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Voltage Regulation in Distribution Network using Fuzzy Logic Controller

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ABSTRACT

Widespread penetration of Renewable Energy (RE) sources in distribution networks may introduce new technical challenges for the distribution network. These issues include voltage rise, voltage unbalancing, voltage regulation problem, thermal overloading, frequency fluctuation, flicker and harmonics. Consequently, the traditional operation of distribution networks limits the penetration level of RE sources and need to be revised to incorporate new control and protection strategies. In this project, a robust voltage control strategy that is fuzzy logic controller, which takes good use of the distributed energy storage (DES) units, is proposed to enhance the voltage stability and robustness of DC distribution network. The characteristics of AC/DC interface in network are analyzed, and the virtual inertia and capacitance are given to demonstrate the interactive influence of the AC and the DC systems. The control strategy for DES which is located at the AC micro grid or at the network terminal bus is designed based on the interactive characteristics, enabling the DES to respond to both voltage variation of DC network and frequency change of utility AC grid. The proposed comprehensive robust control strategy for DESs at different interfaces features independence of communication as well as enhancement of system robustness, and reduces the impact of DC distribution network on utility AC grid

KEYWORDS: *Renewable Energy, Distribution Generation, Voltage Regulation, Fuzzy Logic controller*

I. Introduction

The research, development and implementation of efficient and cost-effective interconnection possibilities for offshore wind are a key element in achieving ambitious European renewable targets. Current trends in research and commercial applications of offshore wind integration are towards Voltage Source Converter (VSC) High Voltage Direct Current (HVDC) transmission [1]. VSC-HVDC displays distinct control and design advantages over traditional Line Commutated Converter (LCC) technology. With the increasing penetration of renewable resources and microgrids, the conventional AC distribution network is facing big challenges in plug-and-play performance and operating stability, where DC systems have more advantages. Therefore, given the demand of power system operation and success of DC technology in some specific applications, e.g., large-scale data centres, shipboard systems [2], [3], medium voltage DC (MVDC) distribution network is getting more attraction in the future smart grid architecture.

Nowadays, general voltage control strategies can be mainly classified into two categories: master-slave control and voltage droop control. In master-slave control strategy, one voltage source converter (VSC) is assigned to be slack terminal, which means it is supposed to track the variation of DC voltage and keep the voltage at the reference value.

This control strategy can achieve high operation accuracy because all the power source converters are regulated according to the state of the system. However, the master-slave control strategy is tightly dependent on fast-speed and high-bandwidth communication. Thus, the redundancy design is required in this control structure. Besides, this strategy is not friendly to the access of new generation sources, for the control frame should be refreshed accordingly.

Droop control strategy is free of communication and uses the voltage signal to regulate the output power of controlled converters. A coordinated droop control strategy is proposed for multi-terminal DC (MTDC) system, which enables the proportional power dispatch among grid side HVDC stations. To address the voltage mismatch, an adaptive droop control method is investigated [12], which is able to minimize the voltage drop and load current sharing difference by introducing a figure of merit index. A hierarchical control strategy is proposed in [13] and [14], which assigns different control aims into several levels to regulate more involving elements and mitigate the influence of droop control.

This paper presents a momentous approach for distributed energy storage (DES) in DC distribution network. This is the flexible voltage control strategy for strengthening the voltage stability and reliability in DC network at various perturbations. Moreover, the parameter of the AC and DC networks are analyzed briefly under demonstrated virtual inertia and capacitances. The control technique is proposed for DES, it is located at the AC microgrid or at the network terminal bus is designed based on the interactive characteristics, enabling the DES to respond to both voltage variation of DC network and frequency change of utility AC grid. A cascading droop control method with fuzzy is suggested for DES in DC microgrid to mitigate the pressure of voltage deterioration of DC network.

II. VOLTAGE CONTROL STRATEGY OF DC DISTRI-BUTION NETWORK

Similar to the AC distribution network, the DC network can be classified into three typical types: 1) the radial structure; 2) the ring structure; and 3) the dual or the multi-terminal structure [26]. Fig. 1 shows the typical dual terminal DC network studied in this paper. To acquire good fault ride-through capability, the substations at the terminal are connected to 4 kV DC network via the isolation transformers and the voltage source converter (VSC), which feature the electric isolation capability and work together to step down the voltage and transfer AC power into DC format. The following three different elements are interfaced into the network via DC cables.

2.1. AC/DC microgrid*:* This type of element usually consists of distributed generators (DGs), ESs and local loads, the power of which is varied periodically in accordance with the change of natural environment factors such as wind speed or photovoltaic irradiation. When there is a shortage in power demand, the microgrid adjusts the power amount absorbed from the DC network. Sometimes, the microgrid can be used to adjust the voltage of distribution network.

2.2. AC/DC loads*:* The aggregative loads feature unidirectional power flow and can hardly be taken into consideration for voltage control. Except for some emergency condition, the loads can be shed in a passive way to release the burden of network.

2.3. Independent ES unit: It can be installed at any node, and offer an ancillary or backup support for DC voltage. The signal of node voltage is collected as the input for ES unit controller to compensate the voltage variation.

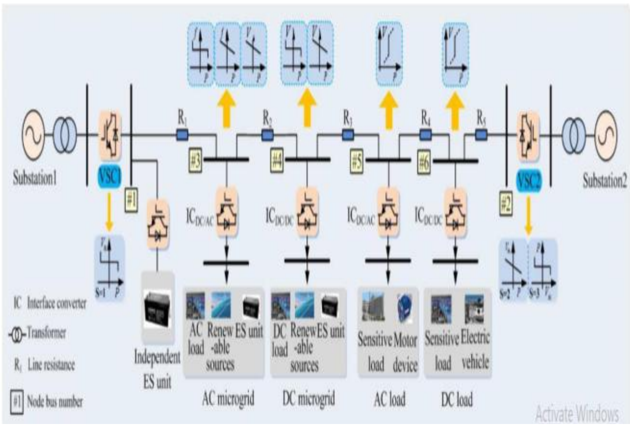

Fig. 1. Dual terminal structure of DC distribution network

III. CONTROL STRATEGY

***3.1. Conventional Control Strategy for Network Bus Voltage**:* According to the classification of network elements mentioned above, the nodes connected with different types of elements show different operating characteristics. Fig. 1 shows the control strategies of different types of nodes in the DC distribution network. More specifically, in this section, the voltage control of the nodes with different elements will be investigated. 1) Terminal nodes. At the terminal of DC network, the AC/DC converters are utilized to offer an access to AC grid for the network. These converters work under one of three control strategies, namely, the constant voltage control, the droop control (V-P) or the constant power control, as shown in in Fig. 2. No matter which topology the DC network adopts, at least one of the terminal converters should adopt the constant voltage control to ensure there is a slack terminal in the system.

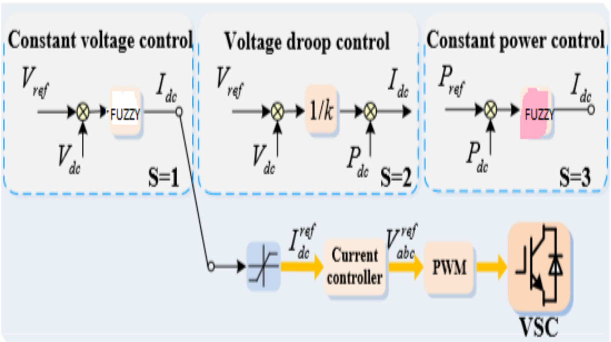

Fig.2 various control strategies for terminal converter.

2) The nodes connected with aggregating loads. These nodes work in a constant power consuming mode. In some emergency cases, some loads may increase the power demand within a narrow range. 3) The nodes connected with micro grids. The micro grids connecting to DC distribution network can output power if the distributed generators have more power that the local loads cannot be consumed, and the interface converters (ICs) are controlled in the similar way as the terminal VSC. When there is a lack of power demand in microgrid, its net power Pnet is defined as

$$P_{net} = \sum P_{load} - (\sum P_{DGs} + \sum P_{ESs})$$

control strategy for ES unit of microgrid can be classified into two modes. In Mode I, ES unit will not be activated during connection, all the net power demands will be satisfied by absorbing energy from distribution grid, and ES units should take part in power adjustment only when the microgrid is isolated from grid, or in the situation that power flow is beyond the capacity limitation, denoted as PN IC, of ICs. This mode can be describedby

$$\begin{cases} P_{dc}^{ref} = \sum P_{load} - \sum P_{DGs} \text{ and } \sum \Delta P_{ESs} = 0, \text{ when } 0 \le P_{net} \le P_{IC}^{N} \\ P_{dc}^{ref} = P_{IC}^{N} \text{ and } \sum \Delta P_{ESs} = P_{net} - P_{IC}^{N}, \quad \text{when } P_{net} \ge P_{IC}^{N} \end{cases}$$

***3.2. Flexible voltage control with DESS**:*
In this paper, the comprehensive demands of the operating characteristics and control aims for different interfaces are taken into account. As shown in Table I, the power flowing from microgrids or AC utility grid to the DC network is considered in the condition of charge, and thus the inverse power flow is in the discharge state. The inner traits describe the variation of the electrical characteristics of elements interfaced to the DC network, such as the frequency of AC grid and the voltage of DC grid. The control objectives of this paper are described in this Table, where the absolute frequency deviation |Δf | is limited within 1%, and the DC voltage variation is within 5%. ΔVdc and ΔVbus represent the voltage variation of DC microgrid and DC distribution network, respectively. It should be noted that when some severe power events occur and the power quality cannot be guaranteed, which means the above delta values are beyond their limits, the common emergency measures like load shedding or microgrid disconnection will be activated to keep the stability of the DC distribution system.

Fuzzy logic is a convenient way to map an input space to an output space. Mapping input to output is the starting point for everything. Consider the following examples:

- With information about how good your service was at a restaurant, a fuzzy logic system can tell you what the tip should be.
- With your specification of how hot you want the water, a fuzzy logic system can adjust the faucet valve to the right setting.
- With information about how far away the subject of your photograph is, a fuzzy logic system can focus the lens for you.
- With information about how fast the car is going and how hard the motor is working, a fuzzy logic system can shift gears for you.

To determine the appropriate amount of tip requires mapping inputs to the appropriate outputs. Between the input and the output, the preceding figure shows a black box that can contain any number of things: fuzzy systems, linear systems, expert systems, neural networks, differential equations, interpolated multidimensional lookup tables, or even a spiritual advisor, just to name a few of the possible options. Clearly the list could go on and on.

Fuzzy inference is a method that interprets the values in the input vector and, based on user defined rules, assigns values to the output vector. Using the GUI editors and viewers in the Fuzzy Logic Toolbox, you can build the rules set, define the membership functions, and analyze the behavior of a fuzzy inference system (FIS). The following editors and viewers are provided.

IV. SIMULATION OUTCOME

In order to validate the proposed voltagecontrol strategy, a comprehensive simulation model of DC network is developed. The independent ES unit is installed at the terminal bus denoted #1 of the DC network, and the micro grids are also equipped with ES units. To acquire a good balance between energy density and fast power response, the Li-on batteries are chosen as the ES units in the simulation cases. Aggregating AC/DC loads are substituted by a constant power load, since theyplay no significant part in the following simulation.

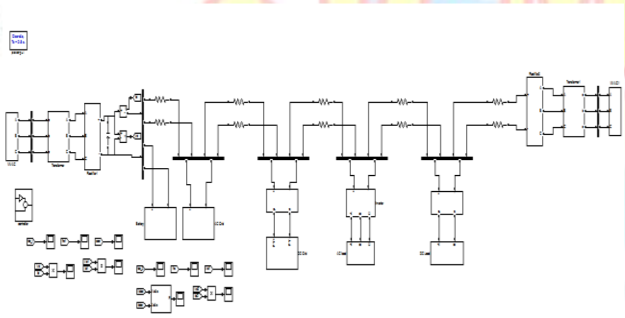

Fig:3.1. simulation diagram of Dynamic Performance on Power Variation

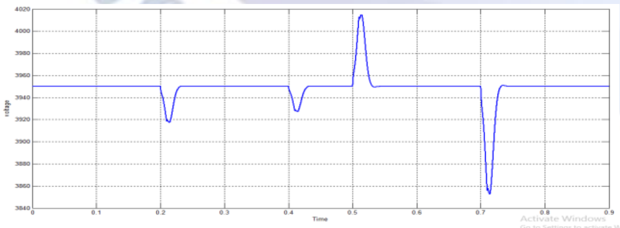

Fig:3.2(a)

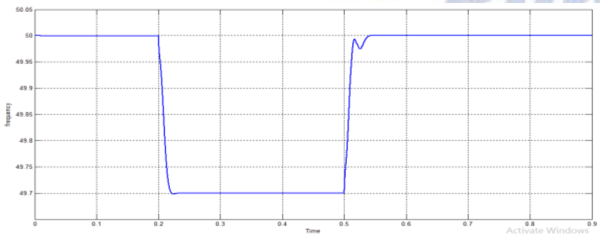

Fig:3.2(b)

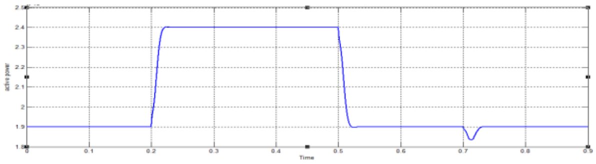

Fig:3.2(c

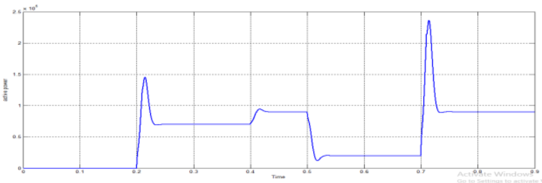

Fig:3.2(d)

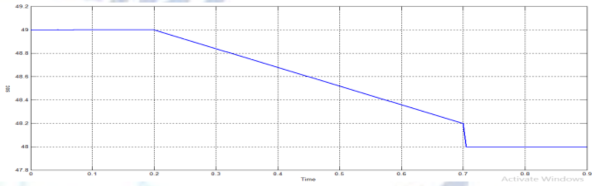

Fig:3.2(e)

Fig.3.2 Simulation results of the AC micro grid for case 1, (a) voltage of DC bus #3; (b) frequency variation; (c) change of net power; (d) output power of the ES unit; (e) SoC of ES unit (with DESs)

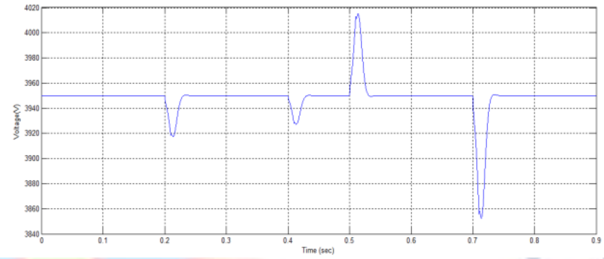

Fig:3.3(a)

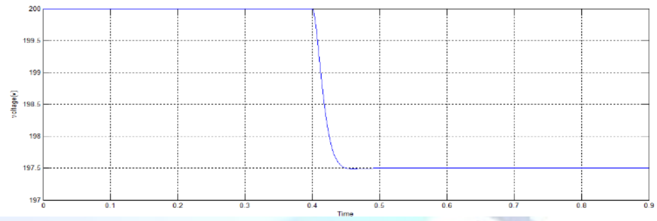

Fig:3.3(b)

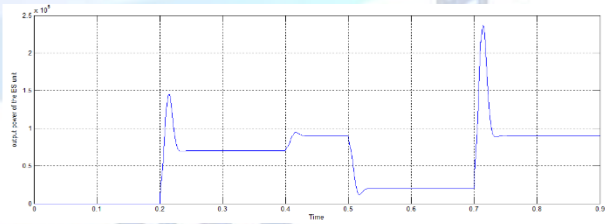

Fig:3.3(c)

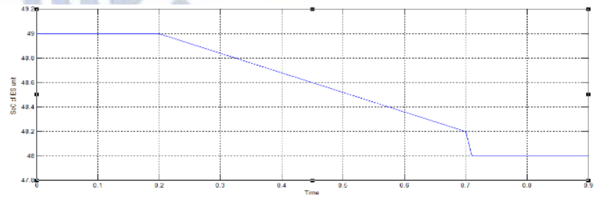

Fig:3.3(d)

Fig.3.3 Simulation results of the DC micro grid for case 1, (a) voltage of DC bus #4;

(b) voltage variation (c) change of net power (d) SoC of ES unit.(without DESs)

Fig 3.4. (a)

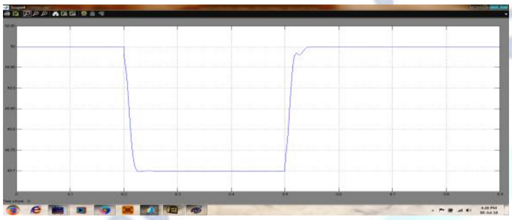

Fig 3.4 (b)

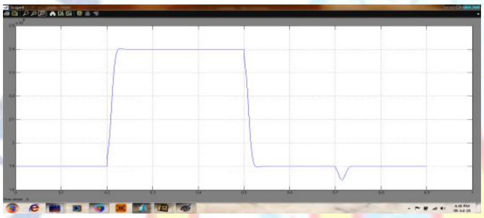

Fig 3.4 (c)

Fig 3.4 (d)

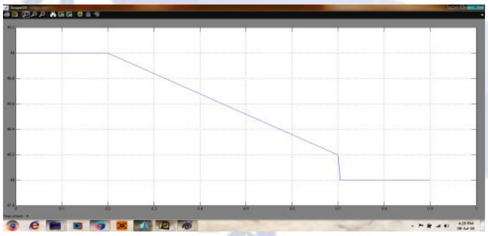

Fig 3.4 (e)

Fig.3.4 Simulation results of the AC micro grid with fuzzy logic controller for case 1, (a) voltage of DC bus #3; (b) frequency variation; (c) change of net power; (d) output power of the ES unit; (e) SoC of ES unit (with DESs)

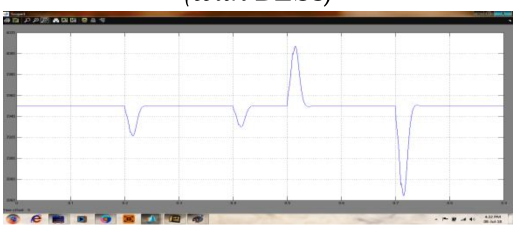

Fig 3.5 (a)

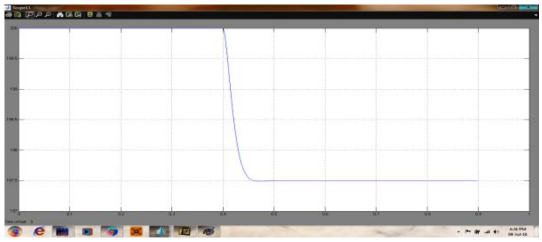

Fig 3.5(b)

Fig 3.5(c)

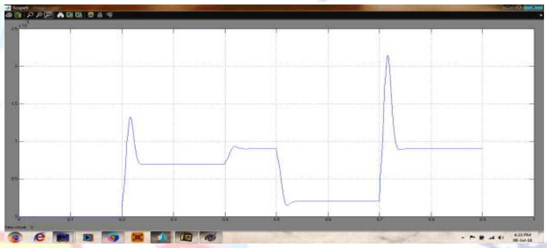

Fig 3.5(d)

Fig 3.5(e)

Fig.3.5 Simulation results of the DC micro grid with fuzzy logic controller for case 1, (a) voltage of DC bus #4; (b) voltage variation (c) change of net power (d) output power of the ES unit (e) SoC of ES unit.(without DESs)

Fig 3.6 (a)

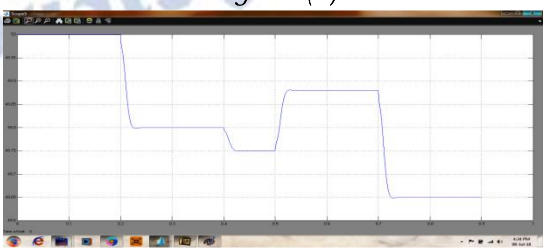

Fig 3.6 (b)

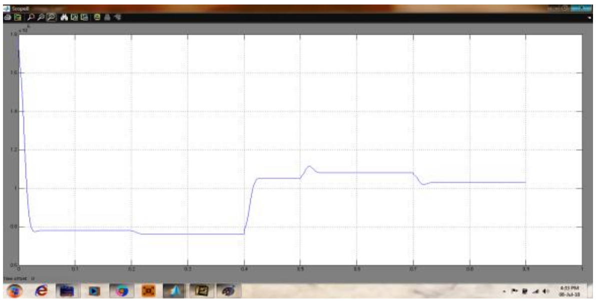

Fig 3.6 (c)

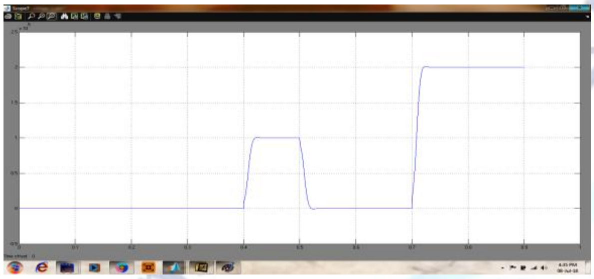

Fig 3.6 (d)

Fig.3.6 Simulation results of DC bus # 1 with fuzzy logic controller for case 1, (a) voltage of DC bus; (b) grid frequency variation of the utility; (c) active power of VSC1; (d) output power of the independent ES unit (with DESs

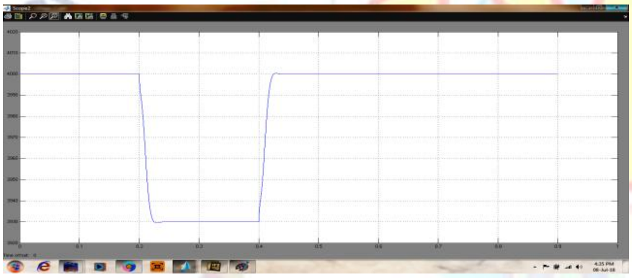

Fig 3.7 (a)

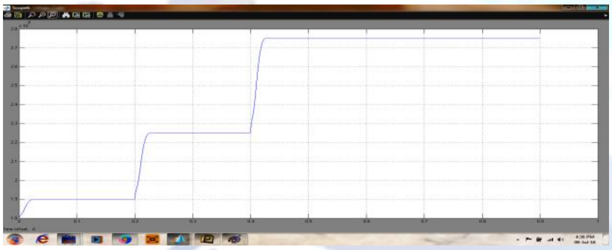

Fig 3.7 (b)

Fig 3.7 Simulation results of DC bus # 1with fuzzy logic controllerfor case 2, (a) voltage of DC bus; (b) active power of VSC1

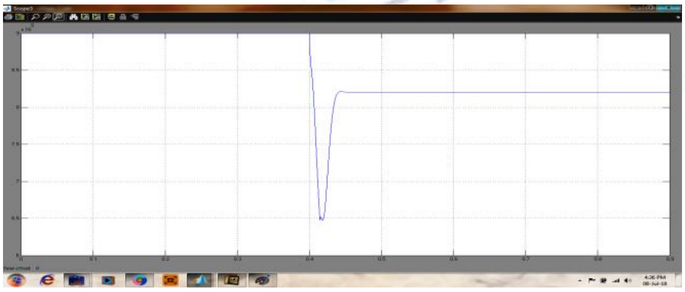

Fig 3.8(a)

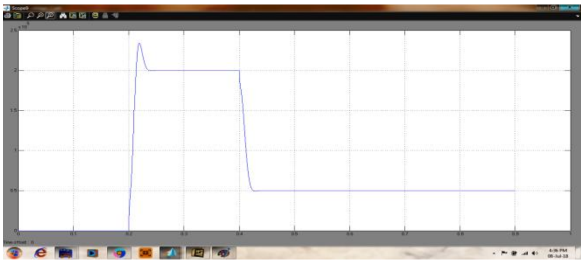

Fig 3.8(b)

Fig:3.8 Simulation results of DC bus #2 with fuzzy logic controller for case 2, (a) voltage of DC bus; (b) active power of VSC2 (without DESs).

Therefore, the stability of the whole system involving DC network and the utility grid can be enhanced.The recommended strategy employed at various networks, at any circumstances the proposed technique rendered the efficient performance. Moreover, the parameter of the AC and DC networks are analyzed briefly under demonstrated virtual inertia and capacitances. The control technique is proposed for DES, it is located at the AC micro grid or at the network terminal bus is designed based on the interactive characteristics, enabling the DES to respond to both voltage variation of DC network and frequency change of utility AC grid. A cascading droop control method with fuzzy is suggested for DES in DC microgrid to mitigate the pressure of voltage deterioration of DC network.

This case is used to test the proposedcontrol strategy on the change of the operating mode of the terminal VSC, and the serious outage fault happensin the network. The simulationresults and the DC voltages of terminal VSCs are given.

V. CONCLUSION

A robust voltage control strategy, which fully considers the regulation ability of the DES units in DC distribution network, is proposed. In this project, a robust voltage control strategy that is fuzzy logic controller, which takes good use of the distributed energy storage (DES) units, is proposed to enhance the voltage stability and robustness of DC distribution network. The characteristics of AC/DC interface in network are analyzed, and the virtual inertia and capacitance are given to demonstrate the interactive influence of the AC and the DC systems. The control strategy for DES which is located at the AC micro grid or at the network terminal bus is designed based on the interactive characteristics, enabling the DES to respond to both voltage variation of DC network and frequency change of utility AC grid. The proposed comprehensive robust control strategy for DESs at different interfaces features independence of communication as well as enhancement of system robustness, and reduces the impact of DC distribution network on utility AC grid. The performance of the proposed control strategy is validated the DC distribution network by Matlab/Simulink simulation results.

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