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Distributed Control using Digital Power Sharing for Improved Voltage Regulation and Proportional Load Sharing in Low Voltage Dc Micro grids

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Abstract **- DC micro grids are gaining popularity due to high efficiency, high reliability, and easy interconnection of renewable sources as compared to the ac system. Conventional droop controllers are not effective in achieving both voltage regulation and proportional load sharing simultaneously. Changes in nominal voltages, extensive load distributions, non-negligible inter-connecting parameters etc. account for the above said problems with low voltage dc micro grids. Though centralized controller achieves these objectives, it requires high-speed communication and offers less reliability due to single point of failure. To address these limitations a new decentralized controller for dc microgrid using power feedback is proposed. Key advantages are high reliability, low-voltage regulation, and equal load sharing, utilizing low-bandwidth communication. The effectiveness of the scheme is verified through a detailed simulation study.**

I INTRODUCTION

DC micro grids can create power systems that are more efficient and more compatible with the fastest growing segment of the load today: electronic devices. In turn, by catering to the needs of digital devices, we naturally expand the networks in which they operate (both power and control) to benefit from or indeed require redundant operation that is primarily available today through the other ubiquitousDC device, the battery. Control objectives of dc microgrid are: 1) to ensure equal load sharing (in per unit) among sources; and 2) to maintain low-voltage regulation of the system. Conventional droop controllers are not effective in achieving both the aforementioned objectives simulta-neously. Reasons

for this are identified to be the error in nominal voltages and load distribution. Though centralized controller achieves these objectives, it requires high-speed communication and offers less reliability due to single point of failure. The main objective of this paper is to formulate a new control strategy so that the proportional load sharing and voltage regulation is improved without any increase in cost of implementation than the present technology.

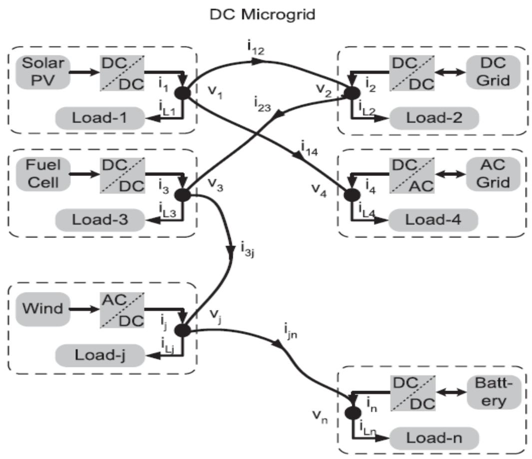


Fig1. Dc micro grid configuration

By locally managing sources and loads, a DC micro grid can optimize its net surplus of power (output to the grid) or deficit (input from the grid). This greater local management of both supply and demand creates a buffer to the grid and relieves some of its burden. Conventional means of Demand Side Management (DSM) do not accomplish these ends as efficiently. This becomes possible because of better exploitation of DC's natural characteristics, which remains the lifeblood of all electronic devices and the de facto fuel of the digital economy.

Different surveys done on dc micro grid control are discussed below.

Tertiary control methods (1), also known as energy management system, communicates with the distribution system operator (DSO) or transmission system operator (TSO) and the secondary control. DSO/TSO decides the schedule of power exchange with the micro grid. Based on this and other inputs from within the micro grid, the tertiary controller prepares the source and storage dispatch schedule. This is communicated to the secondary controller. Secondary controller's objective is to ensure that the power supplied by different sources is in proportion to that scheduled (base value) by the tertiary control. In other words load must be shared proportionally (in per unit) among sources. Typically, both secondary and tertiary controls are included in the micro grid central controller. Secondary control sets the parameters of droop (primary) control such that deviations produced by the droop control are restored and the dc micro grid voltage is maintained within the acceptable values. Objective of the droop control is to compensate for instantaneous mismatch between scheduled power and power demanded by loads. Base don these requirements, droop control generates the voltage reference signals for source. Inner loop (voltage and current) control ensures that the actual voltage of PEC source is equal to its reference value.

Study on the viability of PLC for low-voltage dc system is also reported in (2).DC micro grid can have various interconnections of power cables, thereby making the analysis of channel complex . Typically, digital signal processors/controllers used for power electronics applications include CAN protocol, thereby facilitating CAN communication among these devices.

Control of distributed generation system suggested in (3) utilize the system voltage level as a means of communication. PECs connected to micro grid measure the system voltage level and accordingly set reference value for operation. However, voltage level at different locations varies due to resistive drop across the interconnecting cables. Therefore, use of this control scheme is limited to small systems, in which resistance drop scan be neglected A small ac signal over the dc signal is injected in the method reported in (4)The frequency of this ac signal acts as a means of communication. This method is prone to noise on power cables. Further, it requires circuits for accurate injection and detection of the ac signal. This limits the viability of the scheme.

II CONTROL ARCHITECTURES FOR DC GRID

The main objective of the power-sharing control is to maintain low-voltage regulation without compromising the load sharing(in per unit) among the sources. This control can be classified into three categories.

A. *Hierarchical Control*

A centralized power-sharing (secondary) control scheme for dc micro grid is shown in Fig. Each PEC source includes a primary (droop) control and inner (voltage and current)control. Secondary control is centralized and is responsible for controlling various primary controllers. Secondary control its parameters for the droop law of each PEC source. Fig. shows the secondary and primary controllers for the hierarchical control scheme. Voltage level of the micro grid is compared with the reference value and this error is processed trough the proportional-integral (PI) controller. Output of the PI is communicated to primary control of all sources. This scheme achieves low-voltage regulation. Furthermore, distributed primary control ensures that system operation is not effected by malfunction of a source. However, in case of failure of the secondary control, the system may not be able to ensure low-voltage regulation.

B. Control Without Communication

Decentralized control without communication is shown inFig . It comprises droop control and does not include a separate secondary control unit. For dc systems, droop between voltage and current is most commonly used and is given by

$$v_j^{ref} = v_j^0 - d_j i_j$$

where d_j,i_j, v_j^{ref} and v_j^0 are the droop gain, source current, reference voltage, and nominal voltage (voltage when sourcecurrent is zero) of source-*j*, respectively. Since secondary control is not used, parameters of the droop control are set such that system voltage is maintained within the specified value. Therefore, to ensure low-voltage regulation, low value of droop gain*dj*is used. This control scheme offers complete modularity at less cost as compared to the hierarchical control. However, error in power sharing among sources is high as compared to that in hierarchical control. Following are the two reasons for error in power sharing in droop controlled system without communication.

Unequal Nominal Voltages:

Due to limitations in implementation of primary controllers, the nominal voltages of different PEC sources are not exactly equal. Typically, this is due to error in voltage sensing for closed-loop operation. Small error in nominal voltages results in significant deviation of source currents from their required values. This is due to the small value of the droop gain used to restrict large variation in system voltage(between no-load and full-load conditions. In case of small droop gain, the deviation in source current,($i1-i2$), is large. As the droop gain is increased, ($i1-i2$) reduces. However, the voltage regulation is large and may not be acceptable to loads.

Load Distribution:

In dc micro grid, difference in voltage magnitudes of two nodes varies with the power flow across their interconnecting cables. In other words, voltage of each node depends on the load distribution across the system. Due to droop control, source currents depend on the node voltages. Therefore, source currents depend on the load distribution due to the interconnecting cable resistance. The deviation in source currents can be reduced by increasing the droop gains. This is at the cost of increased voltage variation.

C. Distributed Control for Parallel DC–DC Converters

A distributed control scheme utilizes the average current sharing (ACS) methodology. Instead of a single secondary control, distributed control is incorporated in each PEC source. These controllers communicate to each other using a common bus. Measured value of source current is converted to voltage signal, which is connected to the ACS bus(analog) through a resistance. This signal is added to the droop control. This scheme offers equal load sharing among sources and low-voltage regulation in the parallel dc–dc converter system. In dc micro grid, sources are distributed over a region. The current sharing bus has to be distributed within the region along with power lines. This may inject significant external noise in the bus. Therefore, this scheme may not be suitable for dc micro grid.

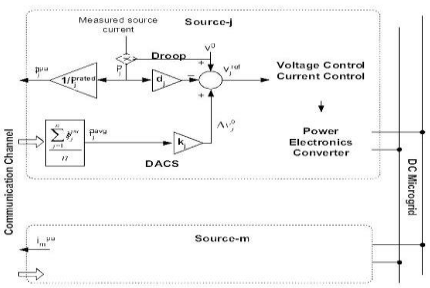
III PROPOSED METHOD

For conventional droop controllers, low value of droop gain ensures low-voltage regulation. But the source currents deviate significantly from their ideal values and equal load sharing cannot be guaranteed. The factors for this be haviour are unequal nominal voltages and load distribution. Though these issues can be addressed by increasing the droop gains higher than the cable resistance, voltage of the system vary significantly from no-load to full-load condition. Following scheme is proposed to address this limitation. Droop characteristics is shifted along the voltage axis by addition of ΔP_j^0 in the conventional droop equation and is givenby

$$v_j^{ref} = v_j^0 + \Delta P_j^0 - d_j i_j$$

where ΔP_j^0 is given by $\Delta P_j^0 = K_j \Delta P_j^{avg}$ and average power $\Delta P_j^{avg} = \sum_{k=1}^{n} p^k / n$

Shift in the voltage Δv0j depends on the total system load. With increase in load, Δv0j increases, making the instantaneous voltage reference vrefjclose to the



nominal voltage, v0. For the dc micro grid shown in Fig.both source characteristics shift. Characteristics before and after shifting observed at load 1 is shown. Even though high value of droop gain is used to ensure equal load sharing, operating voltage is close to the nominal voltage v0j . To determine the value of voltage shiftΔv0j , a low-bandwidth communication is utilized as follows:

The controller of each source communicates with the controller of other sources and sends the magnitude of current supplied(in per unit) by it. Using this information, the individual source controller determines the average value of the current supplied by all the sources using $\Delta P_j^0 = K_j \Delta P_j^{avg}$ and average power $\Delta P_j^{avg} = \sum_{k=1}^{n} p^k / n$

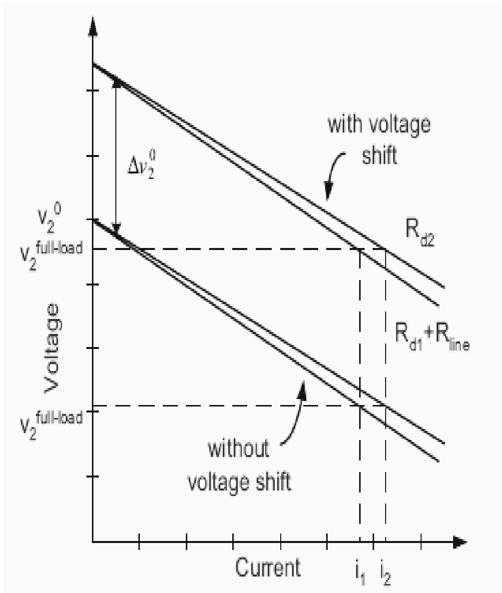


Fig 3 :voltage shifting due to power sharing

IV SIMULATION

The two-load two-source dc system shown in Fig. is simulate dusing MATLAB/Simulink. Parameters used for simulation are given in Table I. Each source is a dc–dc buck converter with inner voltage controller, as shown in Fig. The proposed controller is realized to generate the reference value of voltage for inner controller

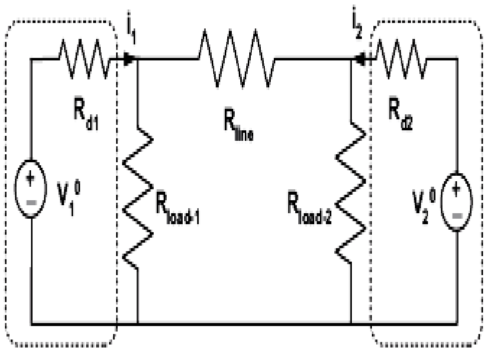


Fig:4 Equivalent Circuit

parameter	value	unit
Source 1	15	volts
Source 2	15	volts
Load 1	10	ohms
Load 2	6	ohms
Interconnecting Cable	200	Milli ohms
Dj (gain for current feedback)	1.9	
Kj(source droop gain)	1.8	

Fig:5 Parameter

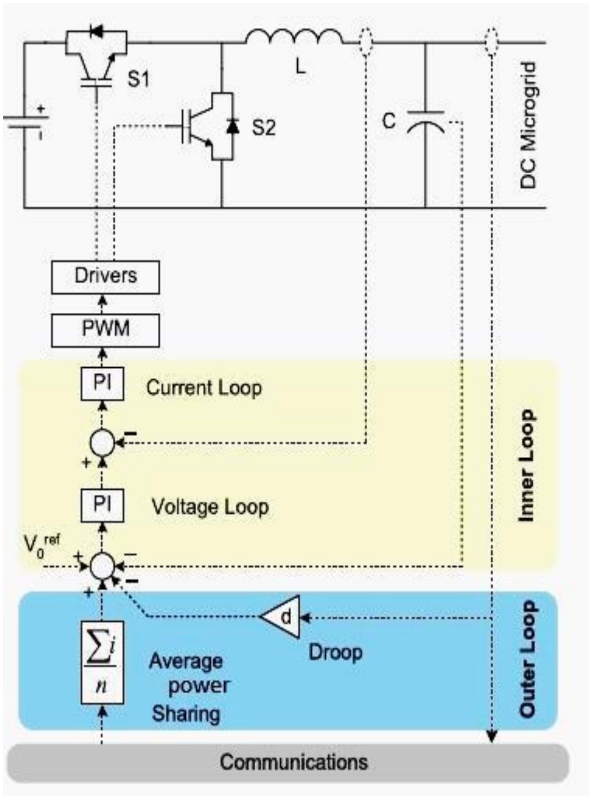


FIG 6 :DC-DC converter employing proposed methodology

RESULTS AND CONCLUSION

The results obtained by simulation are consolidated as follows.

Case1.Both loads are of equal magnitude i.e 20 ohms

Source 1 terminal volt	**14.8 volts**
Source 2 terminal volt	14.8 volts
Source 1 current	.74 A
Source 2 current	.74 A

Case1.With Load 2 alone

Source 1 terminal volt	**14.9 volts**
Source 2 terminal volt	14.95 volts
Source 1 current	.375 A
Source 2 current	.35 A

CASE 1

- Voltage regulation in case 1 is 1.33%
- Maximum current deviation from ideal values is negligible

CASE 2

- Voltage regulation is .66 % and.33% respectively
- Maximum current deviation from ideal values is 5 mA and 20 mA respectively

V CONCLUSIONS

This paper presents a distributed control suitable for dc micro grid systems. As opposed to the conventional hierarchical control approach, it does not require a central controller. The control is based on the droop control method together with a decentralized ACS control. The droop control is a local controller, which does not require any communication system, and achieves good current sharing at the expense of compromising the voltage regulation.. Therefore, the current sharing is hard to achieve when the distance between the sources is considerable. In order to improve this drawback, another loop has been implemented, which uses low-bandwidth digital communication between the sources. It is based on averaging the total power supplied by the sources. The following facts are concluded

1. Low values of voltage regulation have been obtained
2. Proportionate current sharing between the sources in accordance with the change in loads have improved.
3. Slight deviations from expected values are due to the presence of interconnecting cable parameters.

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