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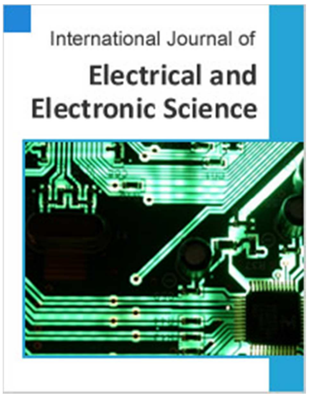

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A Review: DC Microgrid Control and Energy Management System

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Abstract
Continuously increasing demand of microgrid with high penetration of distributed energy generators, specially focused on renewable energy sources is modifying the traditional structure of the electric distribution grid. In addition, DC microgrids diverted the attention of researchers and power electronics industry in recent years to stimulate renewable energy technologies (RETs) and distributed energy resources (DERs) deployment and encouraging technological innovation to reduce green house gas (GHG) emission and achieve energy security and independence to meet the growing electricity demand. So for many studies have been done on successful integration of RETs and DERs, operation and control, protection and stability issues, simultaneously and satisfactorily implemented during feasible operation of microgrid. Studies show that DC transmittable power can increase the system efficiency up to 10% as compared to AC. But still DC bus voltage fluctuation, power quality and flow during the transition between grid connected mode to islanded mode or transient load insertion which intend to DC microgrid instability are the problems which need to be investigated and resolved for the effective use of DC microgrid generation. In this paper DC microgrid voltage, power flow, power quality and energy management different controls and techniques are reviewed and their problems are discussed.

1. Introduction

Microgrid is an alternative approach for integrating small scale distributed energy resources (DERs) which has the capacity from few kilo watts to mega watt. Many research groups around the world are pioneering various microgrid concepts, e.g. smart grid, minigrid, virtual power plant, smart distribution networks, embedded generation, distributed or dispersed generation [1].

Although the microgrid definition is not unified completely, it is generally recognized that a microgrid is a combination and merge of different distributed energy resources (DERs) power generation system, energy storage system (ESS), loads, supervisory control, protection and energy management systems [2-3]. Whereas, microgrid is a flexible and dispatchable system which can be operated in both the mode either in grid connected or stand alone, as well can switch between both the modes by using the static switches; it can provide both electrical and thermal energy to the consumers with the help of related controllable devices [4-5] and to some extent utilization of DERs can potentially reduce the need for traditional system expansion [6].

But high level of penetration and interconnection of DERs to the existing distribution systems has adverse impacts on power quality of the main grid, especially issues related to power fluctuations caused by intermittency of renewable energy sources (RES) [7-10].

Nowadays DC microgrid has diverted the attention of worldwide experts in both energy and power industries because DC microgrid has many advantages over AC microgrid. One of the main advantages of DC microgrid over AC microgrid is that DC MG has no frequency phase or reactive power control, DC output sources such as Photovoltaic (PV), Fuel Cell (FC), Super Capacitor (SC), Batteries and Electric Double Layer Capacitor (EDLC) can be connected without AC/DC conversion, which contributes to total system efficiency [11] and are used to ensure the stability of DC MG to control the power flow. All the renewable energy generation sources like solar photovoltaic, wind are proportional to environmental and metrological conditions [12], [13] and the loads are controlled and operated on their priorities and requirements. So energy storage system and power electronics must be used to manage and control their variable demands to balance the power, moreover high quality power can be supplied continuously when voltage sags or blackout occurs in utility grids [11] [14].

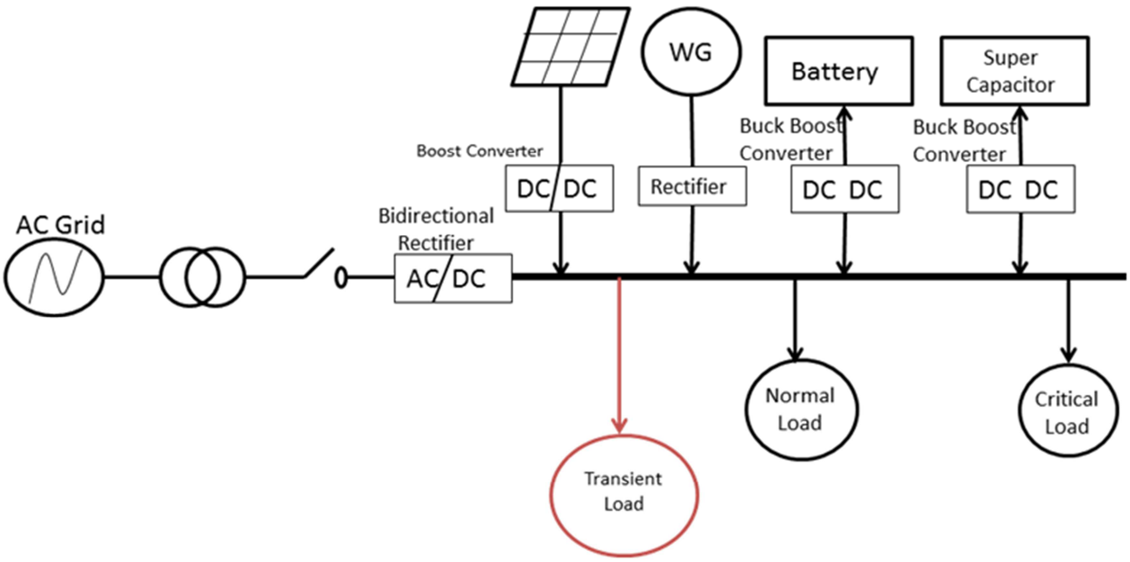

Figure 1. *DC Microgrid with transient load.*

2. Voltage Control

Many research studies on voltage control method in a DC microgrid have been done and it has been proved that DC system has advantages in comparison with of AC system [15]. By using the DC, transmittable power can increase the efficiency of system as much as 10 times than of AC system [16].In DC microgrid during the grid connect operation when the system is isolated from the grid or sudden load is switched ON into the system [17] a heavy step load change will occur and cause high dc-bus voltage variation and fluctuation, and the system might run abnormally or drop into under or over voltage protection [18] as shown in figure-2 [19].

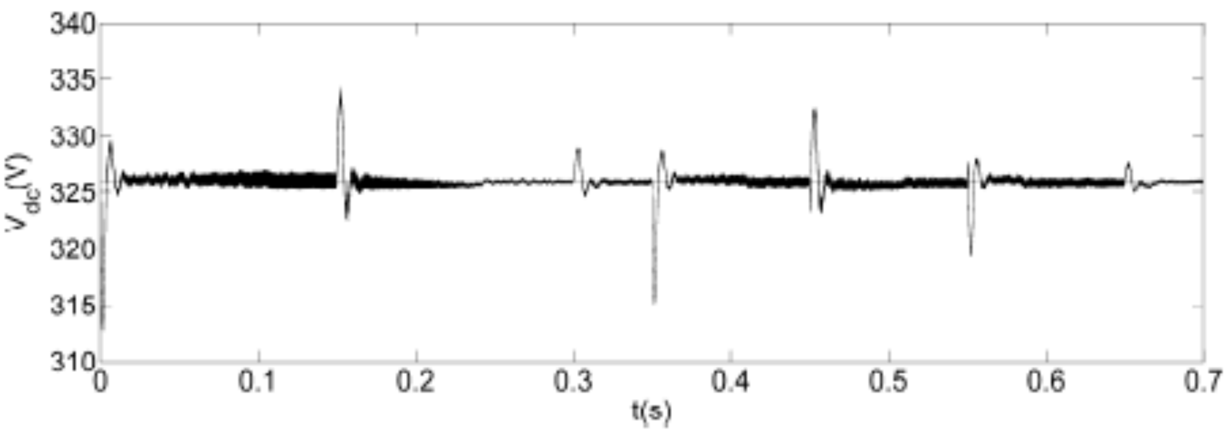

Figure 2. *The Variation in DC bus voltage when transient load or sudden isolation occurs [19].*

For regulating the bus voltage of a DC-microgrid many researchers has proposed droop control concept for voltage control and most of them employed the concept to autonomously regulate voltage, techniques which are proposed in droop control are used for voltage stability in DC-microgrid are discussed in[20]. DC distribution voltages are generally controlled with bi directional voltage source controller (VSC) in grid connected mode and dc/dc buck boost converters are used to control and maintain the storage systems and dc distribution voltage within the required range during the islanded mode [21] [22]. During the intended islanding operation, energy storage systems should have to maintain the dc microgrid distribution voltage with dc/dc buck boost converters. Therefore, if dc microgrid has at least two or more energy storage systems (ESS) and those converters are connected in parallel, which contributes to the system redundancy and voltage regulation. A droop control is one of the recognized methods for the voltage control when two or more converters are connected in parallel, because droop controller detects the current or output power as a feedback factor, and the deviation of dc voltage is controlled in proportion to the output power. However, if the converters are connected to energy storage units in standalone microgrid, the supervisory control should control and manage not only the output power balance, but also the stored energy to stable the DC voltages within the limit. In particular, stored energy balance is important to carry out the operation of microgrid during the islanded mode. Therefore, a novel control method combining gain scheduling and fuzzy control, which accomplishes good voltage regulation, load sharing, and energy balance simultaneously is proposed in [11].

On other way in the case of parallel inverters, the droop method has many drawbacks that limit its application like load-dependent frequency deviation, subtracting proportional parts of the output average active and reactive powers from the frequency and amplitude of each module to emulate virtual inertias[23]. Conventional droop method is not suitable when the paralleled system must share nonlinear loads because the control units should take into account harmonic currents and, at the same time, to balance active and reactive power [24]. Further, by using the droop method, the power sharing is affected by the output impedance of the units, line impedances and load-dependent frequency deviation are discussed in [23] [25].

In DC MG bi-directional inverter must operate in either grid-connection mode or islanding mode. During islanding mode Super Capacitor (SC), Electric Double Layer Capacitor (EDLC), Fuel Cell (FC) can be used to absorb the transient load voltage variation and increase the hold-up time and can suppress the fluctuation of dc-bus voltage and batteries converter being used to charge the battery [26]. When microgrid is in grid connected mode and DG generation is greater than load demand on that time the surplus power will be injected into the utility grid or when the power generation by DG is less than load demand on that time the deficit power will be balanced by AC grid, if microgrid is in islanded mode than batteries will provide the required backup power to DC microgrid [27] as shown in figure-3 [28].

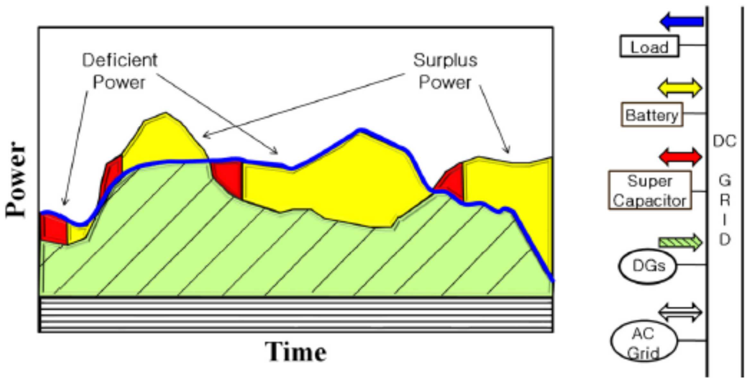

Figure 3(a). *Operation of grid-tied mode.*

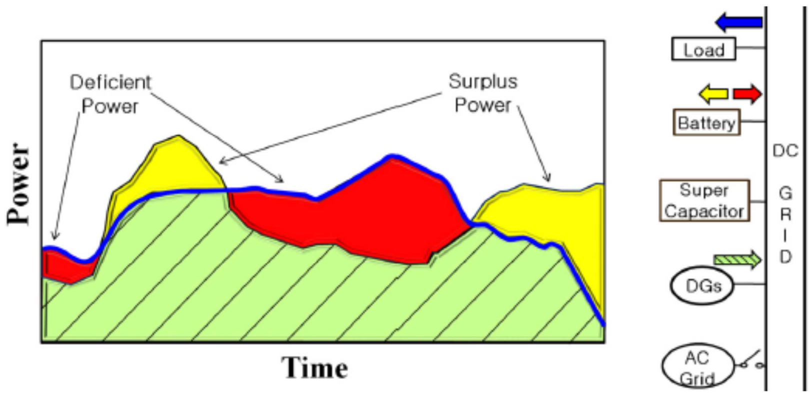

Figure 3(b). *Operation of islanded operation.*

In addition DC microgrid still needs attention to mitigate the key problems of microgrid technology that how to handle these individual distribution generation sources sensibly in order that microgrid can meet the requirements of users in power quality to ensure flexible running mode and high-quality power supply service, solving all problems such as voltage control, load flow control, load distribution when system is standalone, stability, operation and achieve ideal economic efficiency effects [29].

3. Power Flow Control and Power Quality

Power quality and power flow control is still very important issue in microgrid control because many industrial, commercial and domestic appliances are using sophisticated technologies and they need stable power flow for proper operation and production controls. Therefore during transition time from grind connected mode to islanded mode power quality issues like harmonics variations, unbalancing of voltage, sage/swell occurred which effect the operation of equipments and causes the damage, equipment de-rating as well decreasing the equipment life [30] [31].

During the transition between grid-connected to islanded mode microgrid are controlled based on measurements of voltage and frequency (VF) values. Both voltage and frequency should remains within the acceptable limits to maintain power quality PQ. Normally the voltages are linked to reactive power and frequency is linked to active power discussed in [32]. When islanding occurred in microgrid due to sage or fault on that time microgrid must have its own resources to maintain the power quality, the more important are voltage and frequency VF stability [33]. The voltage variations depend of the system reactive power, while the frequency depends of the system active power balance. Voltage control can be achieved by controlling the excitation field of the synchronous generator (SG) [34] [35] or by using power electronics converters [36] [37].

Microgrid power flow, under variable load and generation conditions with different techniques i-e: decouple power converter, grid side converter with nested loop (faster inner current loop and slower outer control loop), PQ inverter, PV inverter, grid forming inverter and optimal control of GSCs are discussed in [38]. As well different control strategies have been investigated by different research for power flow, voltage improvement, and power loss reduction. in [39] a new method for developing a sensitive matrix based on operation modes and control characteristics of typical DGs, including asynchronous generators, synchronous generators with constant values of excitation voltage, and fuel cells is discussed, and an unbalanced three-phase power flow algorithm for radial distribution networks considering DG is presented based on the power summation method in backward/forward sweep technique is elaborate in [40]. Method for calculating the load flow solution of weakly meshed transmission and distribution systems is presented from single phase to three phase, with the emphasis on modeling of dispersed generation (PV nodes), unbalanced and distributed loads, and voltage regulators and shunt capacitors with automatic local tap controls are discussed in [41-42] respectively. The fast power flow for three phase unbalanced power with the choice of modeling DG as PQ or PV node with flexible in modeling algorithm that can handle multiple sources is described in [43-44]. And in [45] and adaptive power flow method for distribution systems with dispersed generation power flow solution method based on the compensation-based method is discussed. Control technique based on the droop control method, to achieve good active and reactive power sharing is difficult and the conventional voltage and frequency droop methods of achieving load sharing have a slow and oscillating transient response is explored in [46].So it is necessary for the stability and efficient power control and management to achieve control over the power flow when transit into grid- connected mode to islanded mode. Therefore bidirectional power flow needs to be investigated in future research to manage the microgrid power flow and power management.

4. Microgrid Energy Management System

Energy management system (EMS) is very important for the stable operation of microgrid (MG) to ensure flexible running and high-quality power supply to the load and end users. To determine when and how to transfer between grid-connected and islanded operating modes, how to manage(normal load, sensitive load and transient load), when and which load needs to be disconnected during islanding as well to manage energy storage systems of Fuel Cell (FC), Super Capacitor (SC), Batteries and Electric Double Layer Capacitor (EDLC) charging and discharging in different ways and to keep the microgrid DC bus voltage and power flow stable within the limits, for energy management and control of microgrid many different control techniques has also been investigated and implemented by different researchers [29].

5. Energy Management Strategy for Microgrid

Energy management system (EMS) strategy can be applied to standalone to grid connected microgrid with an energy storage such as a battery bank as presented in [31]. Figure-4 showed the Energy management strategy Control Flow diagram for microgrid[19]. ESS is important for power balance and voltage stability in a microgrid during islanding operation explored in [47] [48] [49].

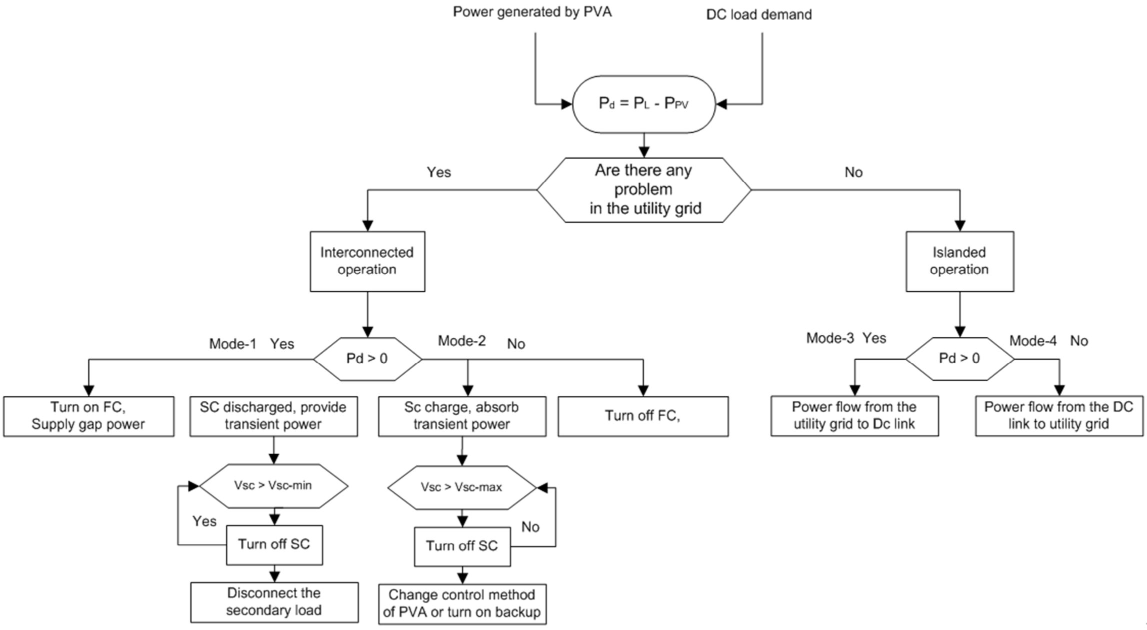

Figure 4. *Energy management strategy Control Flow diagram for microgrid [19].*

6. Standalone Mode

Standalone microgrid is considered when it operates in its own without main grid connection. During the standalone operation a microgrid is completely depending on its own generation sources like solar PV and wind but these energy generation sources are variable because of environmental impact therefore energy storage system (ESS) are used and works as backup for microgrid and are also responsible for system stability, reliability [50]. When power generated by distributed energy resources (DERs) is greater than the load demand on that time energy storage system will charged or when power generated by (DERs) less than load demand than energy storage will be discharged or some of the normal load be disconnected to keep the power flow continued for sensitive load as shown in figure-4 [19][51].

7. Grid Connected Mode

During the grid connected mode a microgrid is connected with utility grid, and the main utility grid is responsible for microgrid frequency and voltage control [52]. In grid connected mode when power generated by distributed energy resources (DERs) is greater than load demand than 1st of all energy storage system (ESS) will be charged, if energy storages are fully charged than the surplus power will be injected into the utility grid. If load demand is greater than (DERs) power generation on than the deficit power will be balanced from utility grid. However most grid connected microgrids are designed to disconnect from the main utility in an event of a disturbance within the utility network and able to operate in standalone mode [53] .

8. Conclusion

In this paper microgrid controls based on PQ, frequency and voltage levels are discussed. It means that a microgrid can operate in a stable manner during nominal operating conditions and during transient load operation or transition between grind connected to islanded mode. As well microgrid energy management system (EMS) is based on supervisory controller structures which optimize the utilization of power generation, charging and discharging of energy storage system and load consumption are discussed. However, an additional research is required, to achieve a high level of stability controllability and compatibility of microgrid to eliminate unnecessary reactive power exchange between rotating or inverter-based generators and fluctuation in DC bus voltage during transition condition and transient load operation.

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