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Mitigation of Voltage Ripple in a DC Microgrid Using a Sliding Mode-Based Feedback Linearization Controller

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Abstract

DC microgrids will play an important role in the near future due to the integration of emerging technologies for renewable energy sources. The system's load must be distributed across several sources while these direct current microgrids are in operation. Both the academic and industrial sectors are proficient in droop control techniques for load sharing. One must carefully choose between load sharing and voltage management while using these droop techniques. Although virtual droop compensation techniques can achieve nearly zero voltage regulation, their high dc bus voltage ripple content depends on the load's characteristics. The system will encounter more voltage ripples and be more susceptible to voltage instability as increases the loads in DC microgrids. The main problem associated with the traditional PI controller does not provide sufficient performance for variable operational conditions with load variations. In order to solve the uncertainty problems and strengthen the control algorithm, the feedback linear control has integrated the sliding mode control technology. This paper proposes a concept of an integrated virtual droop mechanism for a nonlinear control system. Under various operating situations, including Fixed power loads. The suggested droop control method is assessed for a various type of loads.

Keywords: DC Microgrid, Fixed power load, sliding mode control, distributed generator, droop control method.

1. Introduction

The research and developments with applications for distributed generation systems have significantly increased over the last decade. The concept of a traditional central system having large generation-based power systems has been significantly altered by the ability to generate power locally near consumers using distributed clean energy sources. Depending on the applications of the source type with loads, the microgrids can choose as DC microgrid or AC microgrid systems. Alternating current (AC) systems power contemporary conventional homes. Several conversion stages are involved in an AC system with a distributed renewable-based generator, which not only makes system stability more difficult but also lowers system efficiency to below 70% because of losses at each conversion stage. In addition, the traditional AC grid has difficulties with frequency control, skin effect losses, active and reactive power control, and higher insulation levels because of high peak values.

However, a large range of devices and lighting technologies, including computers and televisions, are DC loads. Switching to a new system of having many distributed generation systems has the benefits of a DC Microgrid for smooth integration of various dc sources. One such configuration with various source types and an aggregated load is presented in Figure 1 as a DC microgrid. This is where semiconductor devices and power electronic converters are most commonly used. A DC microgrid minimises losses from multiple conversion stages and can achieve up to 98% performance by improving a simple DC to DC conversion system based on the requirements of the supplied loads. Focusing on having small voltage variations with ensuring equivalent load sharing among multiple sources are the two main objectives that must be accomplished for any DC microgrid system to function in a satisfactory manner.

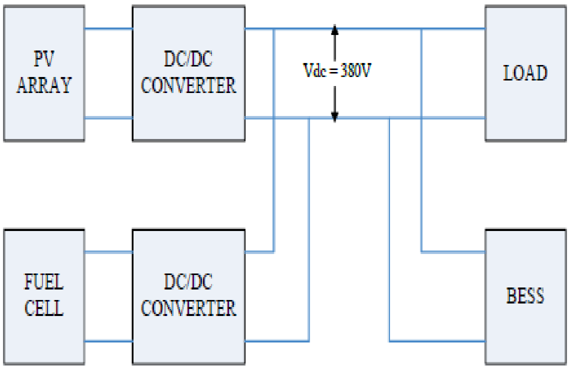

Figure 1. DC Microgrid Overview

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Classification of DC loads can be expressed as Fixed Resistive Loads, Fixed Current Loads and Fixed Power Loads. They will impact on performance differently on the basis on their type, which has been briefly covered in this paper. In general, a PI controller governs the DC systems. These controllers respond satisfactorily to certain types of loads; their performance will be unacceptable for other types of loads. In light of this, this paper investigates and provides a concise overview of how various load types interact and affect system performance using a conventional controller.

According to the investigation, depending on the load's magnitude and the type of disturbance or load shift, CPLs cause ripples in the system voltage and may even cause voltage instability. In order to assure system stability with CPLs, various systems have been employed.

A negative series virtual inductor approach can be used, but it necessarily requires careful controller parameter design. An active damping circuit can also be integrated to ensure stability. A capacitor with an appropriate capacity across the CPL or energy storage devices like batteries or storage devices can also be used to address this instability issue. This paper suggests using a nonlinear controller that can dampen oscillations caused by CPLs in a DC Microgrid without the need for extra circuitry or controls.

The different types of DC loads is discussed in further Section 2 of this paper. Section 3 discusses current DC microgrids control strategies. Section 4 provides a description of the suggested controller, while Section 5 presents the findings and analysis. Section 6 contains closing remarks.

2. DC Microgrid System with Loads

The ensuing subsections provide a brief description of various load types.

2.1 Fixed Resistive Load

These included incandescent lights and loads used for heating applications. Ohm's law governs these loads, which are primarily linear loads. The current in these loads is thus given by (1).

$$i_L = \frac{V_{dc}}{R_L} \qquad (1)$$

Here, i_L stands for load current, R_L represents the resistance of the load and V_{dc} stands for the voltage across DC bus. The power consumed across the load (P_L) is given as (2).

$$P_L = \frac{V_{dc^2}}{R_L} \qquad (2)$$

2.2 Fixed Current Load

The fixed current loads are the load which draws a steady state current, such circuits supplied with a Fixed current. Because a fixed resistance load causes a battery's voltage and current to drop as it discharges, they are essential for test systems that work accurately to characterize the behaviour of battery discharge system.

2.3 Fixed Power Load

Fixed power mode comes under this class of loads. They are regulated to consume Fixed power. Thus,

$$\frac{P_{Lconst}}{V_{dc}} = i_L \qquad (3)$$

Because of the intrinsic properties of Fixed power load system, the current increases to manage a Fixed power because of the voltage drop caused by this non-linearity. The system becomes unstable as a result of the cascading impact. To prevent this, the controller must quickly correct for the voltage drop caused by non-linearity. The many current methods for controlling DC microgrid systems are covered in the section that follows.

3. DC Microgrid Control Strategies

The control strategies of DC microgrid can be mainly classified as:

(i) Centralized Control Method for DC microgrid system
(ii) Decentralized Control Method for DC microgrid system

3.1 Centralized Control Method for DC microgrid system

A large number of centrally controlled topologies exist including load sharing and master-slave control systems. These techniques have the following problems:

i) As many lines of communication are required, this leads to difficulty in complicated systems.

ii) Failure of the master/central controller may result in the system off.

3.2 Decentralized Control Method for DC microgrid system

Decentralized control can be used to get around the known problems with centralized control schemes. One of the most straight forward decentralized control techniques is droop control method.

Conventional Droop Method: A conventional droop controller are governed by the following droop characteristics of:

$$V_J^* = V_J^0 - d_J i_J \qquad (4)$$

Here V_J^*, d_J and V_J^0 are stands for reference voltage, droop gain and nominal voltage of source j, respectively.

Decentralized control can be used to address the noted shortcomings of centralized control schemes Figure 2 & 3 displays a typical droop controller's droop characteristic. In Figure 2 the properties of two converters with different nominal voltages but the same droop values are contrasted.

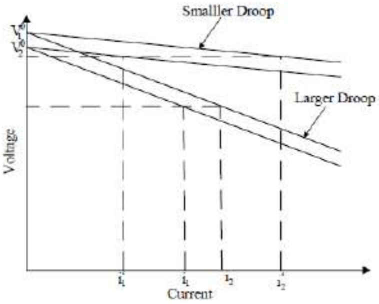

Figure 2. Load Distribution in DC Microgrid due to Unequal Load Sharing

Figure 3 compares the properties of two converters with the same nominal voltage but operating at different droops. It is seen from the displayed characteristics that the system's voltage regulation is comparatively better for smaller droop values. However, the converters' current share is inadequate.

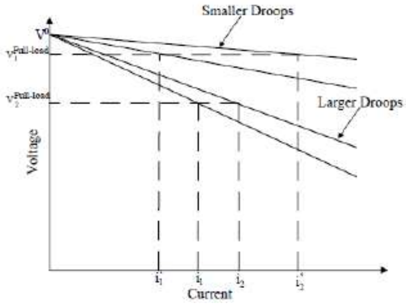

Figure 3. Error in nominal voltages of two parallel-connected DC Converters due to Unequal Load Sharing

3.3 Virtual Droop Method:

In this method, the voltage drop due to line impedance is compensated using a control loop. The governing voltage is represented as (5).

$$V_J^* = V_J^0 - d_J i_J + \Delta V_J^0 \qquad (5)$$

Here ΔV_J^0 is the voltage drop compensation due to the additional virtual impedance available in system. In results, the virtual droop approach provides more precise load distribution among the converters based on the individual droop fixed ratios. As a result, DGs' load sharing is mostly significantly affected by the converters' internal resistances. In contrast to a traditional droop controller. By injecting a voltage ΔVj0 equal to the amount of the voltage drop, the virtual droop method prevents this phenomenon and ensures that an operating voltage remains fixed throughout. Figure 4 shows the block diagram of control with a virtual droop method unequal load sharing system.

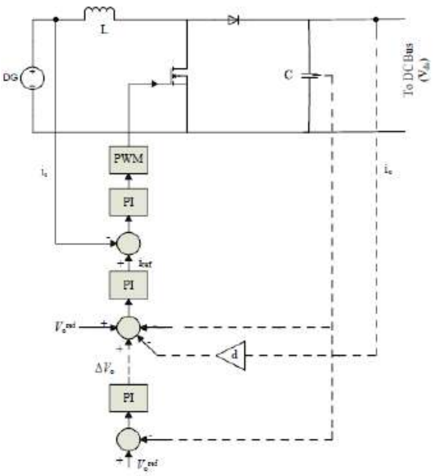

Figure 4. DC Microgrid control system with virtual droop method

To compensate the limitations of PI-based controllers for various loads, it is suggested that microgrids employ a boost line-regulated converter (LRC) controlled by a control algorithm (SMC). The SMC performs better in power electronics applications than a conventional PI controller. Feedback linearization is used to obtain the state vectors. The detailed converter topology is shown in the figure. 5.

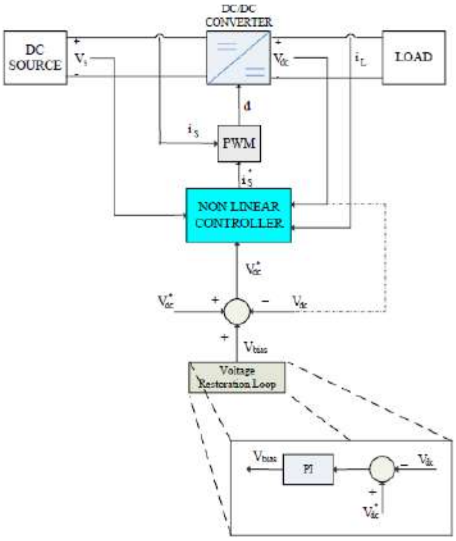

Figure 5. Proposed Control Strategy under a Nonlinear Controller

Thus, the dynamic converter model is given by:

$$\frac{Ldi_L}{dt} = \text{E-(1-d)}V_C \qquad (6)$$

$$\frac{CdV}{dt} = i_C \qquad (7)$$

By Applying KCL at output node, we get the following:

$$i_{dc} = i_{load} + i_c \qquad (8)$$

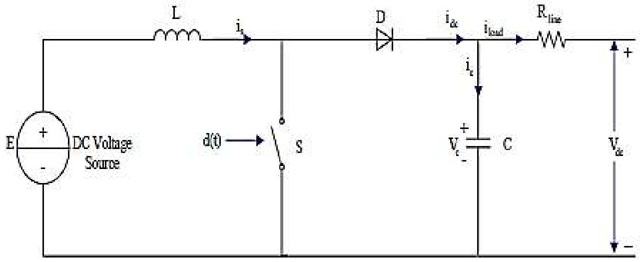

Figure 6. Detailed topology of the DC-to-DC Converter

4. Sliding Mode Control Application with Formulation

The PI controller was the standard approach for determining the reference signal of the PWM switching control for many decades [14]. In most cases, it often leads to significant delays if response time is limited. To solve this problem it is necessary to adjust the controller parameters. However, it can be a bit tedious and time-consuming as it requires trial and error adjustments to achieve satisfactory performance. Despite the adjustments made, some of them may still not meet the desired performance levels when the operating conditions vary. The traditional PI controllers lack the ability to reject disturbances and are not affected by variations in system parameters or non-linear loads.

The state vectors λ1 and λ2 are obtained using feedback linearization. New control inputs u1 and u2 are obtained by applying SMC on a new set of λ1 and λ2. Determining the sliding surface is essential to the SMC's design. SMC offers a reliable and viable control technique by limiting system motion to a state trajectory. The major problem is to find a suitable switching surface which permits the controllable input commands to drive the states for sliding modes. it can be represented as:

$$u_{.}(t) = u_{eq}(t) + u_{sw} = u_{eq}(t) + \rho sign(\sigma) \qquad (9)$$

where, ρ is a positive switching function. According to (10), it has two output states, the number of sliding surfaces that each output will follow can be written as:

$$\sigma_1 = er_1 \ \& \ \sigma_2 = er_2 \qquad (10)$$

Since, the relative degree are i_{dg} and i_{qg} respectively. The errors er_1 (x) and er_2 (x) can be defined as follows:

$$er_1 = i_{dg} - i_{dgref} \ \ \& \ \ er_2 = i_{qg} - i_{qgref} \qquad (11)$$

The procedure for obtaining reference currents i_{dgref} and i_{qgref} has been discussed above. The temporal derivative of error can be obtained as:

$$\sigma_1 = er_1 = \frac{d(er_1)}{dt} \ \ \& \ \ \sigma_2 = er_2 = \frac{d(er_2)}{dt} \qquad (12)$$

The dynamics modifications for the new chosen switching function can be represented as:

$$\sigma_1 = -\rho_1 tanh(\sigma_1) \qquad \sigma_2 = -\rho_2 tanh(\sigma_2) \qquad (13)$$

where, ρ_1 and ρ_2 are positive constants. From the states obtained using the SMC the new dynamics can be deduced as:

$$\bar{\lambda} = (\bar{\lambda}_1 \quad \bar{\lambda}_2)^T = [-\rho_1 tanh(\sigma_1) - \rho_2 tanh(\sigma_2)] \qquad (14)$$

This newly generated control inputs are identified to generate SPWM pulses.

5. Conclusion

Recently, control systems based on virtual droop have been developed to minimize voltage regulation and guarantee proposer sharing among the DGs. In consideration of this, it has been suggested to incorporate a nonlinear sliding mode controller into virtual droop analysis for the regulation of the dc to dc converter for power supply. Sliding control ideas are integrated into the control structure to reduce uncertainty and strengthen the created control algorithm. The VSC uses internal current and external voltage control mechanisms to integrate the MPPT algorithm. For multi-DG systems, the algorithms are currently adjusted. This control algorithm is designed to the photovoltaic inverter system can be regulated to provide reactive power as an additional service.

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