

Novel Protection Scheme for Low Voltage DC Micro-Grid System

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Abstract

This paper presents a method for detection and isolation of fault in DC-bus micro grid system. The protection of DC system has been challenging when compared to the traditional AC system. The DC-bus micro grid system consists of a source, storage and load. The protection scheme isolates only faulty section from the DC grid. Healthy sections are operated without any disturbance and supply continuity is maintained in a loop type system. The current sensor placed at both ends of distribution line continuously monitors the current. Because of fault, current difference occurs in two ends of line. Controller detects this current difference and opens the power switches. To meet the requirement of fast interrupting time and high short circuit current withstanding capability, IGBTs are used as power switches. The protection scheme concept has been verified by MATLAB/SIMULINK.

Keywords- DC-micro grid, faults, distribution systems, solid-state switch

I. INTRODUCTION

Recent developments in the electric utility industry are encouraging the entry of power generation and energy storage at the distribution level. Together, they are identified as distributed generation (DG) units [1]. Several new technologies are being developed and marketed for distributed generation, with capacity ranges from a few kW to 100 MW. The DG includes micro turbines, fuel cells, photovoltaic systems, wind energy systems, diesel engines, and gas turbines. Nowadays, the requirement of renewable energy resources competitively increases.

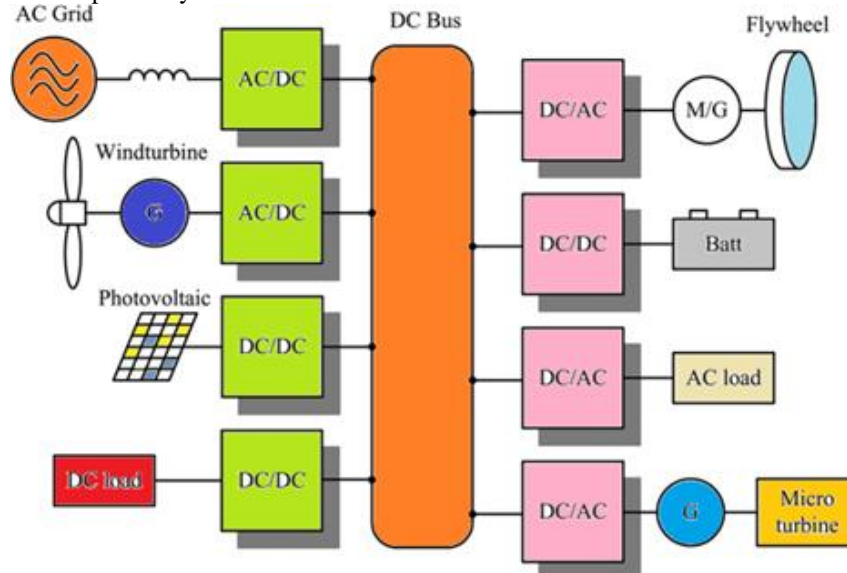


Fig. 1: Conceptual diagram of a DC-micro grid system

In recent days, an interest is increasing rapidly about the small-scaled grid system based on several tens of Photovoltaic power generation. Such a grid system, which is called as micro grid, has advantages to increase an operational efficiency and economics when it is connected to grid or supply a secured electric power at islands, mountains and remote areas without connecting grid [2]. The micro grid is divided into AC micro grid and DC micro grid, which is classified by whether, distributed sources and loads are connected on the basis of AC or DC grid. AC micro grid has a benefit to utilize existing AC grid technologies, protections and standards but stability and requirement of reactive power are the inherent demerits of it. On the other hand, DC

micro grid has no such demerits of AC micro grid and assures reliable implementation of environment-friendly distributed generation sources [3, 4]. Figure.1. shows a conceptual diagram of DC-bus microgrid system.

While the advantages of DC microgrid are considerable, the protection of DC distribution system is challenging. This paper presents detection and isolation of fault within a DC distribution system. The protection scheme aims to detect the fault in segments between devices and also to isolate the faulted section so that the system keeps operating without disabling the entire system.

This paper is organized as follows. Section 2 clarifies the concept of low voltage DC microgrid. Section 3 describes different types of faults in DC system and the devices used for protection of system from faults, while Section 4 explains the new protection scheme for DC microgrid system. The simulation results are explained in Section 5. Conclusion is presented in Section 6.

II. DC MICRO GRID

The paper mainly focuses on the protection of low-voltage DC-bus micro grid system. The low-voltage DC (LVDC) system is a new concept in electric power distribution, when compared to high voltage DC (HVDC) system. For small scale systems, LVDC micro grid has many advantages compared to AC distribution system. Both AC and DC systems require conversion equipment's to connect the sources with loads. The power delivered by the AC system is based upon the rms value, whereas, the DC power delivered is based on constant peak values. So, more power can be delivered in DC systems. Another advantage in DC system is, it does not have skin effect, and hence the losses can be decreased [5, 6].

III. FAULTS IN DC SYSTEM

In DC system, two types of faults exist. 1) Line-to-ground fault and 2) Line-to-line fault. In line-to-ground fault, the fault current path is either in between positive line and ground or in between negative line and ground. Line-to-line fault occurs in between positive line and negative line

A. Single Line to Ground Fault

This is the most common type of fault. This fault reduces the reliability and continuity of supply. When lightning strikes on transmission line one of the conductors may break either positive or negative and fall on earth. This causes the line to ground fault and the line is out of operation till fault is unclear. It may also occur when objects falling on line and providing ground path for current. A single line to ground fault is shown in figure 2.

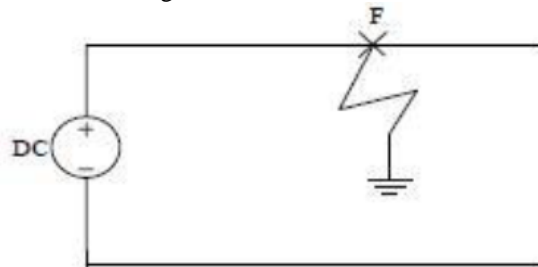


Fig. 2: Single line to ground fault

B. Line to Line Fault

This is most harmful fault for the system than single line to ground fault. This fault rarely occurs in the system. In overhead lines, a double line fault occurs when objects falling across the positive and negative line and shorted them. In underground cables this fault causes because of insulation failure. A line to line fault is shown in figure 3.

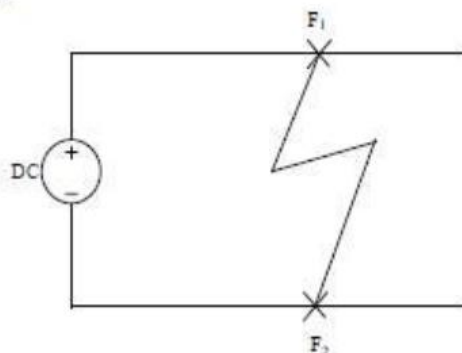


Fig. 3: Line to line fault

C. Fault Isolation Method

1) Conventional Fault Isolation Method

Protection is provided on AC side where AC and DC grid is connected. During fault, AC circuit breaker operates and completely de-energies the DC link. The part of the system which is under normal condition also goes out of operation. This causes the unnecessary outages in the healthy system.

2) New Fault Isolation Method

The new protection scheme isolates only faulty operation and high current withstand capability against short circuit currents

D. Fault Currents

When a fault occurs in a segment, the current flowing through the segment will split into fault current and load current

$$i_{line} = i_{load} + i_{fault} \quad (1)$$

The fault current magnitude depends on the fault location and resistance of the fault current path

E. Solid State Switches

One of the main limitations of DC grids is the lack of DC circuit breakers. In a DC grid, during a DC fault the antiparallel diodes of the Voltage-Sourced Converters (VSCs) conduct and feed the fault. Since in the DC application no natural zero crossing exist, present circuit breaker technology is not able to interrupt large DC currents. Solid-state circuit breakers are currently under development and investigation. However, solid state circuit-breakers have become an existing option for DC power system protection, due to the limitations of fuses and AC circuit breakers in DC systems. Solid-state circuit breakers (SSCBs) use semiconductor devices to provide the power switching, replacing the hard contacts in electro-mechanical circuit breakers. The semiconductor devices such as silicon controlled rectifier have been used for solid-state circuit breakers, but they are only useful for AC circuit breakers.

Other devices such as Bipolar Junction power Transistors (BJTs) could be used for SSCBs, but this is impractical because they have low current gain, limited current capability, and they are subjected to second breakdown, particularly during device turn-off. The Metal Oxide Field-Effect Transistor (MOSFET) device solves the problems of low current gain and second breakdown, but has limited current capability, unless many devices are connected in parallel.

The newer IGBT device, which is basically an improved type of power transistor with many MOSFET type characteristics, provides high gain and eliminates the problem of second breakdown. The IGBT also has the advantage of relatively fast switching speed and high voltage capability. IGBTs are widely used in the low-voltage (1200 V) systems and their advantages include fast interruption time and high short-circuit current withstanding capability. However, high conduction loss is their disadvantage. All of these features make IGBT-based SSCBs quite practical [8].

IV. NEW PROTECTION METHOD

This paper presents a novel protection of the DC-micro grid system. The DC-micro grid consists of a source, storage and load. The schematic diagram of new protection method is shown in figure 4. This method isolates only the faulted segment and rest of the system keeps operating. During this time, the other buses continue to provide power to load. This helps in maintaining the supply continuity to the load. To achieve this, a loop type bus system is suggested. When the distribution system is not so long the loop type system has good efficiency.

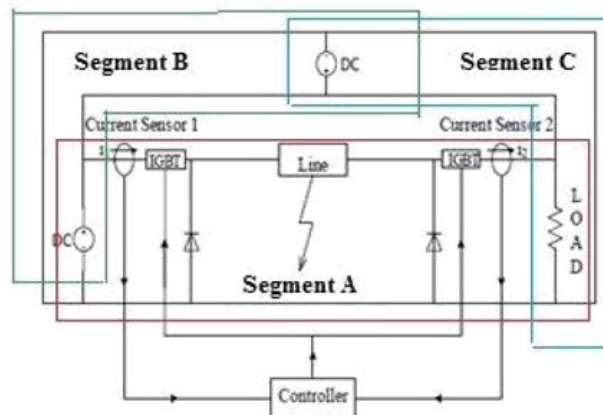


Fig. 4: Proposed Protection scheme

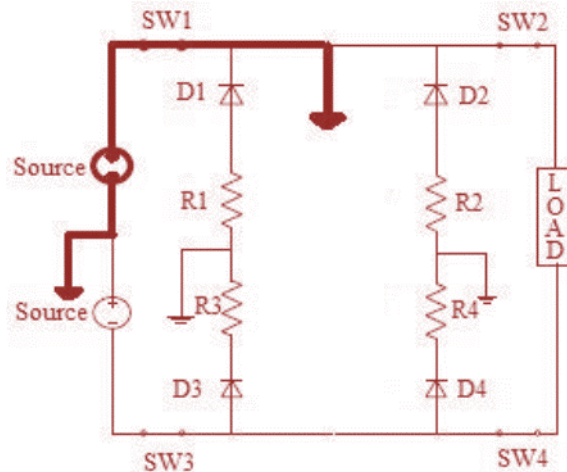
In the new protection method, the whole loop is divided into segments. The segments are named as Segment A, B and C. Segment A is in between source and load while, Segment B is in between source and storage. Segment C is in between storage and load. Each segment consist solid state switches (IGBT), current sensors on both the ends of the segment and a freewheeling path.

Freewheeling path includes a diode and resistor which is active only when a fault occurs in the segment. In normal operating condition, the current at the two ends of the segment is nearly the same. Under faulty condition, a difference of current is measured and the controller provided in the system operates. The controller sends appropriate commands to the gates of IGBT switches to isolate the faulty section from healthy section.

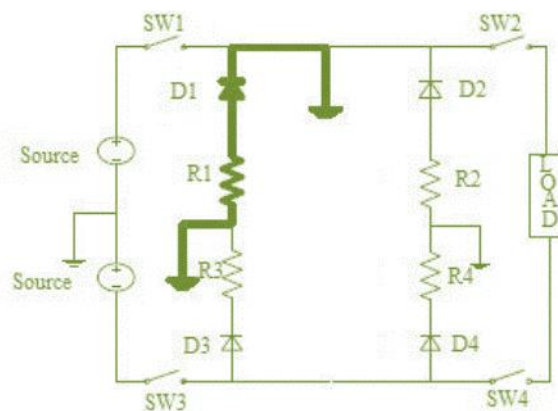
Figure 5 shows only one bus protection. The controller operates only when the two currents are different

$$i_{\text{diff}} = i_1 - i_2 \quad (2)$$

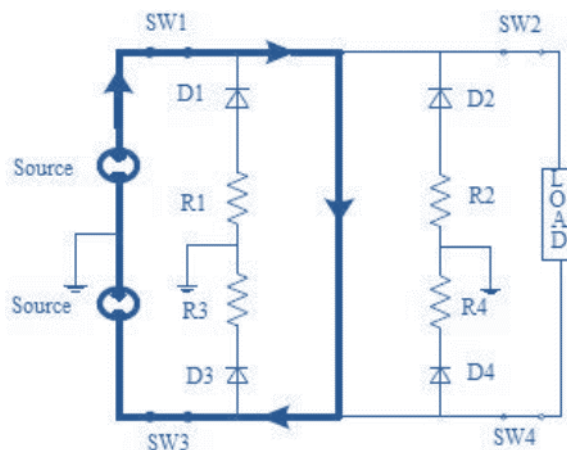
Where i_1 is the sending end current and i_2 is the receiving end current. During normal operation the difference of currents is normally zero. The solid-state switches are opened and isolate the faulty section depending on the controller action. When the faulty section is isolated from the whole system, the fault current is extinguished through the freewheeling resistors and diode. Fault current path and freewheeling current path for single line to ground fault and line to line fault is shown in figure. 5.



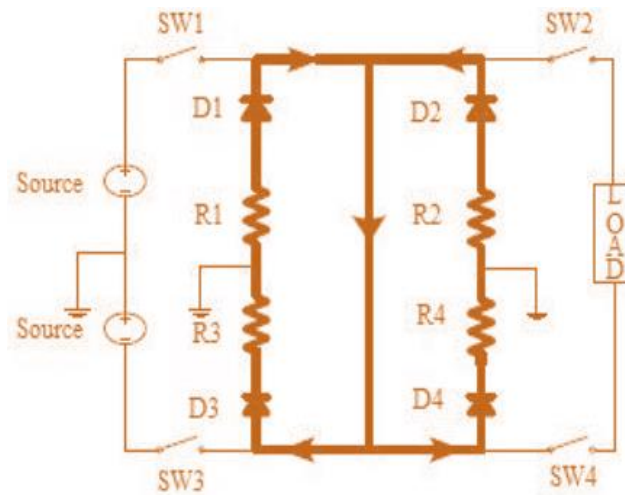
a)



(b)



(c)



(d)

Fig. 5: Fault current path and its extinction in protection scheme. (a) Single line to ground fault. (b) Fault current extinction in single line to ground Fault. (c) Line to line fault. (d) Fault current extinction in line to line fault

V. SIMULATION RESULTS

MATLAB-Simulink model for a bipolar DC bus with constant 240 V supply between two terminals is created. The two sources are connected to feed a common load. The system consists of three segments, segments A, B, and C. Each segment consists of protection scheme. There is a common controller for the system. A positive line to ground fault and line to line fault are created at the middle of each segments at 1ms. Simulation parameters can be found in Table I. Simulation results are also shown below.

Table. 1: Simulation Parameters

DC Bus	Rating
Bus voltage	240 V
Unit resistance, R_u	121m Ω /km
Unit inductance, L_u	0.97mH/km
Unit capacitance, C_u	12.1nF/km
Segment length l	200m
Fault location d	100m
Ground resistance R_G	0.5 Ω
Freewheeling resistance R_{fw}	1 Ω
Load Resistance R_L	75 Ω

Figure 6 (a) & (b) shows the incoming current in segment A with and without protection. The fault current path is as shown in figure 5 (a) & (b). From figure 6 (a), it can be seen that, without protection, the current is increased to about 160A. The fault current is reduced and extinguished after a few seconds when protection scheme is provided

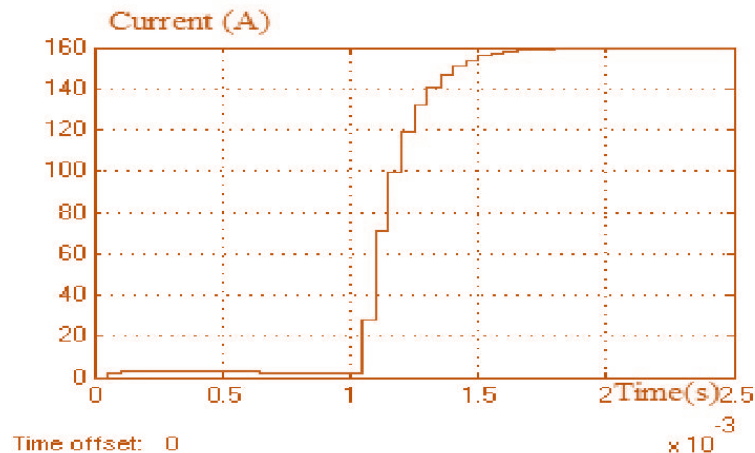


Fig. 6: (a)

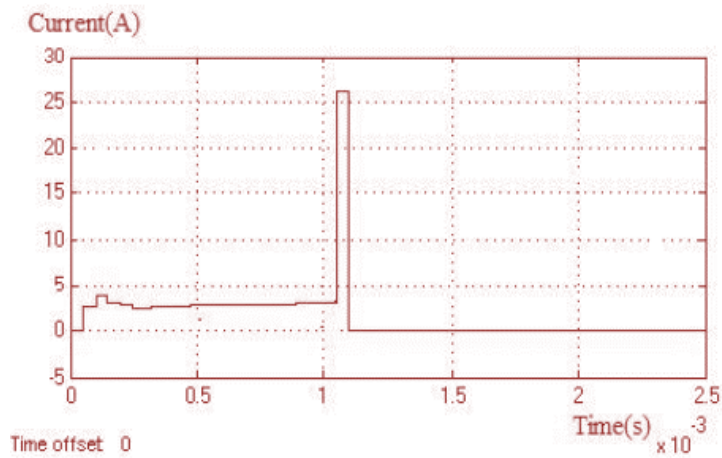


Fig. 6: (b)

When fault occurs in any one of the segments, a current will flow through the freewheeling path provided. Figure 7 shows the current through freewheeling path. Freewheeling current path is as shown in figure 5 (b). During normal condition, there will not be any current through freewheeling path. After the occurrence of fault current is increased.

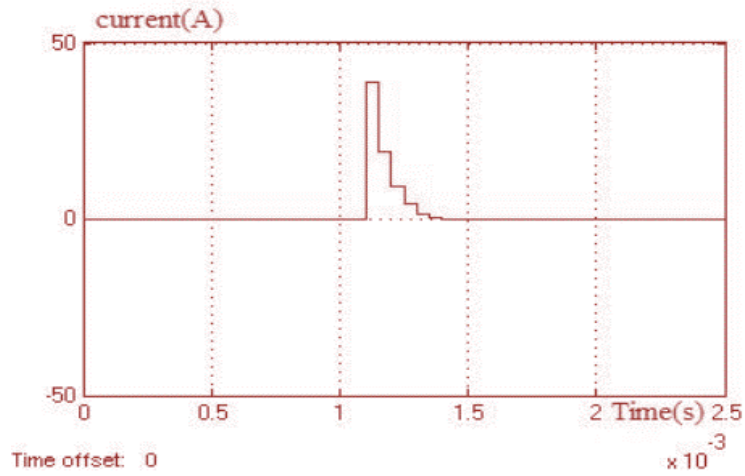


Fig. 7: Freewheeling Current during line to ground fault

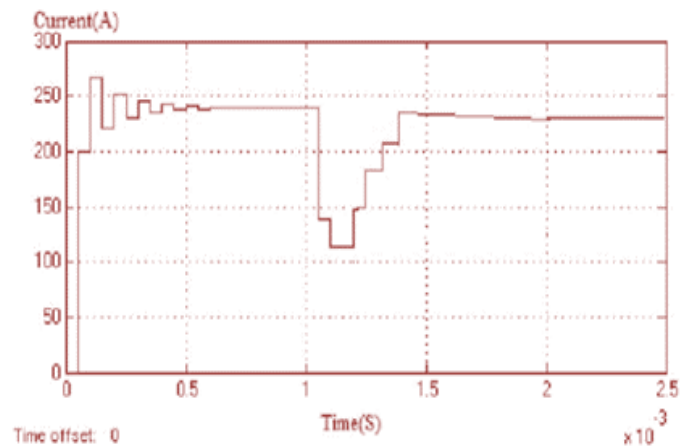


Fig. 8. (a)

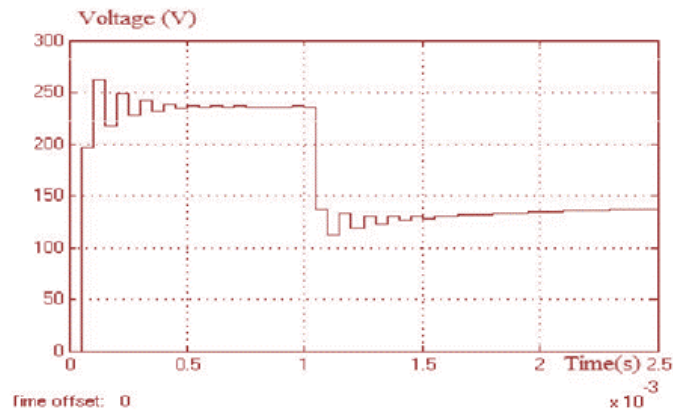


Fig. 8. (b)

Fig. 8: Load Voltage (a) without protection (b) with protection

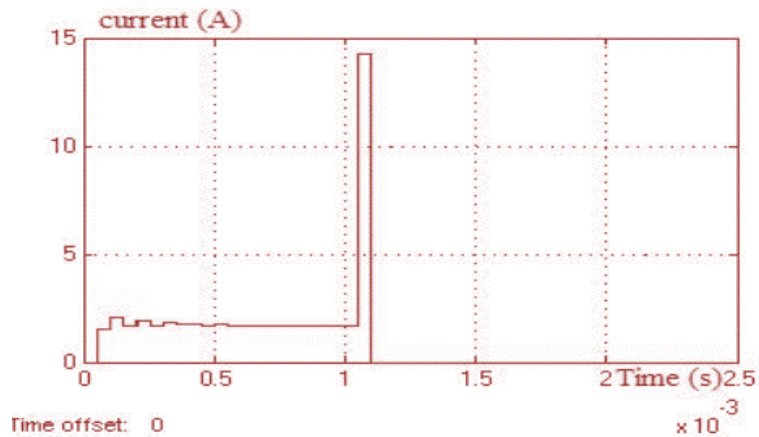


Fig. 9: Incoming current in segment A for Line to Line Fault with protection

Figure 8 shows the load voltage during fault with protection and without protection. We can see that the load voltage is dropped from 240V to around 140V after the occurrence of fault. In the protection scheme the load voltage is restored after a few seconds of the occurrence of fault.

Figure 9 shows the incoming current in segment A during line to line fault with protection. The magnitude of fault current is relatively low in line to line fault. Here also, the current is reduced to zero after the occurrence of fault and the segment is separated from the entire system. The freewheeling current during line to line fault is shown in figure 10.

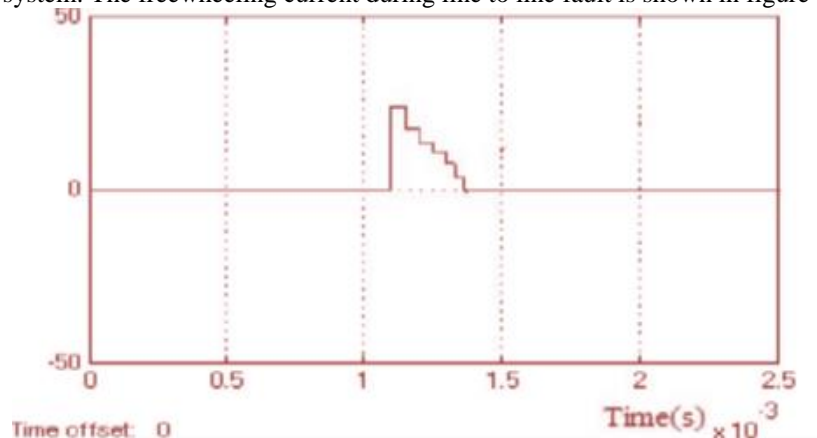


Fig. 10: Freewheeling current during line to line fault



Fig. 11: photo type model

The above figure shown this novel idea implemented and verified using prototype model

VI. CONCLUSION

The paper has presented a new protection method for DC micro grid. The protection scheme for DC micro grid avoids complete shut-down of DC link and isolates only faulty section. In this method, the fault is detected and the faulted segments are isolated from the whole system. It is seen from the simulation results that the controller used for the protection could detect the fault and isolate the faulted segment from the whole system without disturbing the rest of the system. Fault current in the faulty section is extinguished through freewheeling path provided by resistors and diodes. This scheme is useful for the isolated area supplied through distributed generation and also, where the AC and DC grids are connected. But, the minimization of conduction losses in solid-state circuit breakers and fault location techniques need to be investigated.

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