New Scheme of Protection For LVDC Bus Microgrid System

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Abstract—

An LVDC (low voltage DC) bus Microgrid system is a promising technology to be used in future smart distribution system having high level cost-efficiency and reliability, but the protection of DC Microgrid is a quite challenging task. Safety of new distribution system needs to be equal or higher than traditional AC distribution systems. The conventional protection scheme for DC Microgrid uses circuit breaker on AC side, on occurrence of fault AC circuit breaker opens and this cause's complete shutdown of DC link and introduces a forced outage in the system.A new protection scheme for DC micro-grid against line to line fault is presented in this paper. It avoids the complete shutdown of the DC link and continuity of supply is maintained through other buses, as ring type distribution is considered. The current sensors placed at both end of transmission line continuously check the current at both side. When fault occur in line, current difference occurs at both end of line. Controller detects the current difference and opens the power switches which placed at both ends. To satisfy the requirement of fast interrupting time and high short circuit current withstanding capability, IGBTs used as power switches, the proposed scheme is verified through MATLAB Simulink.

Keywords**—** DC bus micro-grid, Distributed generation, DC distribution, Fault protection, IGBT's

I. INTRODUCTION

The ever increasing demand of power puts pressure on generation system and distribution system, this increase in demand causes imbalance between supply and demand. Nowadays there is a large gap between supply and demand of power, and also there is large scarcity of non-renewable sources. To cope up with this, there is need to increase the generation from renewable energy resources like wind energy conversion systems and solar energy systems etc. Power generate from distributed generation, is transferred through the AC or DC grid. When this power is supplied to the isolated area, there is large scope for DC micro-grid instead of AC system [1]. The main advantage of DC microgrid is reduced losses so higher efficiency than AC. Due to change in energy generation patterns from non-renewable to renewable it is convenient to use DC link, as most of them generate power in DC form.

Conventional protection techniques in DC microgrid completely de-energies the DC link. Because such protection scheme the area under healthy condition also goes to dark, this causes forced outage in the system. The main objective of this work is to find out the effective method for protection of DC grid which isolate only the faulty section and avoid complete shutdown of DC grid. So healthy sections are operated without any disturbance and supply continuity is maintained through other buses.

II. DIRECT CURRENT SYSTEM

A. Advantages of D.C System

DC system having number of advantages such as

1. More power can be transmitted per conductor per circuit:For the same insulation, the direct voltage V_d is equal to the peak value (√2 x rms value) of the alternating voltage V_d.
2. Use of Ground Return Possible:In the case of HVDC transmission, ground return (especially submarine crossing) may be used, as in the case of a mono polar DC link.
3. Smaller Tower Size:The DC insulation level for the same power transmission is likely to be lower than the corresponding AC level.
4. No skin effect:Skin effect under conditions of smooth DC is completely absent and hence there is a uniform current in the conductor, and the conductor metal is better utilized.
5. Less corona and radio interference:Since corona loss increases with frequency, there is much lower corona loss and hence more importantly less radio interference with DC.
6. No Stability Problem:The DC link is an asynchronous link and hence any AC supplied through converters or DC generations do not have to be synchronized with the link. Hence the length of DC link is not governed by stability.
7. Asynchronous interconnection possible:For different frequency interconnections both convertors can be confined to the same station.
8. Tie line power is easily controlled:With DC tie lines, the control is easily accomplished through grid control.

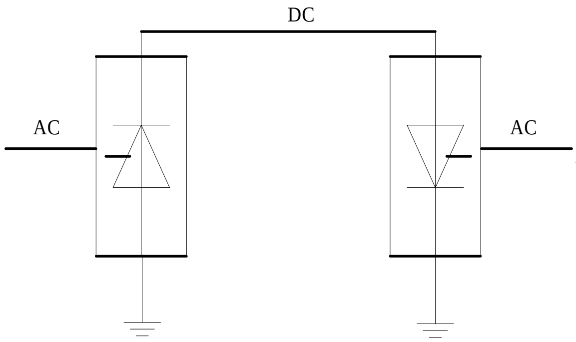
There are also inherent problems associated with DC such as, Expensive convertors, Generation of harmonics, Difficulty of circuit breaking, Difficulty of voltage transformation, Difficulty of high power generation, Absence of overload capacity.

B. Configuration of DC Grid

DC grid can be configured in many ways on the basis of cost, flexibility, and operational requirements.

1. Monopolar Link

In this system, one of the terminals of the rectifier is connected to earth ground. The other terminal, at a potential high above ground, is connected to a transmission line. The earthed terminal may be connected to the corresponding connection at the inverting station by means of a second conductor. Monopolar link is depicts in Fig.1.



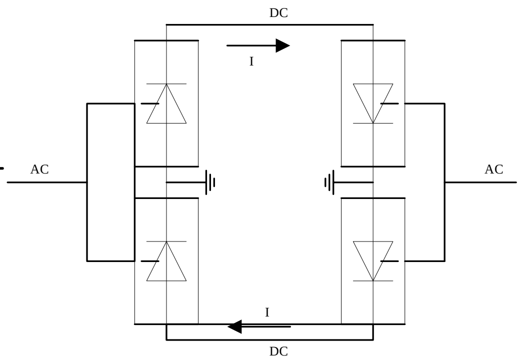


Fig.1 Monopolar linkFig.2 Bipolar link.

2. Bipolar Link

This system consists of a pair of conductors, each at high potential with respect to ground. This conductors are opposite in polarity i.e. one is of positive and other is of negative polarity. Fig. 2 shows bipolar DC link. Since these conductors must be insulated for the full voltage, transmission line cost is higher than a monopole with a return conductor. However, there are a number of advantages to bipolar transmission which can make it an attractive option.

3. Homopolar Link

Homopolar link has two or more conductors all having the same polarity (usually negative) and always operated with ground or metallic return. Fig.3 shows configuration of homopolar link Homopolar link has the advantage of reduced insulation costs. But the disadvantages of earth return outweigh the advantages.

4. Back to Back Connection

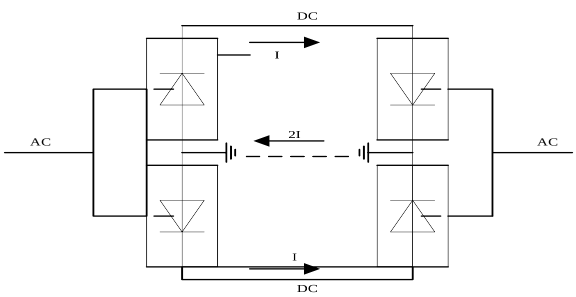
A back-to-back station (or B2B for short) is a plant in which both converters are in the same area, usually in the same building. The length of the direct current line is kept as short as possible.

5. Multi terminal system

The most common configuration of an HVDC link consists of two converter stations connected by an overhead power line or undersea cable. Multi-terminal HVDC links, connecting more than two points. Fig.4 shows a multi terminal connection system.

There are three types of DC grids: a) High voltage DC grids (HVDC): $V_{dc} > 30$ kV; b) Medium voltage DC grids (MVDC) :

1500 V $< V_{dc} < 30$ kV; c) Low voltage DC grids (LVDC) : $V_{dc} < 1500$ V



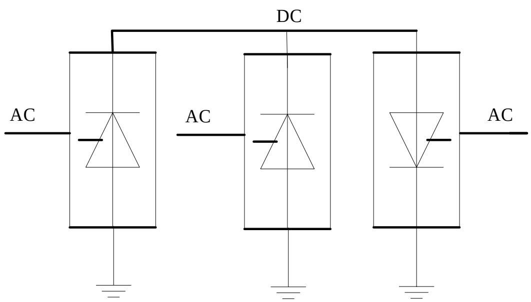


Fig.3. Homopolar LinkFig.4 Multi terminal system.

III.LOW VOLTAGE DC (LVDC) MICROGRID

Low voltage DC grid (LVDC) is emerging concept in distribution system. The microgrid 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 [4]–[6].Due to the distributed nature of the micro- grid approach, the connection to the central dispatch can be removed or minimized, It can be operated in the grid-connected mode, operation in the autonomous (islanded) mode, and ride-through between the two modes [7], [8]. There is simple and easy control and large development in the protection technology of AC system as compared to DC system. But it faces the problem like skin effect, proximity effect, and reactive power control; also losses are more in AC grid. On the other hand DC micro-grid having less loses, and DC system can deliver 1.41 times more power as compared to AC system with the same cable cross section [8], [9].

The schematic diagrams of a LVDC micro-grid is shown on Fig. 5 As the figure indicates, AC loads are interfaced to the grid through power converters. All DER require power converters. General DC loads may require power converters if the voltage rating is not the same as the rated grid voltage. Power converters are used for adjusting generator and load voltages to the standard grid voltage, if required [7].

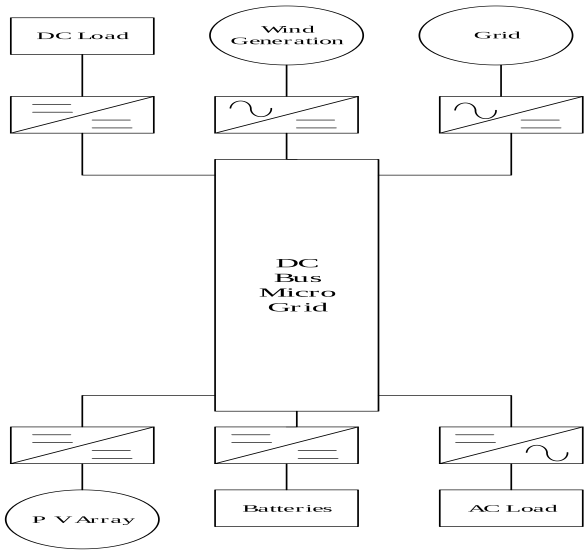


Fig.5 DC Bus Microgrid

The LVDC is well suited for the system such as offices with computer loads or rural power system [10].A DC micro-grid is also suited for integrate a range of DER units, such as internal combustion engines, gas turbines, micro- turbines, photovoltaic panels, fuel cells, and wind-power. Most of these sources are not well suited to operate with fixed frequency, or fixed DC voltage, so they require power converters to interface with either DC or AC electrical distribution systems. The LVDC have many advantages as compared to AC distribution system. Power electronics converters are used for connection of load to either AC or DC bus for power conversion. When load connected to bus is DC such as computers, fluorescent lamp, TV sets; DC bus requires fever power conversion stages [10]-[11]. Since power conversion stages is less, losses in conversion also reduced. Most of the resistive load can be connected to either AC or DC bus. But the AC load cannot connect directly to DC micro-grid [8].

IV.POSSIBLE FAULT IN DC GRID

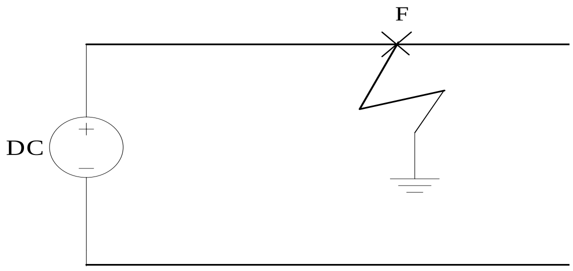
For DC system two types of faults exist, line-to-line and line-to-ground. A line-to-line fault occurs when a path between the positive and negative line is created, shorting the two together. A line-to-ground fault occurs when a path between the positive or negative pole and ground iscreated. A line-to-ground fault is the most common type of fault.

A. 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. 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 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.

This cause an imbalance of the DC link voltage between the positive and negative poles.As the voltage of the faulted line begins to fall and high currents flows. These high currents may damage the converter [12]. A single line to ground fault on positive terminal of line is shown in Fig.6.



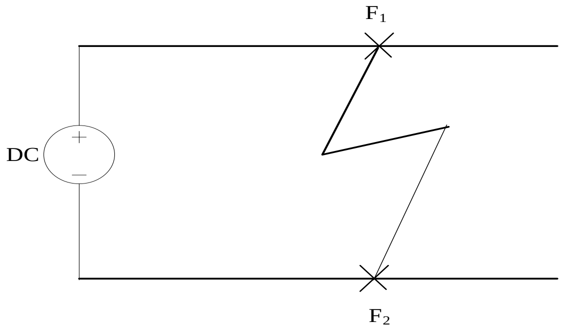


Fig.6 Single Line to ground fault.Fig.7 Line to line fault.

B. Double line fault (Line to line fault)

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 short to the negative bus inside the converter [12]. Fig.7 depicts the line to line fault between positive and negative line.

C. Overcurrent

While overcurrent protection is important during line-to-line and line-to ground faults, it must also operate when the system is being overloaded. Overload 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 overcurrent protection would need to operate. Another option to avoid a wide spread blackout would be to shed non-critical loads [12]

V. CONVENTIONAL FAULT ISOLATION TECHNIQUES

The common practice in DC power systems is not to install any protection on the DC side, and protection only provide on AC side using AC circuit breakers. Upon fault detection the AC CBs that link the AC and DC systems are opened, and disconnect DC link from AC grid. However, this method completely de-energizes the DC system until the fault is removed and the systems can be re-energized. It works for HVDC and medium-voltage DC (MVDC) transmission systems where the DC system is a conduit between the AC systems and loads.

However, this method can create unnecessary outages in LVDC micro-grids where multiple sources and loads are connected to a common bus [13], [14].Fuses also used for protection, but fuses have limitations and ac circuit breaker cannot use in DC systems [7]. There are several alternatives for solid-state devices for the CBs, such as gate turn-off thyristors (GTOs), insulated-gate commutated thyristors (IGCTs), and Insulated-gate bipolar transistor (IGBTs).

VI.NEW FAULT ISOLATION SCHEME

Instead of shutting down the whole system or limiting the bus current, the presented scheme detects the fault and separates the faulted section so that the rest of the system keeps operating. The loop-type DC bus is suggested for the presented scheme to make the system robust under faulted conditions. It has also been reported that the loop-type bus has a good system efficiency especially when the distribution line is not long [16].

In this scheme current sensors placed at the sending end and receiving end of DC micro grid. These current sensors continuously sense the line current and give information tothe controller. In healthy operating condition the current at the two end of line is approximately same.But when single line to ground or the line to line fault occurs in the bus, there is a current difference between the two ends of the line is occurs. When this current difference exceeds the threshold value, controller will operate and gives command to the power switches.

Fig.8 depicts only one bus protection. It is shown that, current sensors placed at two ends bus and near to power switches/circuit breaker. The controller operates when currents different between two ends exceeds a set value.

$$i_{operation} = i_1 - i_2$$

Where i_1 and i_2 is the line current at each end of the bus segment. When fault occurs in the system, current difference exceeds the threshold value. And the controller sends the appropriate commands to power switches/circuit breaker, so that the faulted segment can be separated from the system. Because this system uses the differential relaying principle monitoring only the relative difference of input and output current of a segment, it can detect the fault on the bus regardless of fault current amplitude or power supply's feeding capacity.

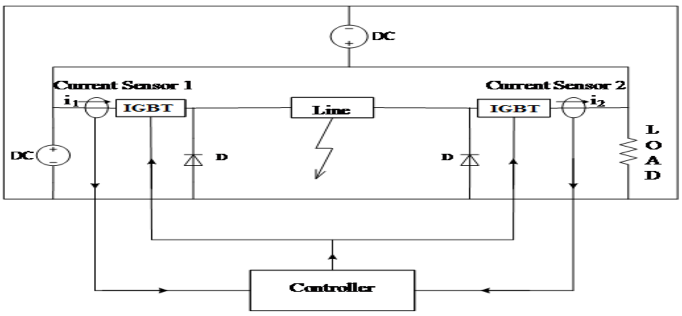


Fig. 8 Placement of current sensor and power switches.

Once the faulted segment has been isolated, the load voltage will be restored and remainder of the system can continue to operate on the loop-type bus. Even with multiple faulted segments, the system can operate partially if the segments from some power sources to loads are intact. The possibility of the fault around the device connection point can be minimized, if the sensors are installed as close to the connection point as possible.

When faulty section is isolated using switches (SW), the fault current in this section is extinguished through the freewheeling resistors (R) and diode (D) is used for the freewheeling path. In healthy operating condition freewheeling diodes are in blocking mode, and there is no current passing through the freewheeling path. But when circuit breaker opens and isolates the faulted bus, diodes comes into conduction mode

Fault current freewheel through diode, resistors and extinguished. How the fault current flows in the system and how this current extinguished through freewheeling path for single line to ground fault is shown in Fig. 9 (a) and 9 (b) respectively. Fault current path and freewheeling current path for line to line fault is shown in Fig.9 (c) and Fig.9 (d) respectively.

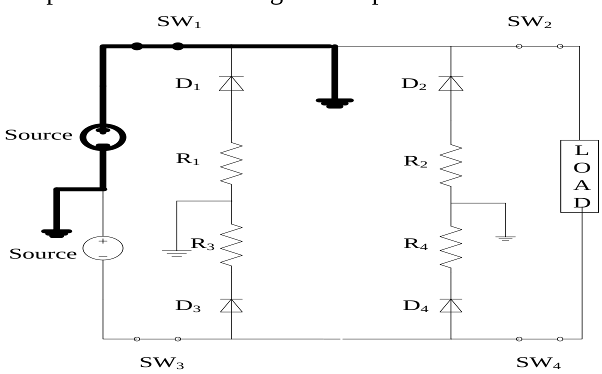


Fig 9.a

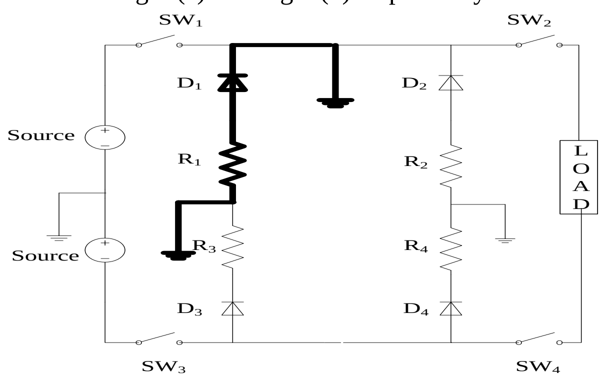


Fig 9.b

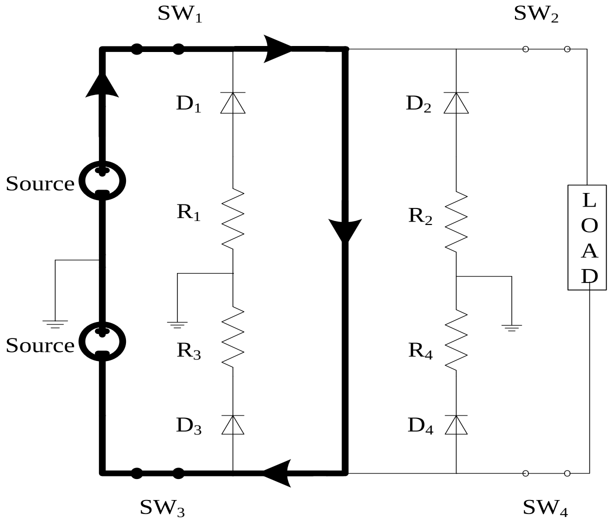


Fig 9.c

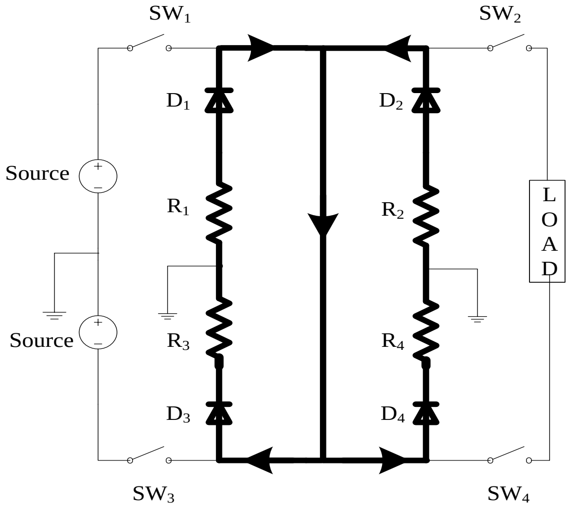


Fig 9.d

Fig.9 Fault current path and extinction in presented scheme. (a) Fault current path in single line to ground fault. (b) Fault current extinction in single line to ground Fault. (c) Fault current path in line to line fault. (d) Fault current extinction in line to line fault.

Fault current extinction rate depends on resistance of freewheeling path. If the freewheeling resistance is large, current dissipates largely and fault current is extinguished quickly.

VII. RESULT

MATLAB-Simulink model created for a 400 meter bipolar dc bus with constant 120 volt dc supply between two terminals. A line-to-line fault in the middle of the line is simulated at 0.02 sec. The fault current magnitude depends on the impedance of the fault path. The currents at each end of the segment which has been identical before fault. When fault occurs in the system current at the both ends of segment shows clear difference.On this current difference controller will operate and opens the power switches, considering speed of controller and switching devices is fast. The simulation parameters of system are given in Table 1.

Parameter	Specification
Bus voltage	120V
Bus length	400m
Line resistance	121mΩ/km
Line capacitance	12.1nF/km
Line inductance	0.97mH/km
Freewheeling resistance	50 Ω
Load	2 KW

The simulation results are shown in Fig.10 for line to line fault. Fig. 10(a) Shows that when there is no fault in the system i.e. in normal operating condition voltage across the load is constant, no disturbance in the system. When fault occurs at 0.02 second, voltage across the load is falls down rapidly. It is seen in the Fig 10 (b), when protection is applied to the system the controller will operate on current difference and opens the switches in 0.025 second. The voltage is immediately restore and the faulty section is isolated. The faulty bus is switched out from the operation and other buses will take care the load

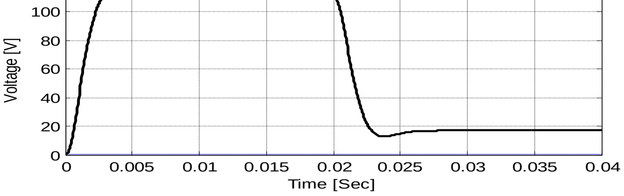


Fig 10 (a)

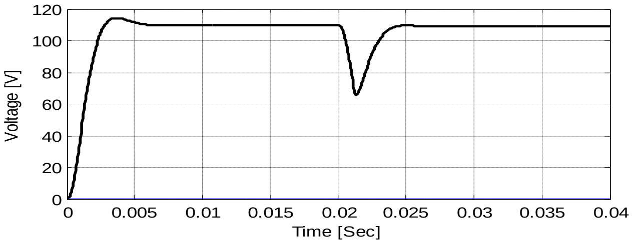
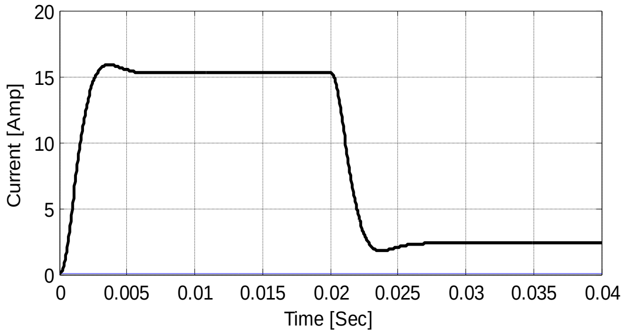


Fig 10 (b)

Fig. 10 (c) depicts that before occurrence of fault load current is constant. But during faulty condition load current is falls down quickly and it remains as it is if protection is not used. When said scheme is applied, section under trouble is isolated and load current is again



(c)

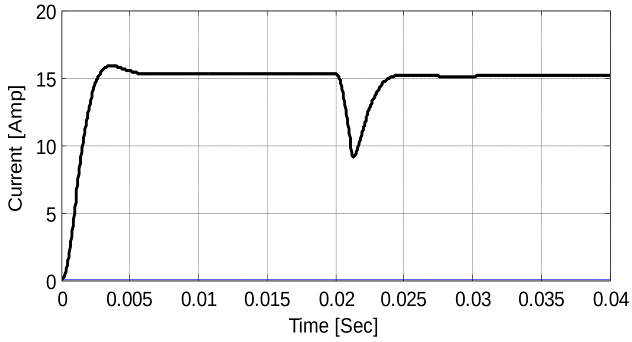


Fig 10

Fig 10 (d)

Fig. 10 Load voltage and current; without protection and with protection. (a) Load voltage without protection. (b) Load voltage with Protection. (c) Load current without protection. (d) Load current with Protection.

Bus current is normal during healthy condition, it is very high on the occurrence of fault, and it remains high without protection is shown in Fig.11.

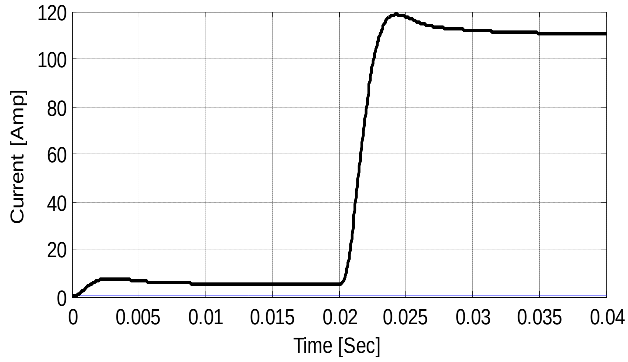
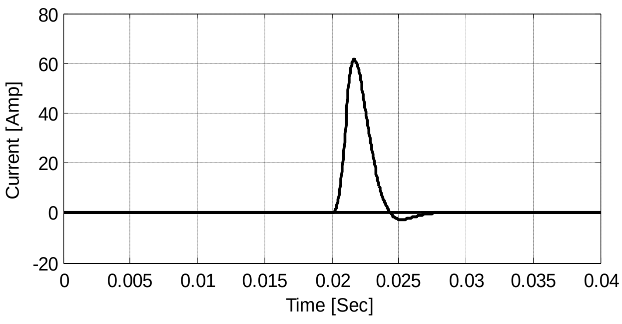


Fig.11 Fault bus current without protection.

Fig. 12 depicts the fault path current and also the current in the freewheeling path. When there is no fault in the system, no current difference occurs at the two ends of line and there is no controller action. Therefore zero current flows through the freewheeling path. But when fault happen in the system current difference at the two ends of line is occurred. The current sensors sense the difference if, this difference exceeds a defined value the controllerwill operate and switches are opened. When switches are opened diodes starts conduction, freewheeling current flows through it and extinguished through resistors. Depending upon the value of resistors the rate of fault current extinction is determined. If high value resistors are used the fault current extinguish quickly.Fig.13 depicts the fault bus current which is high during faulty condition and goes to zero after the disconnecting or isolating this bus



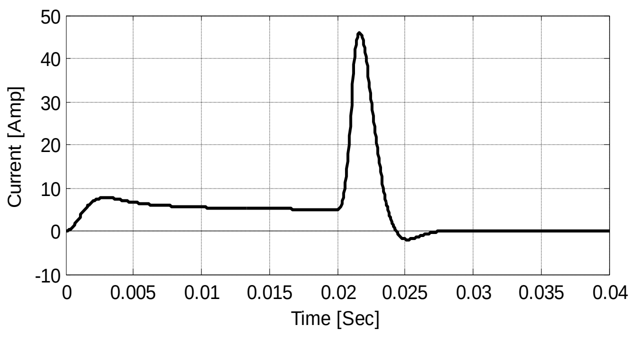


Fig. 12 Fault path currentFig. 13 Fault bus current with protection

VIII. CONCLUSIONS

With the new interest in green energy, the smart grid and distributed generation micro-grids may soon become an integral part of our electric grid. DC micro-grids have proven to be a viable competitor to AC micro-grids. Protection of the DC bus is an integral part to the DC micro-grid, and must be able to isolate faults with minimal impact to the overall system. It can be seen that the conventional techniques require a complete shutdown of the DC bus. This is not suitable for critical loads.

The new fault detection and isolation scheme for low-voltage DC-bus micro-grid system is shown here. The loop-type bus allows multiple paths for power to flow when a section has been isolated. Successful fault detection and isolation was shown using MATLAB simulations. Though the fault detection and isolation proves successful for suppressing fault current, locating the faulted zone and isolating thezone for line-to-line fault. Also, when a fault occurs and a source is removed from the micro-grid, the remainder of the sources must accommodate the load. This will improve stability in the grid and maximize efficiency from all of the sources.

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