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Research Article

Power Management in DC Microgrids Using Hierarchical Control

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Abstract: This paper suggests voltage control and power management scheme for a dc microgrid. A microgrid integrates a number of distributed energy sources and can be operated in islanded and grid connected modes. DC microgrids have a number of advantages as compared to AC microgrids because of their higher efficiency, stability and reliability. DC microgrids are prevalent because they are compatible with PV panels, batteries and dc loads. Different dc sources are co-ordinated using hierarchical control. Thebus voltage is a measure of any unbalance between supply and demand. A hierarchical control scheme is suggested for the failsafe performance of the grid. A tradeoff between maximum power harvest and essential battery management is there in this control technique. To verify the results, proposed microgrid isimplemented in MATLAB.

Introduction: With the advancements in the use of solar energy in distribution systems and increasing dc loads, dc microgrids are gaining attraction as they are highly efficient for integrating dc sources with dc input and loads [1-2]. DC microgrids provides features which are more compatible, more efficient and more robust. As the energy produced by the renewable energy sources is random, robust and steady, performance of a DC microgrid is dependent on the control techniques for power management at both generator and consumer ends. Also, the regulation of DC bus voltage in addition to the maximum power management andbattery storage management requires both power balance control and higher level energy management strategies.

Different power management techniques are centralized, decentralized and distributed[3]. In Centralized control, a central controller is used to share data/ information among different converters. However, if anycommunication link/ channel fails, it leads to degradation of system stability. In decentralized control, this limitation can be nullified by the use of decentralized control where power electronic interfaces operate onthe basis of local area measurements [4-5]. Though reliability is increased, system stability and optimal operation suffers due to the lack of information and operating conditions of others.

Distributed Control gives a solution on stability with the maintenance of reliability [6-7]. DC-bus signalling (DBS) is a distributed control technique. Here, bus voltage is used as a signal for determination of operating modes as defined by the voltage thresholds [3]. But this technique also suffers from a few drawbacks. The ratings of different sources and storage systems are restricted by the number of levels in voltage. So voltage signalling is valid only for a small dc microgrid [8]. Droop control is an efficient technique to control a microgrid with a number of sources and storage systems with same priority of voltage, so that current could be shared according to their ratings.

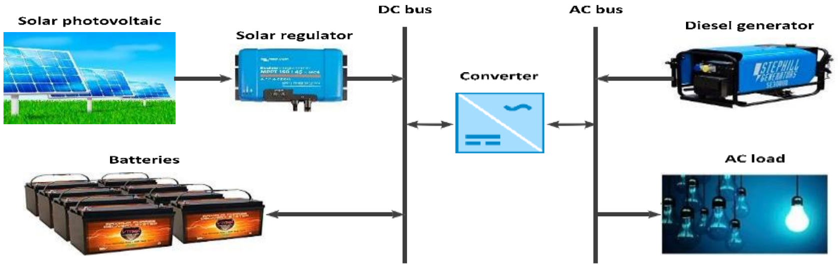

Fig.1 DC Microgrid Configuration

In a dc microgrid, there is a slight deviation in voltage of different terminals because of the voltage drop, but due to this, there is an inaccuracy in current sharing[9]. The above mentioned constraints in distributedcontrol strategies, necessitates the combination of distributed control andhigher layer management system.

This paper proposes hierarchical control structure for the management of DC microgrids. The hierarchical control structure consists of three levels. Level I which is known as primary control maintains the bus voltage within limits by varying the mode of operation of converters. Level II which is also known as secondary control has the ability to attain real time voltage regulation. Level III helps to handle extreme operating conditions like instant change in load or source because of any failure in the system.

Control Structure of DC Microgrid

For operating a DC microgrid, the distributed energy sources, loads and energy storages must behave in a co-ordinated manner. PV modules operating in MPPT mode and battery energy storage system operating in charging /discharging mode and loads which may consume or supply electric power are the main components of dc microgrid.

For stable operation, maintainence of bus voltage by maintaining power balance in the system is needed. If the losses are ignored, power balance can be expressed as

Sum of the powers produced by PV + Sum of the powers produced by battery = Sum of powers absorbedby load

$$\sum_{i=1}^{m} P_{pvi}(t) + \sum_{i=1}^{n} P_{bi}(t) - \sum_{i=1}^{l} P_{li}(t) = 0 \qquad (1)$$

Here, m is the number of PV sources, n is number of BESS and l is number of loads respectively

$P_{pvi}(t)$ is the power produced by the ith PV source;

$P_{bi}(t)$ is the power dissipated into the bus from the ith BESS which is positive when BESS is discharged; and $P_{li}(t)$ is the power dissipated into the ith load. Power balance involves a complex problem

where maximum energy from the renewable energy sources is to be harvested, BESSs are to be used optimally, bus voltage is to be maintained within limits. The bus voltage is separated into five sectionsusingthe four predefined voltage boundaries determined by system operation requirements.The variations in voltage between adjoining thresholds must be judiciously selected so that it is neither toosmall to avoid faults during mode changing due to measurement errors nor too large to sidestep major busvoltage variations which may disturb the normal operation of the load. The relationship among the thresholdvalues is as follows: $VL2 < VL1 < Vdcn < VH1 < VH2$ (2)

where Vdcn is the dc-bus nominal voltage, VL2 and VH2 are the boundaries of the allowable dc voltage

band of the dc microgrid, and VH1 and VL1 are threshold values actuating the battery charging anddischarging, respectively.

Level I Control

The foremost aim of proposed control is to find the maximum powers from renewable energy sources and maintain the reliability of basic operations. Detailed control schemes for different operation regions are asfollows

1) Region 1

$VL1 < Vdcn < VH1$ (3)

To avoid recurrent charge/ discharge operations, Region1 is the operating region where all battery energy sources are in idle mode. PV converters operate in MPPT mode, so that maximum renewable energy could be utilized and the loads could be given continuous operation. Constant bus Voltage indicates power balance between loads and sources. The bus voltage can be varied in Region 1 according to power variations in loads and sources. Sum of powers produced by PV sources is equal to power consumed by load.

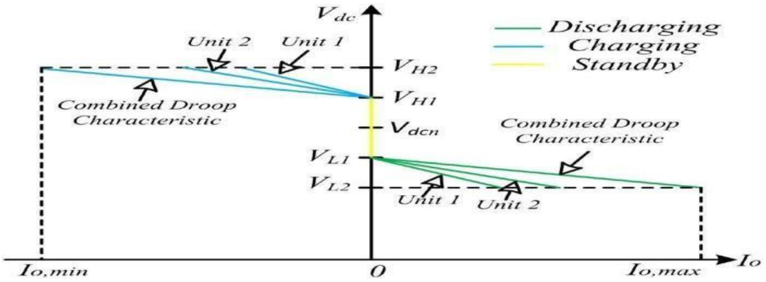

Fig. 2 Battery droop characteristics

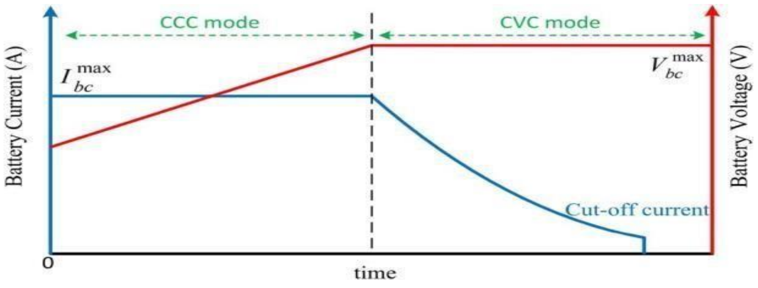

Fig. 3 BESS charging scheme

Level II Control

2) Region 2 - VH1 < Vdcn < VH2

If PV modules produce power more than demanded, voltage falls in the region 2. Battery Energy Storage Systems are activated for storing the surplus power. Power is shared among the different Battery Energy Storage Systems using droop control according to the given equation for distributing the voltage equally among different Battery Energy Storage Systems. The charging current of different batteries may exceed their maximum allowablelimit.

Vref bi = VH1 – mbi.Ibi (4)

Vref bi, mbi, Ibi are the reference voltage, droop coefficient, bus side current respectively

DC bus voltage reference value	450 V
ESU's capacity	200
Maximum state-of-charge threshold	80%
Minimum state-of-charge threshold	20%
ESU's reference voltage	100 V
Maximum power of solar power unit	20 KW
Solar constant voltage control reference power	15 KW
Diesel generator power	10 KW

Table I Parameters of DC Microgrid

3) Region 3- VL1 < Vdcn < VL2

Low bus voltage is the indication for system power deficiency. In this region, PV converters operate in MPPT mode, and BESSs are in discharging mode to compensate the power shortage. To prevent the bus voltage from collapsing, NRS changes from idle mode to BM mode at $VL2$. The capacity of PV panels and batteries should be designed carefully so that they can fulfill thenormal operation requirement of the loads most of the time and NRS would only be occasionally activated for unpredicted peak demand.

Level III Control

Over or undervoltage may arise due to sudden loss of loads or PV modules in system operation. Due to this system components may suffer and mismanagement in system control may arise. To prevent these unwantedsystem conditions, Level III Control is considered to manage the dc bus voltage within the tolerable band when abnormal system conditions arise.

4) Region 4 -Vdc > VH2: When the bus voltage reaches VH2, the ballast is switched on to absorb powerand control the voltage within VH2.

5) Region 5 -Vdc< VL2 : Voltage drop occurs in this range of voltage due to deficiency in power. If the available sources, including the non renewable sources, are not able to supply the load, bus voltage falls below VL2.Load can be shed to supply part load to control voltage in limit. Loads can be supplied according to their priority i.e. according to their importance and may be shut down in sequence during load shedding

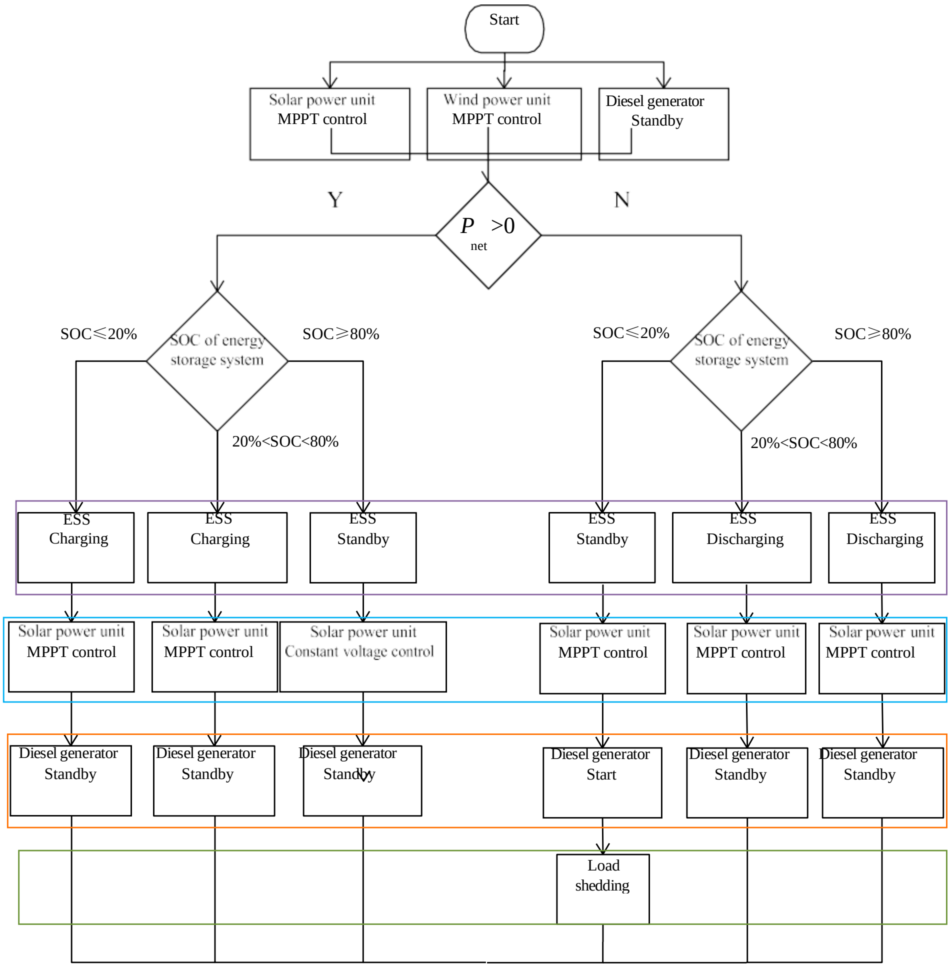

Fig. 4 Flow Chart for Control StrategyExperimental Results:

The proposed microgrid is implemented in MATLAB. Results for DC are shown in Fig.5.

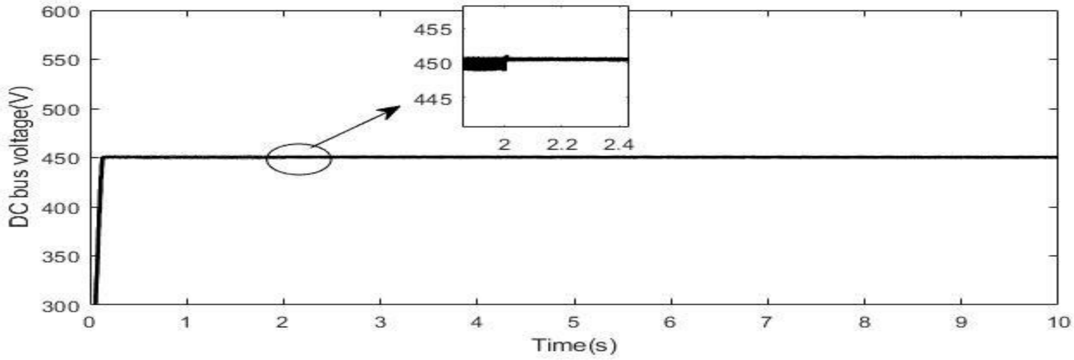

Fig.5 DC bus Voltage

Conclusion

The limitations in HLI control can be improved through real-time information sharing among converters in HLII control. Communication link generally brings full observability over the dc grid, including real- time bus voltage, power flow,and operation status of converters, and thus, system optimal operation in terms of reliability and cost could be achieved through coordination control on system elements. Although the effectiveness of system operation depends heavily on the communication quality in HLII, the system reliability would not be degraded due to HLI as backup. Once failure happens inthe communication links, all elements, including PV modules and battery storages, can retain the system stability under HLI control at the cost of losing global optimization.

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