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Study on DC Microgrid

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Abstract : *The recent trends of the power community is swiftly tending towards more flexible form of power generation for feeding sensitive loads like electronic and commercial loads. DC Microgrid is one of the solution to these emerging problems due to its efficiency, reliability and stability of the system. In this paper, the advantages of DC microgrid over AC microgrid is discussed, and a review of different performance improvement approaches and trends of DC microgrid is presented. This paper classifies different aspects of DC microgrid into two : Control techniques and Converter topologies.. Each aspect is discussed in detail in view of the relevant existing technical literature.*

Keywords: *Droop control, Economic Dispatch, Microgrid, Optimization*

I. Introduction

MICROGRIDS have attracted significant attention in recent years due to providing significant advantages for electricity consumers and power grid operators. Microgrid deployments are trusted to improve power quality, reduce emissions, reduce network congestion and power losses, increase energy efficiency, and potentially improve system economics. Microgrids can also eliminate investments on additional generation and transmission facilities to supply remote loads. Moreover, microgrids islanding capability in the event of faults or disturbances in upstream networks would enhance grid and customers' reliability and resilience [1].

The development of microgrids comes as a necessity for the integration of renewable energy sources into remote communities. The increasing interest in integrating intermittent renewable energy sources into microgrids presents major challenges from the viewpoints of reliable operation and control. Bidirectional power flows, Stability issues, Modeling, Low inertia, Uncertainty these are the most relevant challenges in microgrid protection and control [2].

A microgrid is capable of operating in grid-connected and stand-alone modes, and handling the transitions between these two modes. In the grid-connected mode, the power deficit can be supplied by the main grid and excess power generated in the microgrid can be traded with the main grid and can provide ancillary services. In the islanded mode of operation, the real and reactive power generated within the microgrid, including the temporary power transfer from/to storage units, should be in balance with the demand of local loads. Transition between these modes of operation is one of the desirable feature of the microgrid control system. For the reliable and economical operation of the microgrid, the control system should include some other desirable features also. These are, Output control (voltage and current), Power balance, Demand side management and Economic dispatch[2].

With regard to the architecture of a power system's control, two very distinctive opposite approaches can be identified: centralized and decentralized. A fully centralized control relies on the data gathered in a dedicated central controller that performs the required calculations and determines the control actions for all the units at a single point, requiring extensive communication between the central controller and controlled units. On the other hand, in a fully decentralized control each unit is controlled by its local controller, which only receives local information and is neither fully aware of system-wide variables nor other controllers' actions. A compromise between fully centralized and fully decentralized control schemes can be achieved by means of a hierarchical control scheme consisting of three control levels: primary, secondary, and tertiary [2].

- Primary control: It is also known as local control or internal control, is the first level in the control hierarchy, featuring the fastest response. This control is based exclusively on local measurements and requires no communication. Given their speed requirements and reliance on local measurements, islanding detection, output control and power sharing (and balance) control are included in this category.
- Secondary control: It is also referred to as the microgrid Energy Management System (EMS), is responsible for the reliable, secure and economical operation of microgrids in either grid-connected or stand-alone mode.
- Tertiary control: It is the highest level of control. This tertiary control is responsible for coordinating the operation of multiple microgrids interacting with one another in the system, and communicating needs or requirements from the host grid.

Primary control can be done by two approaches, inverter output control and power sharing control. Droop based method and non-droop based method are included in the power sharing control. The two different approaches included in secondary control are, Centralized Approach and Decentralized Approach. The rest of the paper is organized as follows: Section II compares AC and DC microgrid. Section III reviews the different control topologies applied in DC microgrid and discusses the classification of control techniques. Section IV presents an overview of different converter topologies used in DC microgrids. Finally, some conclusions are drawn in Section V.

II. AC vs DC Microgrid

The investment cost is typically higher for DERs compared to conventional energy resources within large-scale power plants due to economies-of-scale of the latter. Nevertheless, DERs can provide less expensive energy in comparison with the energy purchased from the main grid specifically during peak hours when the market price is high. The total planning cost comprises three parts: 1) the investment cost; 2) the operation cost; and 3) the reliability cost. In reality, several components should be considered to install the microgrid, but only the investment cost of DERs, rectifiers, and inverters are included in this paper.

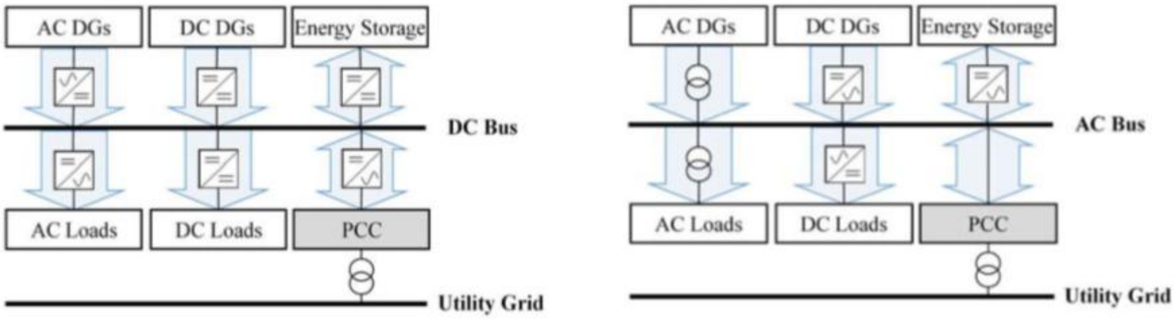

Fig. 1.a) General structure of dc microgrids 1.b) General structure of ac microgrids

A general structure of dc microgrids is shown in Fig. 1.a In dc microgrids, three-phase ac-to-dc rectifiers and transformers are required to connect ac DERs to the common bus, single- and three-phase dc-to-ac inverters are needed for supplying ac loads, and a three-phase dc-to-ac/ac-to-dc converter, a transformer, and a point of common coupling switch are required for connecting the microgrid to the utility grid.

A general structure of ac microgrids is shown in Fig. 1.b In ac microgrids, three-phase dc-to-ac inverters are required to connect dc DERs to the common bus, three-phase ac-todc rectifiers are needed for supplying dc loads, and similar to dc microgrids, a transformer and a point of common coupling switch are required to connect the microgrid to the utility grid. The direction of arrows in Figs. 1 and 2 shows the direction of power flow. It should be noted that different dc loads require different dc voltage levels, so some dc-to-ac converters have to be considered as well in order to change the voltage level of the dc sources to desired levels. In both microgrids, a common bus is considered to show all the connections of loads and DERs. In reality, however, the common bus can represent one or more loop/radial distribution networks that connect loads and DERs within the microgrid. In dc microgrids, the common bus would handle dc voltages and currents, while in ac microgrids the common bus would be used for ac voltages and currents.

DC microgrids could, however, offer several advantages compared to ac microgrids: providing a more efficiently supply of dc loads and reducing losses due to the reduction of multiple converters used for dc loads, easier integration of dc DERs, and eliminating the need for synchronizing generators. It was verified that the decisive factor in determining the type of the microgrid would be the ratio of dc loads. , for ratios smaller than the threshold ratio, ac microgrid would be more economical and for ratios larger than that, dc microgrid would be more economical.[1]

In a DC microgrid, no reactive power and harmonics exist in the system, so higher power quality and system efficiency are obtained compared to ac systems [3].

III. Control topologies

There are several control issues related to dc microgrid, which includes voltage control among parallel converters, load sharing, interconnection schemes between DERs and common dc grid, maximum power point tracking, and energy storage [3]. These control issues can be solved by using different control techniques. It can be categorized into three. a) Load sharing and voltage control, b) Storage based control and d) Optimisation and Economic dispatch

A. Load sharing and voltage control

There are several advantages of parallel connected converters such as: efficiency, reliability, expandability of output power and ease of maintenance. The main issue associated with voltage control is poor load sharing among the parallel connected converters and the circulating current arising due to this problem. The circulating current issue is caused, when there is a mismatch between the converters output voltages [3].
Droop control is able to achieve proper sharing of loads among the different DG units that are connected in parallel. The droop controller achieve this without the use of any communication infrastructure. The main challenges designers face while designing a DC microgrid are the voltage control and load sharing.

On the other hand, in the case of dc system having two or more power source connected in parallel, the droop method comprise of subtracting a proportional part of the output current from the output voltage reference of each module. The operational mechanism of a conventional droop method has been shown in Fig. 2. Where the control level adjusts the reference voltage Vref provided to the outer voltage and inner current control loops and Rd is the droop gain.

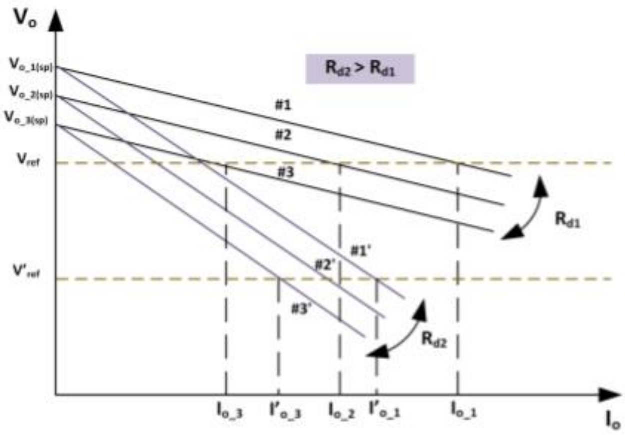

Fig. 2. Load regulation characteristic of droop method

Where Io is the output current and Vref is the output voltage reference at no load. As it can be seen from Fig. 2 that as the value of Rd is high, then the current sharing accuracy increases but the output voltage variation is increased. To overcome the limitations and to improve the output current sharing accuracy without degrading the output voltage regulation, an adaptive droop control technique have been proposed in [3].

An observer-based dc voltage droop and current feed-forward control for a dc microgrid has been proposed in [4]. With the proposed control scheme, dynamic response of dc voltage control can be improved effectively through using an observer. Moreover, the feedback current for dc voltage droop and the feed-forward current are both obtained from the observer without additional current measurement. Furthermore, system stability analysis shows that, the propose method has enhanced robustness and stability when compared to the traditional droop method under variations of system parameters, such as loads, cable impedances and droop control gains [4].

Paper [5] proposed a distributed control method for dc microgrid to ensure the proportional load sharing by taking into account the different line impedance. In this method, the operation point of each DG is effectively defined based on the power rating and the instantaneous power of the DG to achieve the proportional load power sharing. A low bandwidth communication is used to transmit the data required to determine the power reference for all DGs. In order to balance the power per unit requirement, the output voltage of each DG is controlled by a power controller to adjust the desired operating point [5]. Therefore, all DGs can operate at the balanced operating point on the droop curve to ensure the proportional load power sharing. This paper also considers the load shedding to prevent the dc microgrid from operating under overload condition.

Combination of two controllers namely P/V droop controller and Busbar voltage stabilizing controller (BVSC) is explained in the paper [6] Using P/V droop controller; and efficient load sharing among the converters with respect to their KVA rating is established. To remove voltage droop due to increased power demand, BVSC controller is used which is augmented with PID controller.

B. Storage based control

DC microgrid is required to operate at a regulated voltage for the critical loads in the system accommodating all the control measures using controlled battery energy storage systems (BESSs). Since most of the control strategies in an autonomous DC microgrid are centered around the operation of BESSs, more focus on its degradation should also be determined thoroughly. Following are the recommended way of charging for BESSs, i.e constant current/constant voltage (CC/CV) charging, the conventional methods undergo mode switching using a floating reference value to control CV charging which doesn't guarantee zero current when the battery is fully charged.

The paper [7] presents a multi-objective adaptive power management scheme which consists of a novel adaptive gain based proportionate charging/discharging strategy in order to provide energy balancing between battery energy storage systems (BESSs) of different capacities. To guarantee zero current when the battery is fully charged, a novel progressive de-rating control scheme for PV in a seamless fashion to carry out CV charging of BESSs is done using the adaptive mechanism introduced by model reference adaptive control (MRAC) scheme for optimized power management between sources and loads. The adaptive update provided from MRAC theory to design progressive de-rating scheme in this paper [7] facilitates the CV charging process for BESSs and works efficiently for any disturbance. Moreover, an adaptive proportionate charging/discharging scheme is proposed for energy balancing between BESSs of different capacities. This scheme allows to fasten energy balancing process between each BESS without violating maximum power contribution from them.

This paper [8] discuss a new DC output voltage control for the battery energy storage system (BE SS) based on the battery state of charge (SoC). The proposed control scheme in [8] consists of BESS, photo-voltaic (PV) panel, engine generator (EG), and DC load. This control scheme provides relatively lower variation of the DC grid voltage than the conventional droop control.

The paper [9] proposes the novel use of multi-agent sliding mode control for state of charge balancing between distributed DC microgrid battery energy storage systems. Unlike existing control strategies based on linear multi-agent consensus protocols, the proposed nonlinear state of charge balancing strategy (i) ensures the battery energy storage systems are either all charging or all discharging, thus eliminating circulating currents, increasing efficiency and reducing battery lifetime degradation, (ii) achieves faster state of charge balancing, (iii) avoids overloading the battery energy storage systems during periods of high load and (iv) provides plug and play capability. This control strategy can be readily integrated with existing multi-agent controllers for secondary voltage regulation and accurate current sharing [9].

Hybrid energy storage system (HESS) facilitates the integration of various energy storages (ESs) with different ramp rate. Virtual capacitive control (VCC) is used to ensure the idle condition of super capacitors (SCs) when HESS is in steady state and dynamic power sharing in transition. Improved virtual capacitive droop (IVCD) is proposed in the paper [10] by introducing DC bus voltage regulation for batteries. Compared with VCC, HESS under IVCD eliminates redundant SCs SOC regulation controller and realizes SOC recovery by automatically transferring power from the battery to SCs in transient state. Therefore, both SCs SOC recovery and DC bus voltage regulation are concurrently achieved.

C. Optimization and economic dispatch

An operating cost is associated with each generator in the microgrid, including the utility grid, combining the cost-efficiency of the system with demand response requirements of the utility. The power flow model is included in the optimization problem, thus the transmission losses can be considered for generation dispatch. A typical DC microgrid consists of a point of common coupling connected to the utility, and various DGs, such as battery ESS, fuel cells, wind power and PV systems. By neglecting the maintenance cost of these components, the correspondent operating costs are; Utility Power Cost, Energy Storage Cost, Fuel cell costs, Renewable Energy Cost and Transmission Power Losses Cost.

The objective of this study is to minimize the total operating cost in one optimization cycle in the context of real-time pricing. In the paper [11] optimization problem is solved in a heuristic method. Simulation results show that under variable renewable energy generation, load consumption and electricity prices, the proposed method can successfully reduce the operating cost by dispatching economically the resources in the microgrid.

In the paper [12], a consensus algorithm based adaptive droop control for DC microgrid is addressed. The optimum energy solution for each convention generator in the microgrid to minimize the system cost is found through a collaborate operation of a droop controller and a consensus algorithm based economic regulator. The proposed control strategy is fully distributed and cooperative such that it eliminate the center coordinator. The primary advantages of this method are 1) the output of each device will converge to global optimum without requirement of central coordinator, and 2) the communication between different converters are limited because each inverter only communicate with its neighbor. 3) The load information are not required

IV. Converter topologies

The main converter topologies that are utilized in a dc microgrid are boost converter for boosting the voltage level from the renewable source to a higher value and bidirectional converter for integrating the energy storage systems to the existing dc microgrid for ensuring continuous power flow during abnormal conditions. It can also be used in different areas like control techniques in the load sharing and voltage control, storage based control, etc.

In a bipolar dc microgrid, there is an interesting issue of voltage unbalances caused due to unequal distribution of loads across the two poles of the grid. The effects of voltage unbalance are reported in and methods are proposed to mitigate them. In the paper [13], an attempt is made to mitigate the voltage unbalance issue in a bipolar dc grid by reducing the neutral currents. A boost-SEPIC type interleaved dc-dc converter is utilized as a dc compensator to mitigate the unbalance.

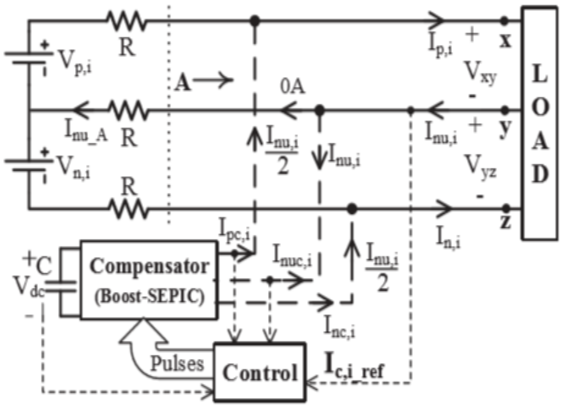

Fig. 3.Circuit with a Boost Sepic converter

A boost-SEPIC type interleaved compensator is connected across the load to mitigate the voltage unbalance. As shown in Fig. 3, the compensator absorbs the neutral current from the load and distributes it equally among the other two lines. In other words, the compensator action makes the total load seen from the terminal A to be balanced. Similiarly, different converters can be included in the system. It is seen that the proposed method mitigates the voltage unbalance by reducing the neutral line current. Hence, the line voltage unbalance rate (LVUR) and the overall line losses in the

Harmonics instability is a key issue in DC microgrids which is generally affected by the following two factors: 1) interactions among multiple power converters, and 2) CPL behavior of tightly regulated load However, the effect of these two factors on system stability varies depending on the resonance frequencies in different microgrids. The paper [14] investigates and solves the harmonics instability issue in a DAB converter enabled DC microgrid. Although frequency response of the DAB converters at high frequency range are mainly determined by the output capacitors which means high stability robustness, their impedance characteristics at low frequency range vary due to the control schemes and different operation modes [14]. This method not only increase system damping ratio when the DESD operates in DCM, but also help achieve larger stability margin in CCCM. Thus, system stability is improved.

The paper [15] presents a novel 400V to 12V isolated bidirectional DC-DC converter based on a phase shift controlled modified dual-active-bridge power stage. The proposed converter consists of a half-bridge and center-tap with active clamp circuit, which has promising performance for low-voltage high-current applications. The ability of GaN devices to improve efficiency and power density is evaluated in bidirectional power flow and low voltage, high current applications in place of a Si MOSFET. Bidirectional DC-DC converter is capable of achieving low power loss and high power density in both soft switching and hard switching modes for this specified application.

In the paper [16], a hybrid-DCES is proposed for the voltage regulation in DC grids. It synthesizes the advantages of both types of DCES: (i) it can realize simultaneous operations of DC voltage regulation and harmonic cancellation, (ii) it can reduce the required storage capacity through the active interaction with the NCL. Beside the hybrid-DCES can decouple the operations of the two functionalities, which leads to a reduction of battery pulsating current. This will lead to an extended battery lifetime. Although an extra harmonic filtering inductor is required to form an alternative path for the harmonic current, it is still cost-effective and practical to be implemented. Hence, the proposed H-DCES can be an effective technology for the voltage regulation in DC grids.

V. Conclusion

The development of microgrids comes as a necessity for the integration of renewable energy sources into remote communities, and as an intermediate milestone towards the realization of the SmartGrid. This paper presented a study on DC microgrid and Categories it into different aspects. The paper reviewed the different control techniques and converter topologies to improve the performance of a DC microgrid. DC microgrids could, however, offer several advantages compared to ac microgrids. Performance of a DC microgrid can be improved by the implementation of different control techniques and converter topologies. Which can be applied in different areas as, Load sharing, voltage control, Energy Storage, Optimization and Economic dispatch.

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