FAULT PROTECTION OF A LOOP TYPE LOW VOLTAGE DC BUS BASED MICROGRIDS

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ABSTRACT

The micro grid system can be divided into AC micro grid and DC micro grid. As compared to DC system, the traditional AC system have the years of practical experience and standards. However the problem with the AC grid still persists. The DC micro grid system has lesser number of conversion stages and it reduces the losses, so the system efficiency becomes increases. But the fault protection of DC system is very difficult because when a fault occurs, it completely de-energizes the system. A loop-type dc-bus-based micro grid system against various faults is presented in this paper. The goal of the proposed system is to detect the fault in the DC bus and to separate the faulty section only so that the healthy portion keeps operating without any disturbances. The proposed scheme consists of one master controller and two slave controllers which are connected at two ends of the transmission line. By using the differential relaying principle the controller opens the power switches during fault. In addition, a converter protection is also provided which acts as a back up protection for the feeder. The MATLAB Simulink results are presented for the proposed concepts.

Keywords: DC Distribution, Fault Protection, Micro Grids, Power System Protection, Solid State Switch

1. INTRODUCTION

The demand of electricity increases day by day and which causes an imbalance between supply and demand. Now a days, many distributed power system have been researched and developed to meet this increasing demand by using renewable energy resources such as photo voltaic systems, wind energy systems and other distributed energy resources [1],[2]. The application of distributed resources in the electric power system opens new possibilities. Because the distributed systems posses many advantages such as better operational and economical generation efficiency, capacity to relief transmission and distribution, improved reliability, power quality and eco-friendliness.

Microgrid is an isolated electric power system that uses bidirectional communication between distributed energy resources, loads and control systems to improve power quality, optimal use of renewable energy resources and possibility of consumers to manage their electricity usage and minimize their expenses [3],[4]. The microgrid can be classified into AC bus and DC bus systems depending on the characteristics of the grid supply voltage. Currently all the commercially installed micro grids are AC because they are simple and easy to control [6]. Also they have the benefit to utilize existing AC grid technologies. But AC system faces many drawbacks such as stability, the need for reactive power control, reliability problems and the increasing number power electronic converters is responsible of increasing waveform distortions and power losses [5],[7]. There is more scope for DC bus systems instead of AC systems because most distributed generation sources such as PV, fuel cells and variable speed wind power units directly generate DC power. Moreover the DC systems do not have the problems like skin effect, waveform distortion that AC systems do. By using DC power as a medium, the typical ac-dc-ac power conversion stages can be reduced and which in turn reduces cost and size of the system [7]. A diagram of DC bus micro-grid is shown in   Fig 1.
However, the DC distribution system needs further development in the field of protection. Due to the lack of guidelines and experience, protection has been challenging in DC systems [8]. This paper presents a fault protection method for low voltage DC microgrid systems. The primary goal of the proposed scheme is to detect the fault in the bus segment between the devices and then to isolate the faulted section only, so that the other healthy segment continue to provide power to the load and which in turn maintaining the supply continuity to the load. To achieve this, a loop type dc bus based microgrid system is proposed. The loop type system has good efficiency if the distribution system is not so long. The secondary function of the proposed scheme is to protect the converter from the fault occurs in the DC bus segment. The converter protection in this scheme acts as a back up protection for the feeder protection.

1.1. Low Voltage DC Microgrid

The Low Voltage DC (LVDC) microgrid system is relatively a new concept in distribution system. As compared to traditional AC distribution system, LVDC systems have many advantages. LVDC microgrid has been used in office buildings with sensitive computer loads and rural power systems [9]. And also the sources, loads and energy storage can be connected through simpler and efficient power electronic interfaces. The losses in the DC system are less because it requires lesser number of power conversion stages and it can deliver 1.41 times more power than an AC system for the same cable [10]. When comes to system protection, it is difficult in DC system because of no current zero crossing.

The possible faults in a DC system are line to ground fault and line to line fault [8]. A well designed protection method is necessary to ensure reliable operation of the LVDC microgrid. The common practice in DC system is to install protection on AC side where AC and DC grid is connected. The protective devices commercially available for LV systems are DC protective switch gear as well as conventional AC devices such as CBs and fuses. But during fault the AC CBs are problematic because this scheme shut down the entire system and which causes unnecessary outages in the healthy system [11],[12]. Fuses are slow thermal devices and they do not have the ability to distinguish whether a fault is temporary or permanent. To overcome these limitations, now a day’s solid-state CBs such as IGBTs are used in DC system. These are bidirectional solid state switches and they offer fast switching operation and high short circuit current capability [13].

1.2. Converter Protection

Both AC/DC and DC/AC converters are used to interface different sources and loads to the DC bus. To achieve high efficiency, the converter must be able to handle voltage variations in the DC grid. The internal switch fault in the converter cause short circuit fault [7]. In most cases, this fault cannot be cleared and the only solution is to replace the device from the system. Also due to the fault in the DC bus side, there is a chance of fault occur in the converter. The fault current withstanding capacity of converter is only twice the converter full load rating. So the fault current must be detected and extinguished as quickly as possible [8].

2. PROPOSED FAULT PROTECTION SCHEME

2.1. Proposed Loop Type DC Bus System

The proposed system does not require a complete isolation of the system; only the affected area is separated and de-energized. The healthy buses keeps operating, provide a power to the load and maintaining the supply continuity. A loop-type dc-bus-based micro grid system against various faults is presented in this paper. The loop type system offers good efficiency if the distribution line is not so long [14]. The proposed scheme consists of one master controller and two
slave controllers, freewheeling branches between each line and ground. The slave controllers connected at two ends of the transmission line. The diagram of proposed protection scheme is shown in fig.2.

![Diagram of proposed protection scheme](image1)

**Fig. 2. Proposed protection scheme**

The figure shows protection of one bus segment only. The implementation of proposed scheme is shown in fig 3. Snubber circuits are used to protect the solid state CBs from voltage transients.

![Implementation of proposed scheme](image2)

**Fig. 3. Implementation of proposed scheme.**

### 2.2. Detection and Isolation of Fault

In this scheme, the fault detection and isolation is based on the differential relaying principle. The slave controller read the current at two ends of the line connecting two components and provides this information to the master controller. Under normal condition, input and output currents are nearly same. If there is any fault occurs in the line, there is a current difference. When the difference exceeds a critical value, the master controller gives an appropriate command to open the IGBT switches, so that the faulted line is isolated from the healthy section and system can continue to operate on the loop-type bus [7]. After isolation, the fault current in the faulted bus segment flows through the freewheeling diodes and resistance. The freewheeling path resistance determines fault current extinction. When the resistance is large, the fault current extinguished very quickly [7]. The path of current during fault and freewheeling time is shown in fig 4.

![Diagram of fault and freewheeling](image3)

**Fig. 4. Path of current during fault and freewheeling.**
Fig. 4. Fault current path and its extinction in proposed scheme. (a) Line to ground fault. (b) Fault current extinction in line to ground fault. (c) Line to line fault. (d) Fault current extinction in line to line fault.

This is the primary protection of the feeder. If this protection fails to clear the fault, the backup protection must operate and protect the feeder. This is similar to the conventional method. There is a main switch in between converter in the source side and DC bus. If the primary protection fails to clear the fault, the main switch just opens and cuts the supply to the DC bus and hence de-energizes the complete system as like in the conventional method. In all other cases, the main switch in the closed condition. This is also a protection for the converter. Because if the feeder protection fails to clear the fault, there is a large fault current in the DC bus. The converter is directly connected to the bus and so have low impedance. When the DC link voltage becomes almost zero, the fault current will flow through the converter and leads to failure of the converter. So the fault current must be detected and extinguished as quickly as possible.

3. SIMULATION RESULTS

A MATLAB simulation has been performed for a LVDC microgrid system. It consists of two sources; three phase AC and battery are connected to feed a common load. A three phase 440 V supply is given to AC/DC converter connected at the source side. A line to ground fault is created in the middle of the bus segment A only. The simulation circuit is shown in fig. 5. The input source is a three phase AC which connected to the DC bus through an AC/DC converter. Battery source is connected between line segment B and line segment C. These two sources are connected to a common load. The simulation parameters are given in the table 1. The main switch is connected in between the converter and the DC bus.
Fig. 5. Simulation circuit. (a) Complete diagram of Proposed scheme. (b) Line segment A

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input AC supply</td>
<td>440V</td>
</tr>
<tr>
<td>Line resistance</td>
<td>0.75Ω</td>
</tr>
<tr>
<td>Line inductance</td>
<td>0.097mH</td>
</tr>
<tr>
<td>Line capacitance</td>
<td>12.1nF</td>
</tr>
<tr>
<td>Freewheeling resistance</td>
<td>0.5Ω</td>
</tr>
<tr>
<td>Load resistance</td>
<td>1000Ω</td>
</tr>
<tr>
<td>Snubber resistance</td>
<td>5Ω</td>
</tr>
<tr>
<td>Snubber capacitance</td>
<td>10μF</td>
</tr>
</tbody>
</table>

A positive line to ground fault occurs in the middle of the bus segment A at 0.5ms. The load voltage with and without protection is shown in fig. 8. Without protection, the load voltage drops to zero after fault is shown in fig.
6(a) when protection is used, the voltage is quickly restored after the separation of the faulted segment which is shown fig.6(b).

![Fig.6. Load voltage. (a) without protection. (b) with protection](image)

When the IGBTs in the line segment A open due to fault, the fault current freewheels and extinguished through the resistor is shown in fig 7.

![Fig.7. Fault current in the freewheeling path](image)

Fig.8 and fig.9 shows the source side bus current and load side bus current for a line to ground fault with and without protection. The bus current is high during faulty condition and goes to zero after separating the bus.

![Fig.8. Source side bus current (a) Without protection (b) With protection](image)
If the IGBTs in the segment A fails to clear the fault, the main switch just open and cut the supply to the DC bus and de-energizes the complete system. Fig. 10 shows the main switch operation. The gating signals to the main switch are shown in fig. 10 (a) and the output voltage is shown in fig. 10 (b).

In the fig. 10 (a), first shows the fault, second one is status of switches in the segment A and third shows the gating signal to the main switch. A fault occurs at 0.5ms, from the figure it can be seen that, after the fault also the IGBTs in the segment A are conducting. So to protect the converter and the complete system, it is necessary to switch off the main switch immediately. So a gating signal is send to switch off the main switch, which is shown in the third figure. Then the output voltage goes to zero.

If the protection of line segment is proper, the main switch operation is shown in fig. 11. The gating signals to the main switch and corresponding load voltages are shown in fig. 11 (a) and fig. 11 (b) respectively.
A fault is occurs at 0.5ms and at the same time itself, the gating signals of the switches goes to zero which is shown in second portion of the fig11(a). Therefore the already conducting switches in the line segment turned off and separate the segment from the healthy system. The third portion shows the gating signal. So the main switches are conducting to provide a power to the load through other healthy bus segments. Then the output voltage restored after the separation of the faulted segment.

4. CONCLUSION

The application of distributed resources opens new possibilities in the electric power system. There is more scope for DC microgrid systems. But the protection of DC bus is more challenging. The proposed protection scheme avoids the complete shut down of the system and isolates the faulted section only so that the other healthy segment continue to provide power to the load and which in turn maintaining the supply continuity to the load. A loop type DC bus based microgrid system was utilized. This provides additional protection to the converters. If the primary protection fails to clear the fault, the main switch which is connected in between source converter and the DC bus, just open and cut the supply to the DC bus and hence de-energizes the complete system as like in the conventional method. This is act as a back up protection for the feeder. The proposed protection concepts have been validated by MATLAB simulink. This scheme can be applied to green buildings with sustainable energy resources, data center with a server array etc.

REFERENCES