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Unbalanced and over Current Fault Protection in Low Voltage DC Bus Micro Grid Systems

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Abstract: Traditional AC distribution systems, protection has been difficult for DC systems. In AC power systems the current will be oscillating and will cross zero once in 10ms when the power frequency is 50Hz and so the fault current can be interrupted at current zero. But in DC power systems the current is continuous and so during fault there will not be any current zero for safe interruption of the fault current. Therefore, interrupting the fault current in DC system is more difficult than AC system. Also, the current power electronic devices cannot survive or sustain high magnitude faults. Moreover the converters will put away to protect themselves under faulted conditions. This makes locating faults in DC system difficult and causes the DC bus to de-energize. A fault safeguard algorithm and method for a low-voltage DC-bus micro-grid system is presented in this project to revolve the above issues. The main goal of the protection method is to detect and isolate faults in the DC system without de-energizing the entire DC bus systems. In order to achieve this parallel transmission lines are utilized to feed a dc load. Every transmission line is fitted with solid state bi-directional switches at the transmission and receiving end to isolate the transmission line in the event of a fault. This paper deals the fault clearing algorithm which has been developed to clear the fault either fast or slow depending on the requirement. The control setting can be 1 to 8. When set to 1, the fault is cleared very fast and the rise of fault current will be less and this setting is suitable for low fault level. When set to 8, the fault is cleared after a long delay and the rise of fault current will be large and this setting is suitable for high fault level. The fault clearing delay time will increase when control setting is increased from 1 to 8.The settings can be selected to adapt the real time fault level in the system and so the algorithm is called adaptive fault clearing algorithm. This proposed method of simulation will be executed by hardware in future.

Key words: DC Distribution · Fault Protection · Micro Grids · Power Systems Protection · Solid State Switch

INTRODUCTION

Now-a-days, numerous distributed power system have been researched & developed to meet the need for high penetration of renewable energy resources such as wind turbines, PV system & fuel cell etc., Fig. 1 The distributed system have many advantages like improved reliability, economical generation efficiency, eco-friendliness & power quality. Micro grid system can integrated renewable energy resources.

It is a small- scale distributed power system which consists of distributed energy sources & loads. Due to the distributed nature of microgrid approach, the link to the central dispatch can be separated or minimized and in turn the power quality to the sensitivity loads can be enhanced. Mostly power electronic converters play a vital role for the conversion processes which is interfaced with the distributed energy source. Two modes of operations are available: stand alone (islanded) and grid-connected operation [1].

The micro grid systems can be separated into AC-bus & DC-bus systems, according to the bus requirement the components like energy sources, loads and storages are connected. DC bus based systems are small micro grid, localized systems where the transmission loss is negligible. In AC bus based systems many issues like synchronization, reactive power control & bus stability are still raised. The only advantage of ac bus system is that the quick availability of ac power grid technology.

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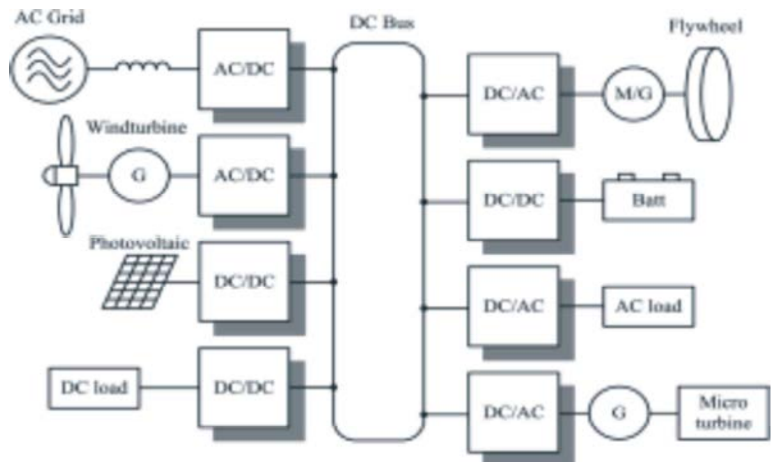

Fig. 1: Diagram of a dc-bus micro grid system

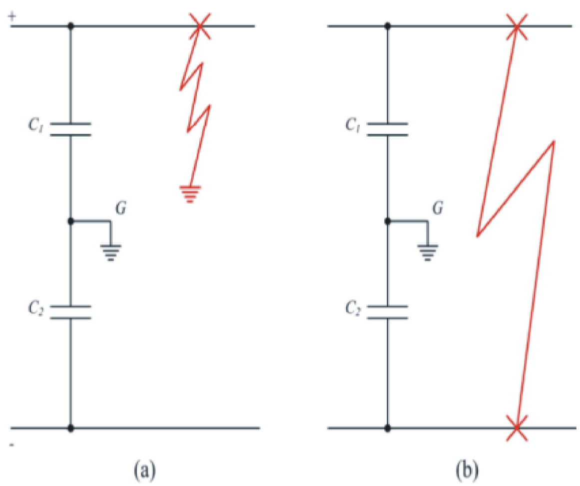

Fig. 2a: Line-to-Ground Fault b) Line-to-Line Fault

Since in dc bus systems, the cost of the system and size can be reduced compare to ac-dc-ac conversion configuration. The primary goal of the proposed method is to detect the fault in a bus segment between devices and isolated the faulted section so that the system keeps operating without disabling the entire system [2-17].

Existing System: DC-Bus micro grid system can be protected under fault condition, the whole system cannot be shut down for isolating the fault. Fault can detect & separate from healthy part. In the existing paper a loop-type dc-bus-based microgrid system, this has a segment controller between connected components. The segment controller consists of master and slave controllers that monitor currents and control the segment separation, which include solid-state bidirectional switches and snubber circuits [1-4]. The existing system can detect faults on the bus regardless of fault current amplitude or the power supply's feeding capacity. The proposed concepts have been verified by OrCAD/PSpice simulations.

Low Voltage Dc Bus Micro Grid Protection

Possible Faults: For DC system two types of faults exist, line-to-line and line-to-ground, as can be seen in Fig. 2. 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. Hence, DC fuse would be proper protection device [1, 8].

Line to Ground Fault: 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 [18-32]. 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 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 inadvertently 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 [8, 22-24].

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 [8]. A line-to-line fault may be either temporary or permanent.

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[14]. 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.[1]

The novel protection method and algorithm for the DC bus micro grid system is proposed in this research. Unlike many other methods, the proposed scheme does not require a complete shutdown of the grid. Rather, only the affected section of the micro grid is isolated and de-energized. This is achieved through use of a bus configuration for the main DC bus, creating several zones of protection within the bus and installing a grounding resistor to limit the fault current. This is done for both the positive and negative bus. The proposed protection scheme can be split into three sections: Fault Detection and Isolation, Breaker Failure Detection, Reclose and Restore. The bus will be split into zones and each zone is monitored by an Intelligent Electrical Device (IED). The IED will continually monitor the current through its assigned breakers. Once a fault is detected the IED will open the zone breakers. The IED will then ensure that all of the breakers have opened and that the faulted zone is de-energized. If the zone has not been de-energized the zone IED will send signals to adjacent IED until the fault is extinguished. If the zone was successfully de-energized the IED will attempt to restore the faulted zone by reclosing the breakers[8]. If a fault is then detected the zone breakers are again tripped and the zone is isolated.

Fault Detection and Isolation: The micro grid under study consists 12 zones of protection. Each zone is classified by the type of energy device it has been assigned. The zones can be split into 4 categories: uni-directional, bi-directional, load and link which is shown in Fig. 3, 4 & 5. Each zone consists of 2-3 breakers and a section of cable. A local IED is assigned to each zone. The IED will monitor and control each of the breakers within its assigned zone. Each IED is programmed with the specific set of rules that define a normal zone operation. This is dependent on the source that the IED is monitoring. It should be noted that due to the ring bus configuration, current has several paths to flow. Therefore several normal operating conditions must be accounted for and they must all fail before a fault is declared. Once fault has been detected all breakers in the affected zone are tripped, regardless of the pole the fault is on [33].

This is done to keep the microgrid and converters in balance. In the examples specific rules that are needed to define a fault are provided. One rule for each zone type is given. Once the faulted segment is isolated, the remainder of the sources and loads can continue to operate on the ring bus. Even with multiple faulted segments, the system can operate partially if the segments from the main source to some loads are intact. It has been assumed that the segment controllers can detect it and open/close Solid State Circuit Breakers in some seconds.

Breaker Failure Detection: Each zone IED continually monitors the status (open/closed) on their respective zone breakers. Under normal conditions this can be used for information purposes to operators of the micro grid. Once a fault inside a zone is detected and trip signals are sent, the IED waits 1 second then enters breaker monitoring mode [8]. The breaker monitoring mode operates under two different conditions:

- Status and Current condition
- Current

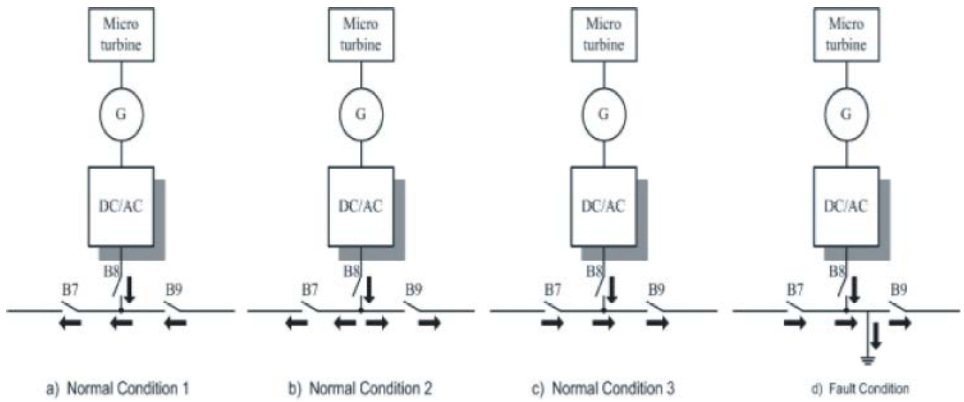

Fig. 3: Uni-Directional Zone: Normal and Faulted Current Flow

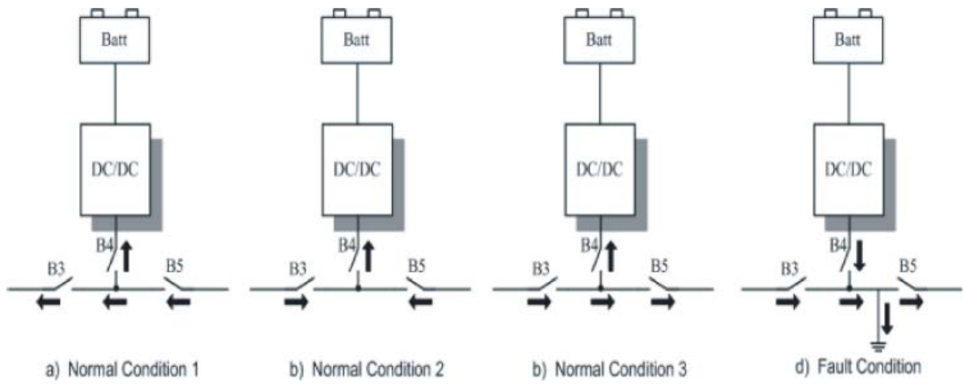

Fig. 4: Bi-Directional Zone: Normal and Faulted Current Flow

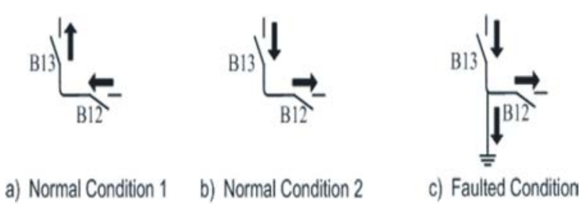

Fig. 5: Link Zone: Normal and Faulted Current Flow

Status and Current Condition: In the Status/Current conditions the zone IED that a trip to all breakers has been sent. The IED then checks to see if all of the breakers are showing a closed status. If a breaker status is closed and the IED expect it to be open a breaker fail condition is suspected. The IED must also confirm that current continues to flow is the faulted zone. If both the closed status and current in the zone are detected the faulted zone IED will then send a signal to the appropriate zone controller to trip its zone breakers. For example, if a fault is detected in Zone 4, but Breaker 5 fails, then a signal from the Zone 4 IED would be sent to the Zone 3 IED. The Zone 3 IED would trip its associated breakers [6-8].

At this point both Zones 3 and 4 have been de-energized and locked out. Locking out the zone means that the controllers will not try to automatically reclose and restore the zones. Restoring the zones after a lockout condition requires manual restore, after the fault had been removed from the system. This condition requires two pieces of information, but extinguishes the fault with the least amount of impact to the DC bus.

Current: If all of the breakers in the faulted zone are providing an open status, but the IED continues to read current in the zone then all of the adjacent zones will be tripped. Using the Zone 4 example, but this time all of the breakers provide an open status. The Zone 4 IED would send signals to both the Zone 3,5 IED's, de-energizing Zones 3,5,5. This condition ensures that the fault will be extinguished even if the IED receives a false status from the breakers. However, it requires large sections of the grid to be de-energized.

Reclose and Restore: Once the faulted zone had been tripped and none of the breakers failed, the IED will the reclose and restore. Often, faults are temporary due to

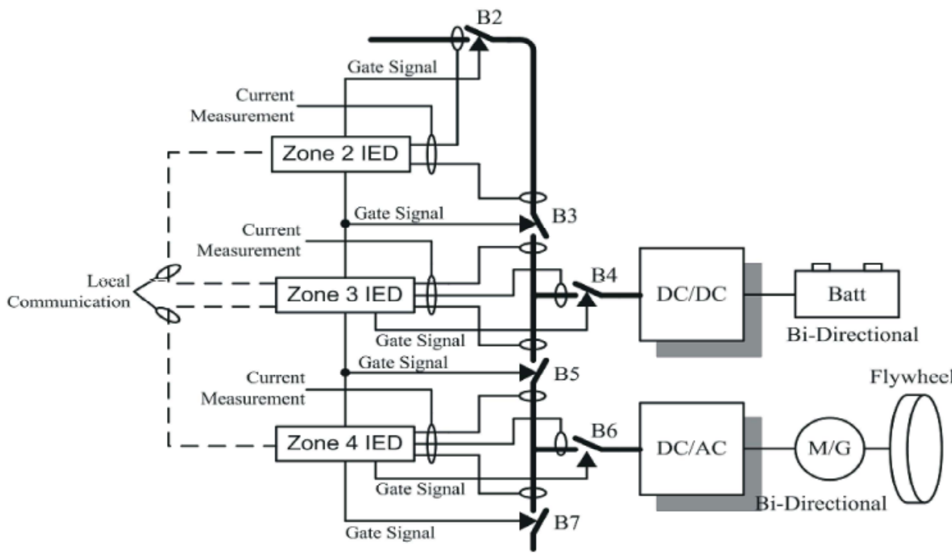

Fig. 6: Zone Controller Connections

debris or animals coming in contact with the cable or line. The temporary faults will clear themselves after current flows through the unwanted ground source. The reclose and restore mode allows the IED to autonomously restore power back to the de-energized zone. This is done by waiting 1 second after the trip signals have been sent. After that 1 second the IED will send close signals to all of the breakers. If the fault has been successfully cleared, the microgrid will continue to run normally. However, if the fault is permanent and it is detected after the first reclose, all of the zone breakers will again be tripped and the zone will be locked out.

Solid State Circuit Breakers: Due to the limitations of fuses and traditional circuit breakers in DC systems, a solid state circuit breaker is utilized. When selecting a solid-state circuit breaker there are several options: GTO, IGBT and IGCT. GTOs over a high blocking voltage capability and a low on stare voltage, but suffer from slower switching speeds. So in this project IRFP460 Mosfet is used as a switch.

Grounding: The magnitude of a ground fault current is dependent on the distance from the source that the fault occurs and the resistance of the ground fault path. The grounding options are:1)solid grounding; 2) low-resistance grounding; 3) high-resistance grounding; and 4) ungrounded [8-15]. Although ungrounded systems are used in some applications to avoid the effect of low-resistance pole-to-ground fault and stray current, ungrounded systems are sensitive to changes in the grounding plane and can be dangerous especially under abnormal fault conditions. The advantages of the grounding in a DC distribution system include predictable operating conditions, minimum voltage stress for the system components and easier fault detection. The line-to-ground faults are the most common types of faults in industrial distribution systems and the ground fault current can be limited by using the resistance grounding. Since the typical power electronics converters connected in the LVDC systems cannot feed large fault currents, it would be beneficial to reduce the fault current to an appropriate level for detection and extinction [13].

It is a common practice to ground power systems at one point only and as close to the source as possible. Multiple ground points could form unnecessary circulating current paths. Possible grounding point for a DC system is either one of the poles or the mid point of the bus and it has been reported that the balanced DC side grounding significantly reduces circulating current compared to the AC side neutral-grounded system. Although the ground resistors can be used to detect the ground fault as well, it is not able to identify the location of the fault because of the single ground point practices.

Proposed System: In the proposed system fault detection and isolation is performed with the help of a PIC microcontroller & bidirectional switches. The system will also have fault override capability during transient faults or short duration faults. It detects the fault in a bus segment between devices and isolates the faulted section so that the system continues to operate without disabling the entire system[1]. Adaptive fault clearing algorithm is implemented in the software part using Matlab software.

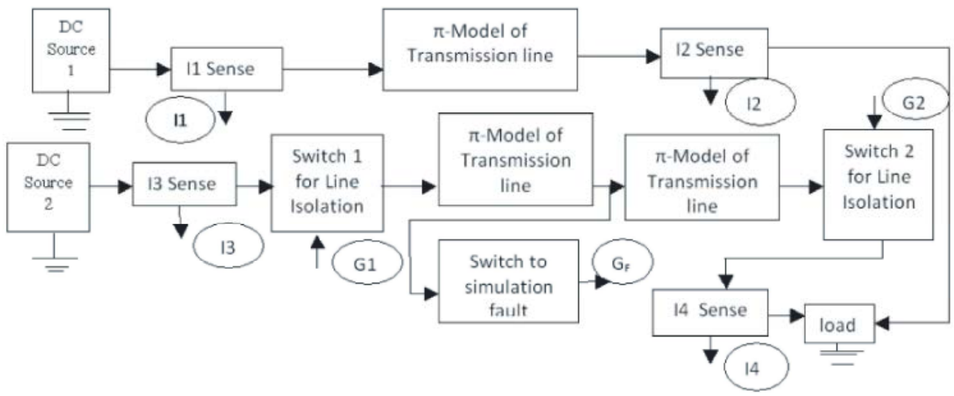

Fig. 7: Block Diagram

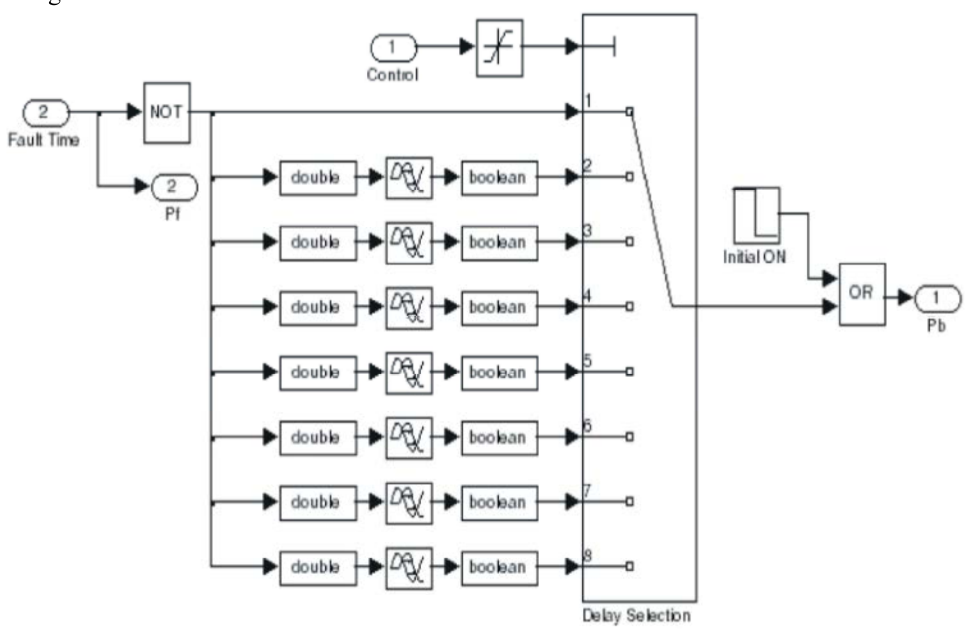

Fig. 8: Control setting block

DC source current can be measured using sensor & amplified. The PIC microcontroller monitors the source and load-side current and the controller sends out a digital output to the gate driver board, which generates isolated gating signal using optocoupler in the hardware part.

Due to the limitations of fuses and traditional circuit breakers in DC systems, a solid state circuit breaker is utilized. When selecting a solid-state circuit breaker there are several options: GTO, IGBT and IGCT. GTOs over a high blocking voltage capability and a low on stare voltage, but suffer from slower switching speeds. So in this project IRFP460 MOSFET is used as a switch. For demo purpose two parallel dc transmission lines are employed to feed a load. The transmission lines are modelled as pi-network and each transmission line has a separate DC source. In each transmission line the currents are sensed at the transmission end and transmission end. The currents are sensed by connecting low value resistance in series with the line and the voltage drop in the resistance is amplified using differential amplifiers and fed to ADC of microcontroller. The digital output of ADC is scaled in software to determine the currents. During normal working conditions the load current will be shared by both the transmission lines and during fault in one of the line the fault line will be isolated and entire load current will be supplied from the healthy line [20-22].

Functional Block Diagram

Functional Description: For demo purpose two parallel dc transmission lines are employed to feed a load. The transmission lines are modeled as pi-network and each transmission line has a separate DC source. In each transmission line the currents are sensed at

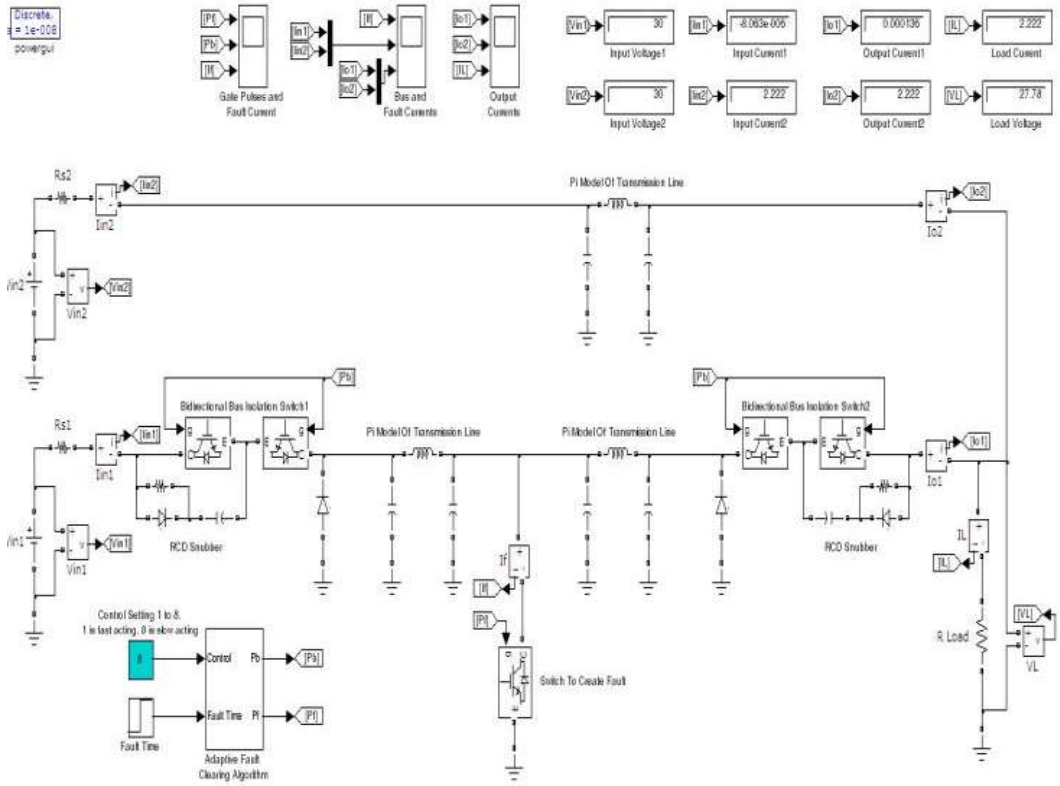

Fig. 9: Proposed system Simulink diagram

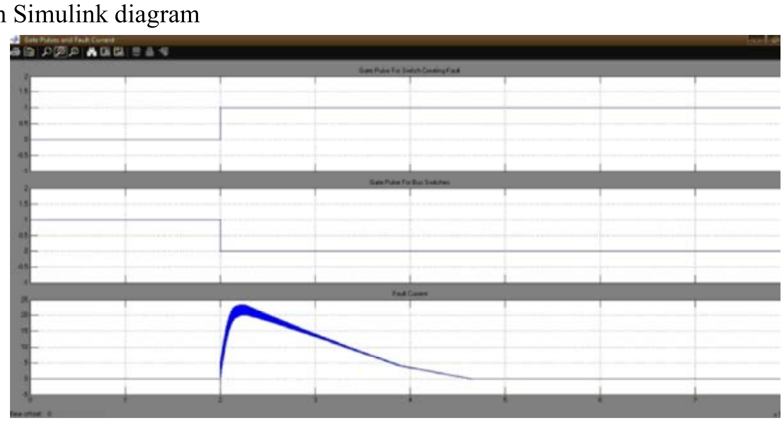

Fig. 10: Gate pulse and fault current for setting 1

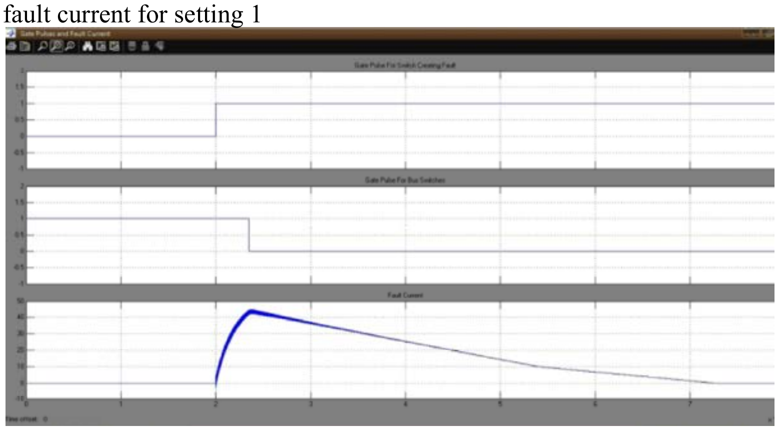

Fig. 11: Gate pulse and fault current for setting 8

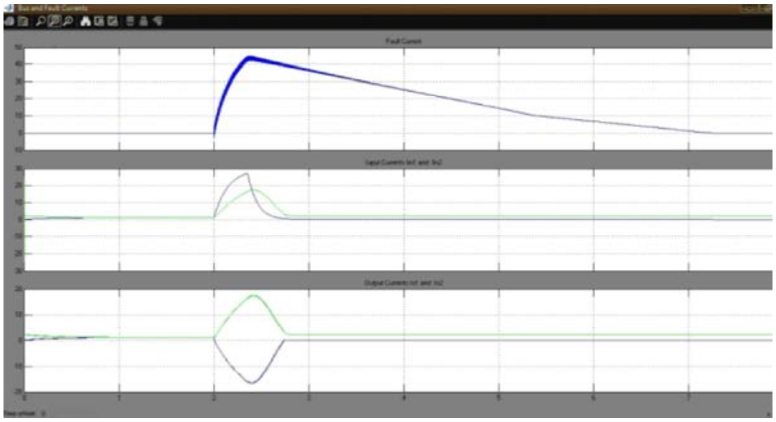

Fig. 12: Bus and fault current for setting 1

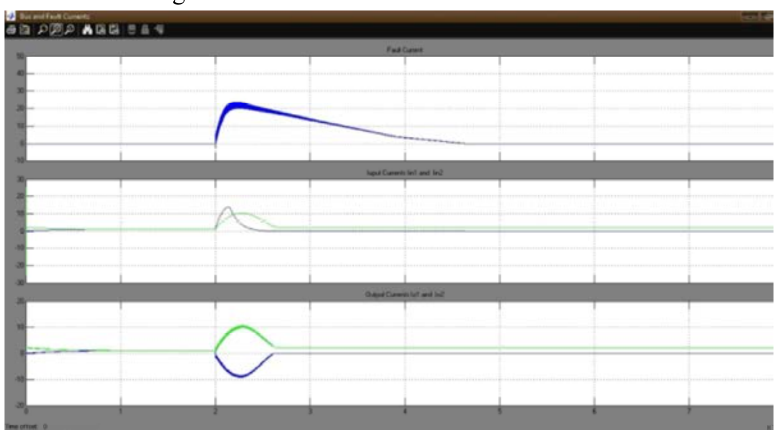

Fig. 13: Bus and fault current for setting 8

the transmission end and transmission end. The currents are sensed by connecting low value resistance in series with the line and the voltage drop in the resistance is amplified using differential amplifiers and fed to ADC of microcontroller. The digital output of ADC is scaled in software to determine the currents.

During normal working conditions the load current will be shared by both the transmission lines and during fault in one of the line the fault line will be isolated and entire load current will be supplied from the healthy line.

Adaptive Fault Clearing Algorithm: The fault clearing algorithm has been developed to clear the fault either fast or slow depending on the requirement. The control setting can be 1 to 8.When set to 1, the fault is cleared very fast and the rise of fault current will be less and this setting is suitable for low fault level. When set to 8, the fault is cleared after a long delay and the rise of fault current will be large and this setting is suitable for high fault level. The fault clearing delay time will increase when control setting is increased from 1 to 8. The settings can be selected to adapt the real time fault level in the system and so the algorithm is called adaptive fault clearing algorithm which is given in Fig. 8.

Simulation and Experimental Results: To verify the feasibility of the proposed strategy, a simulation is carried out.

CONCLUSION

In the proposed work, a new fault detection and isolation scheme for low- voltage DC-bus micro grid system. The proposed protection scheme consists of intelligent controller which is capable of detecting abnormal fault current in the bus and isolating the segment to avoid the entire system shutdown. The bus allows multiple paths for power to flow when a section has been isolated. The use of resistance grounding was utilized in order to limit the fault current, to protect the source converters and also allow the controller enough time to detect and isolate the fault. The successful fault detection and isolation is done with the help of intelligent controller.

Though the fault detection and isolation proves successful for suppressing fault current, locating the faulted zone and isolating the zone for line-to-ground faults, line-to-line faults will still create very large fault current. This is because the fault consists of two sources (positive and negative) and the grounding resistor has no influence on the fault current. Creating an algorithm or control scheme to detect and limit a line-to-line fault is an issue that should be addressed. Also, when a fault occurs and a source is removed from the micro grid, the remainder of the sources must accommodate the load. Determining a real time load current flow control scheme for the micro grid would improve stability in the grid and maximize efficiency from all of the sources. The fault clearing algorithm has been developed to clear the fault either fast or slow depending on the requirement. The control setting can be 1 to 8. When set to 1, the fault is cleared very fast and the rise of fault current will be less and this setting is suitable for low fault level. When set to 8, the fault is cleared after a long delay and the rise of fault current will be large and this setting is suitable for high fault level. The fault clearing delay time will increase when control setting is increased from 1 to 8.The settings can be selected to adapt the real time fault level in the system and so the algorithm is called adaptive fault clearing algorithm.

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