig. Since the current sensor in the faulted link will detect more current due to the feeding current from the source, the IED will trip the CB in the faulted link first to separate the faulted section only. However, for a low resistance fault the fault current can rise fast enough to trigger over current fault for all of the CBs in the node. In this case, a reclose and restore procedure, which will be explained in Section III-C, will restore the intact bus segments. In case of the high fault resistance the fault current may not exceed the threshold; however, this can readily be detected by differential current. When a CB is tripped by over current, the CB in the other end of the link will trip by the status communication to separate the faulted segment, unless it is already tripped by its own over current threshold.

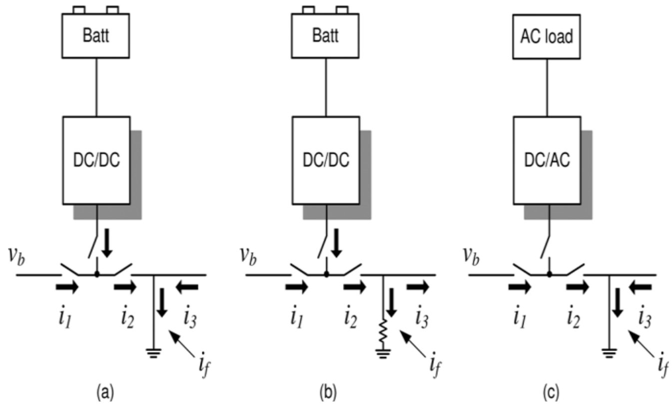

Fig. 4. (a) Low fault resistance case (b) High fault resistance case (c) Fault currents in load node.

E. Breaker Failure Detection

After a fault is detected and trip signals are sent, the IED enters the breaker monitoring mode to ensure that the faulted link is de-energized. If the link has not been de-energized due to the CB open failure, the IED will open all of its breakers and broadcast status signals through communication links. The adjacent IEDs will open the CB on the link to separate the faulted node. The remainder of the sources and loads can continue to operate on the ring bus once the faulted segment is isolated. Even with multiple faulted segments, the system can operate partially if the segments from the main source to some loads are intact. For example, if a fault is detected at point B in Fig.4, but CB B73 fails, a signal from the Zone 7 IED would be sent to the Zone 8 IED after opening B71 and B72. The Zone 8 IED would trip B83. At this point, Zone 7 has been de-energized and locked out, meaning that the zone controller will not try to automatically reclose and restore the zone. Restoring the zones after a lockout condition requires a manual restore, after the fault has been removed from the system.

F. Reclose and Restore

Once the faulted link was successfully separated and de-energized, the IED will attempt to reclose and restore. Faults are often temporary caused by debris, animals, or other transients (e.g., lightning) contacting an energized line or bus. The temporary faults will clear themselves after current flows through the fault path. The reclose and restore mode allows the IED to autonomously restore power back to the de-energized zone. This is done by waiting a certain amount of time after the trip signals have been sent. After that, the IED will send close commands to all of the breakers. The waiting time depends on system configuration. For example, the minimum reclosing time for the high-voltage ac CBs is 0.3 s in IEEE standard. So far, the bus CBs has been reclosed without knowing the status of the fault. If the fault has not been cleared, the same fault current would flow again and it could damage the system.

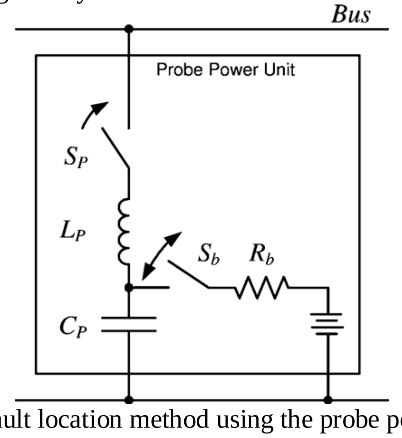

Fig. 5. Fault location method using the probe power unit

In the proposed protection scheme, a probe power unit is used to test the fault status of the bus segment before reclosing the main CB. A circuit diagram of the probe power unit is shown in Fig. he probe unit consists of a capacitor, reactor, power source (e.g., a battery), and CBs. The power source applies a certain voltage that is just high enough to inject a probe current to see if the fault persists. The IED will not detect the return current if the fault was cleared. The capacitance can be determined accordingly to extract the characteristics of the bus segment in the fault path. Since the energy stored in the probe unit is finite, the probe current will be small and extinguished quickly. Therefore, the reclosing can be conducted much safer because the main CB will be closed only when no-fault status is confirmed. The location of the fault can be identified by the analysis on the return current when the fault is present. The system will return to normal operation if the fault is cleared, but in case a permanent fault is still detected, the IED will lock out the zone. The IED can identify a permanent fault by the re-closing sequence using the probe power unit. A selected number of attempts will be made to reclose. The number of retry depends on the bus configuration and related code. After attempts without success, the IED determines that the fault is permanent and will not allow the breaker to close.

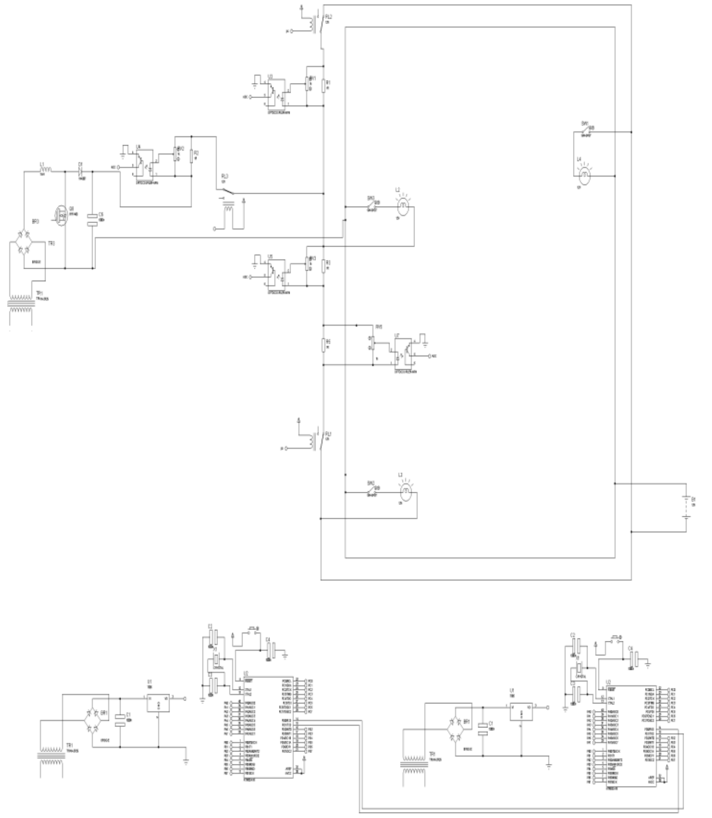

Fig. 6. Circuit of Proposed System

The fault in the system can be identified by the difference in current. Whenever a fault occurs somewhere in the zone or between two zones or due to over current in zone, the current in the system increases rapidly. The increase in current is detected by current sensors. According to Kirchhoff's law the sum of current from different zones must be zero. In the source side, the bridge rectifier converts ac to dc when the MOSFET shorts heavy current flows through the circuit. Current gets stored in the inductor. The polarity of the inductor is negative to positive the polarity changes. The series current gets added and there is a voltage drop occurs across diode. The optocoupler combined current sensor works on the principle of Hall effects. The sum of three current must be zero for faultless power flow. There are two IED devices to sense the current flow. The IED is nothing but microcontrollers. The IED detects external faults and internal faults. The IED communicates with the zone and within each other. One controller senses the current in two adjacent zones. It is opens the circuit breaker contacts according to the type of fault and location of fault. The current flow through bus is sensed by another controller. There are three series resistor. It is fixed resistor. Across the series resistor a variable pot is connected. The voltage drop value is fixed. It is connected to opto coupler sensor. There is a ADC pin in optocoupler which is connected to controller. The voltage drop across the series resistor gets monitored. In case of fault, the voltage drop differs. The current across zone differs. So difference in current gets sensed by IED. The IED sends signal to relay to isolate the faulty section.

V. CONCLUSION

A fault protection and location scheme for the dc micro-grid system has been presented . The proposed protection scheme consists of zone IEDs which are capable of detecting fault current in the bus segment and isolating the segment to avoid the entire system shutdown. A ring-bus-based micro-grid system, which consists of overlapping nodes and links with IEDs, has been used. For the separated faulted segment, a fault-location algorithm using a probe power unit without having to reclose the main CBs has also been presented. This bus probing method can ensure the proper line status before reclosing and hence, improves the system reliability and mean time between failure (MTBF) of protective gear. Furthermore, it can be readily applied to ac power systems to eliminate the issues caused by reclosing failure, as well as to identify the fault location. Successful performance of fault detection, isolation, and location has been shown using hardware experiments. The intent of the project is to demonstrate a fault location technique , the project is demonstrated on a lab design, the full system proposed has not been built or tested in a real-life setting.

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