DC Microgrids: Architecture and Challenges

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Abstract. In the evolving era, microgrid wins the heart in all power fields. Among that DC configuration achieved more demand because of its less complex structure, low cost, more reliability and more power quality and last but not the least the control scheme is less complex than AC microgrid. Management of power and energy are the evolving traits adopted by researchers now a days. This paper mainly aims at the comparative analysis of different topologies, structure, and operational mode of DC microgrid. Despite the global energy crisis and the increasingly atmospheric pollution, distributed generation integration with renewable energy is becoming a potential trend in technology. Finally, attention has been paid to the recent challenges to the DC microgrid system.

Keywords: DCMG (DC Microgrid) structures, Multiterminal DC Microgrid, Multi-bus DC Microgrid, Islanded Mode, Distributed Generation (DG)

1. Introduction
Micro-grid is the combination of Distributed Generations (DGs) or small Distributed Energy Resources (DERs), energy storage, loads and measurement system. This is used to control the supply system for demand. In the realm of the Microgrid, the specialist co-ops or utility and purchasers have unobtrusive apparatuses and methodologies to watch, manage and respond to any or a wide range of vitality issues. In current years, conventional energy sources like fossil fuels are reducing and integration and penetration of renewable energy source in a high scale will improve the microgrid concept in electrical power market[1].According to demand and supply, microgrid is categorized as three basic models: AC Microgrid, DC Microgrid, AC/DC hybrid Microgrid. In spite of their own merits, DC microgrid is the better energy provider than AC Microgrid[2][3].DC Microgrid gives a traffic opportunity for the DGs to integrate properly to the existing system and give a perfect established power system[4].As the demand for load is lower in rural areas than in urban areas, DC microgrid will be better option to reduce transmission and daily maintenance costs[5].

There are several advantages of DC microgrid over AC system. Voltage in a DC MG system is scalable so this will used for approximating the network power balance and power efficiency. The control technique of DC microgrid is more simple and the remote coordination between the power generating units are more reliable over conventional AC microgrid, so that the strength of DC microgrid will improve [6].
In the schematic layout of this paper, section 2 explains about various challenges of DC microgrids. In section 3, mode of operations and components of DC microgrid is discussed and in section 4 different topological structure and comparative analysis between them are explained. Section 5 concluded the whole idea of this paper.

2. Challenges of DC microgrid

In a new trend, the penetration of DC power is increasing day by day. Integration of PV system and other DC loads increasing the efficiency of the system. Although DC microgrid has so many advantages, there are so many shortcomings in the system. Mostly some difficulties are there to switch from islanded to grid connected mode. As all the transmission lines and their designs are framed already based on AC system; changing the entire thing to DC modified is really challenging. Without implementing digital communication link(DCL) to the parallel converters, a popular method is identified as Droop control method. On top of that addition a virtual resistance to the system can even improve the efficiency by distributing the current equally in the system. For building a DC microgrid, bidirectional DC/DC converter is the key object [7-9]. There are various problems related to DC microgrid. Among them the most significant one is instability problem related to constant power load(CPL) with rigidly bounded power electronics loads. To overcome this situation various methodologies are implemented. Among them virtual resistance, virtual impedance, pole placement of pole methods, virtual capacitor and loop cancelations methods are more approachable than others.

Other problem related to DC microgrid is a pulsed power load (PPL) which is used for remote microgrid like electric vehicle[10],electric aircraft[11],electric ship[12] and in aerospace application[13]. PPL is used to draw a large amount of current for a short duration of time. Because of the PPLs' pulsing activity with high-power characteristics, they may shift the microgrid. Therefore, major voltage falls may occur, and the device might also become unreliable because traditional linear control systems can not be sufficient to maintain machine reliability across a broad variety of operations. In order to accommodate PPL's high power and fast dynamics requirements, high power density energy storage systems (ESSs) require rapid dynamics to make up for the lack of the main energy source (synchronous condenser)'s fast transient output power. Different linear control strategies are there for meeting the challenges in DC microgrid like limit based voltage control, continuous voltage control, average voltage control[14]. For optimal stability, good dynamic response and optimal performance linear methods are not more feasible so for that some advanced linear methods are implemented like model predictive control, passivity based control(PBC),back stepping, Artificial neural network control, sliding mode mode (SMC) and so on. Compared to traditional linear control systems, this will greatly increase the efficiency of bidirectional DC / DC converters.

The key triggers of system efficiency in DCMGs [8] are:

● Difference between power in DERs and storage system
● Instant switching of loads
● Flickering of voltage in the distribution of electricity between grid and DCMG.

The main obstacles faced by DC Microgrid are [10]:

1) Proper sharing of load current and better regulation of voltage with simple and less cost control strategies.
2) Efficient way of storing the energy, optimum energy usage and maintaining the DC bus voltage within a range.
3) DC microgrids data transmission method used for control aspect should have less cost, less complex and good to use for remote locations.
4) Overcharging and undercharging of battery will happen during charging and discharging time. So, a proper coordinated control strategy should be implemented based on slight change in load [15].
5) More than one battery should operate with a proper charge distribution technique.
6) Switching effortlessly between grid connected and isolated modes [16].
7) A challenge is optimal grounding that reduces the current of the DC offset current and ensures the safety of the individual.
8) Due to non-zero crossing of DC currents, designing of a circuit breaker with less cost is very challenging.

3. Components and mode of operation

A generic grid connected structure of DCMG containing a PV, a wind battery and a load is shown in Figure 1[10].

![DC Microgrid Generalized Structure](image)

Figure 1. DC Microgrid Generalized Structure [10]

A. Components involve in DCMG

The DCMG components explained in detail are as follows [8]:

1. Generation system

PV, battery storage system, wind power and other DC supply systems are DER to DC microgrid system [17]. A DC-DC converter is connected from a standalone PV system to the DC bus system. This is an unidirectional flow of power. Similarly, a wind turbine is connected to AC-DC converter to the DC bus for efficient power flow. The DERs can be operated in degraded mode under certain network conditions.

2. Battery

Energy storage is attached to DC rail, regardless of the equipment (lead acid, li-ion) utilizing bidirectional converter. For a grid connected mode, battery charging takes place when the demand is less than generation. The load may be supplied in independent mode using a generator. An effective energy storage system as battery will work bidirectionally for better result.

3. DC Load

DC bus connected to corresponding DC load for rated voltage. For a multilevel DC system, a bidirectional converter will used with the existing AC grid.

4. Grid connected converter

A bi-directional converter with transformer and circuit breakers are used to connect AC grid system. This part is not shown in Figure 1.

Power network systems affect other aspects, such as maintenance costs, robustness, durability, device management and hierarchy, efficiency, quality, resource use and market versatility [18-22]. Specific basic considerations should be taken into account in determining the configuration of the
network, i.e. effects on the environment, capacity accessible at various stages, optimal usage of energy and possible scalability [23-24]. A variety of topologies have been documented in the literature and it is observed that six styles of structures may cover almost all structures [25].

B. Modes of Operation

DCMG connects with a bidirectional converter to balance the both sides of power flow from grid side and load side [9]. If any failure happens, converter should be able to disconnect from the supply side. That time the battery storage system will help to continue supply to the load. That is called off-grid mode. Maintaining voltage level as well as, smooth power transfers the converter switching should be proper and smooth. When again the problem in supply recovers the load should connected back to main supply and battery will also charge for the next discharging period. Concluding there are basically two mode of operation available in all microgrids. That is: Grid connected mode and isolated mode. Grid connected mode also divided again by grid controlled and uncontrolled mode. That is mostly depend upon the, control regulation of voltage as well as power management.

a) Grid connected mode

DCMG in this mode, a power converter is responsible to keep a control between load and dc link bus voltage level. If total amount of energy storage in the storage device is excess, then that will provide the surplus charge to power grid. Power management in this mode will circulate the balance between the storage devices. So DCMG can operate perfectly with less loss.

b) Isolated mode

DCMG is separated from the utility grid and can be operated in standalone conditions. During islanding mode those converters will be connected in parallel to DC bus. Grid connected converter will not operate during this process and microgrid converter will operate at that condition and maintain the control in grid. As the converters are not connected to provide control on DC bus, only DC link voltage is maintained by the converter’s storage elements. So, battery will operate as a main element to maintain DC voltage level and supercapacitor which is one of the storage device will act as a power supplier during transient conditions.

4. Operational structure of DCMG

The architecture of a DC micro grid is mostly available in six different arrangements. Different topologies and their comparative analysis are discussed in detail in this section. Figure 2 explains about different topologies of DC microgrid.

![Figure 2. Different topologies of DC microgrid](image)

A. Single-bus DCMG structure

This type of arrangement is the simple way to approach a DC microgrid. In this structure basically one main bus is there and all the other device like a wind turbine, PV array and battery bank will be connected as a source. Stack of batteries are connected to main bus so that bidirectional power transmission can happen. Figure 3[18] explains the diagrammatic representation of single bus DCMG [26-28]. Due to this, stability of the system will increase. DC loads and utility grid are connected as a load. This type of arrangement is also called as a radial arrangement. The interfacing devices like power electronics
converters need to be properly placed and should ensure the system stability as well as robustness. Due to single line, the single point failure problem will occur if the state of charge condition of battery will not be achieved properly [26-28]. More no of battery will increase the voltage regulation [29,30]. This type of structure is more suitable for low voltage application. Two different approach of DC/AC conversion can be implemented for stability improvement [31].

![Figure 3. Single-bus DCMG structure [18]](image)

**B. Multi-bus DCMG structure**

This type of structure is a combination of various single bus systems. Because of the repetition of the same scheme, the existing structure acts as a robust and more reliable structure. Because of redundancy, this type of configuration can be used in naval ships [27]. Figure 4 [18] explains the layout of multi bus system. Because of flexible nature, the voltage range can be varied up to three different levels so that the data can be transmitted to the neighbouring bus and less change of repetition will exist. Although there are some disadvantages, but it is very much suitable for secure communication. As there are several voltage sources, selecting a proper range of voltage which will increase the efficiency, quality and viability of the system [32-35]. These types of systems can be operated for low and medium range of voltage.

![Figure 4. Multi-bus DCMG structure [18]](image)

**C. Multi-terminal DCMG structure**

Energy flow in the multi-terminal network is dynamic, but at the same time this mechanism is still robust. The key aim of this sort of device is to preserve the balance of power between the various components of the network. Change in the voltage and frequency will improve the reliability of the system. In wind turbine, this configuration is highly recommended. Extra amount of voltage or deficient of voltage will manage by a voltage source converter with an AC distribution system. This is more suitable for high voltage application [36]. Mesh structure is more advantageous because of the redundancy nature of the configuration [27]. Figure 5 [18] explains about this scheme. The security issue is a more challenging topic in this arrangement [37-39]. In [37] the typical structure of a multi terminal system with quick security system is explained.
D. Ring-bus DCMG structure

Ring bus arrangement is ideal for any type of system like for low voltage system and high voltage system [40]. Ring structure is a well-defined, reliable, secure arrangement which can be implemented to all systems. If one direction of busbar connection is failed, then other direction of current flow will keep the continuation of the supply. All the given systems are connected to each other like a ring structure. If any fault happens then that can be check proficiently by shutting down that part, so that remaining are in ON condition. So, the maintenance is also hassle free [41-44]. Figure 6 [18] illustrates a detailed description of ring like structure. Fault detection technique is the best part of this type of structure [45]. Fault can be permanent and temporary. For any classification of fault, reducing the fault effect from system is discussed in [46]. Distributed coordinated control strategy can be implemented in this scheme to increase the output voltage [47].

E. Ladder-bus DCMG structure

Ring type structure is a subset structure for ladder bus structure. The performance of the distributed energy sources is related to the ladder DC structure. Any one bus of the ladder type can provide the supply to the other buses. The stability of the network is significantly enhanced in this way. A standard configuration of the DCMG ladder bus system is shown in Figure 7[18]. The design has the greatest reliability relative to any other device that, this is capable of successfully removing one points of fault detection and open circuit faults and maintaining maximum efficiency [29,40]. Its scalability is high, making it possible to incorporate centralized sources without disrupting the other sections of the network. Multi Input and Output (MIMO) converter instead of a Single Input Single Output (SISO)
converter are used for detection of fault and can be implemented for natural disaster situation. Because of most efficiency technique, high reliability, high scalability implemented in electric vehicles, have rendered it the best option for industrial structures such as electrical vehicles, data centers and telecommunication equipment.

F. Zonal DCMG structure

DCMG is separated into zones with the addition of duplicate buses, each zone has its own core of security and boarding. This type of structure is divided each part into different zone and each zone will not connecting to each other physically only communication will be established. Advantage of this type of structure is, a zone will be connected to different Distributed Energy Resources (DERs) and the ESDs. These are solely responsible for that zone [47]. Although different techniques are there to enhance the stability but the biggest problem is the reliability problem and one-point failure problem may arrive. So, to improve it a solid-state transformer can be added to the network [45]. If the safety is concerned, a Z-source inverter can provide efficiently to the network [28]. The detailed diagrammatic representation of this structure is shown in Figure 8[18].
From above all structures, many can be used for high voltage and low voltage applications, reliability changes with structure and inherent stability also varied proficiently. Interpretation of different categories along with merits and short comings are also expressed in detail in Table.1 [48].

|           | Interpretation                                                                 | Merits                                      | Shortcomings                                                                 | Inherent Stability | Reliability | Applications                          |
|-----------|--------------------------------------------------------------------------------|---------------------------------------------|------------------------------------------------------------------------------|--------------------|-------------|----------------------------------------|
| Single bus| • Improves versatility of operation • DC voltage regulation improves           | • Improve dynamic stability • Multiple ESS (Energy storage system) will improve reliability. | Uncontrollable DC voltage and non-regulated battery supply                    | Yes                | High         | Telecommunication system               |
| Multi-bus | Multiple microgrid connected in series and parallel to improve efficiency and power sharing ability | Proper channelization of power in between microgrid clusters | Sudden short down of a microgrid can create fault in system                  | No                 | Medium       | LVDC (low voltage DC), Interfaced MVAC(Medium voltage AC) |
| Multi-terminal | Various power flow direction improves reliability | Flexible, reliable, and repetitive operation | Power flow is more complex                                                  | No                 | High         | Radial configuration in DCMG           |
| Ring bus  | During fault condition, restructured arrangement provides better power flow     | Load connected in two-way manner to the common DC bus. | Limitation in voltage and power                                               | No                 | High         | DC distribution system                 |
| Ladder    | Can connect to either of the bus to provide bidirectional power inflow          | Scalability is high                          | Structure complex to design and control                                        | No                 | Very high     | Multi Input and Output (MIMO) converter used in Electric vehicle |
| Zonal     | • Different zone provides better reliability • Each zone powered by AC utility grid and distributed generations (DGs) | • Higher reliability • Flexible by using more switches • Islanding allowed • Error minimization | Proper DC voltage selection is must                                          | No                 | Medium       | Zonal AC distribution system           |

5. Conclusion
In this paper a detailed review of various modes of operation and operational structures has been discussed. In both the modes of operation, a DC microgrid can operate efficiently by implementing a proper power and energy management techniques. Other than that, various challenges involved in DC Microgrid were also discussed. By checking various field in power efficiency improvement technique and by designing a proper controller which will reduce the voltage flickering and increase the stabilization in both grid connected and islanded mode. Smooth switching between these modes are also can be a key area for research.
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