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Modified Voltage Control Strategy for DC Network with Distributed Energy Storage using Fuzzy Logic Controller

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***Abstract*—This paper presents a momentous approach for distributed energy storage (DES) in DC distribution network. Which 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. The simulation outcomes rendered the fruitful response for improving the voltage stability in DC distributed network as compared to other existing techniques.**

***Keywords*—Distributed energy storage, flexible voltage control strategy, AC and DC networks, fuzzy, voltage stability.**

1. 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. Sinceno concerning factors such as reactive power and phase synchronization and the like, the DC voltage plays a key role in the system operation stability.

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 [4], [5]. 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 [6]-[10]. In [11], 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. Which 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.

2. VOLTAGE CONTROL STRATEGY OF DC DISTRIBUTION 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

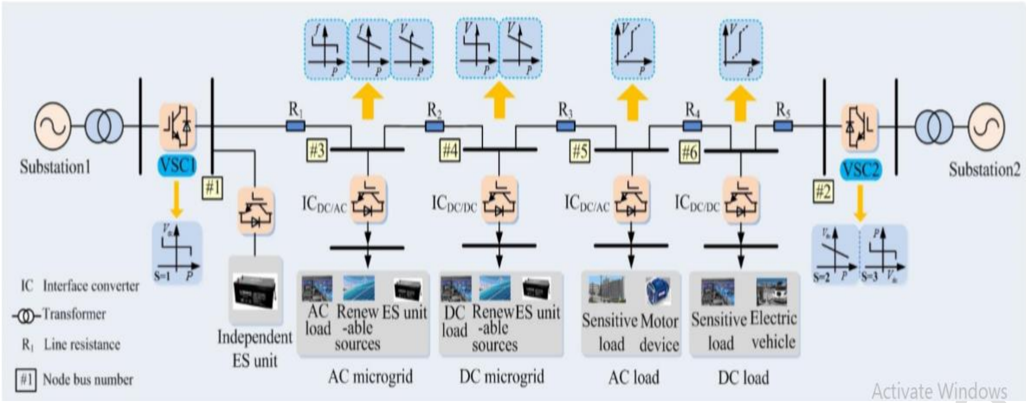

Fig.1 The schematic diagram of DC network with dual terminal.

3. 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.

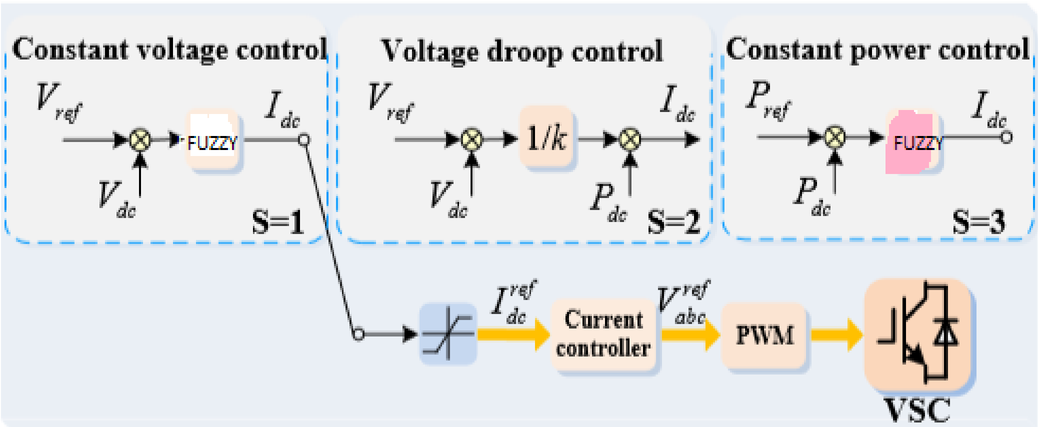

Fig.2 various control strategies for terminal converter.

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 microgrids. The microgrids 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

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

The control strategy for ES unit of microgrid can be classified into two modes. In Mode I, ES unit will not be

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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 described by

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

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.

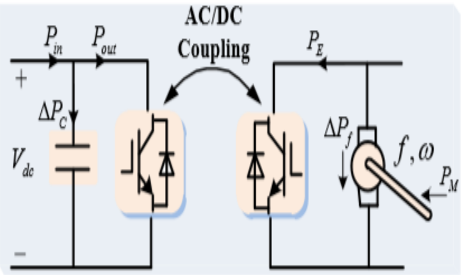


Fig.3 The power relationship between AC and DC.

4. FUZZY METHOD

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection. To understand why use of fuzzy logic has grown, you must first understand what is meant by fuzzy logic. Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of fl. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalve logical systems.

In fuzzy Logic Toolbox software, fuzzy logic should be interpreted as FL, that is, fuzzy logic in its wide sense. The basic ideas underlying FL are explained very clearly and insightfully in Foundations of Fuzzy Logic. What might be added is that the basic concept underlying FL is that of a linguistic variable, that is, a variable whose values are words rather than numbers. In effect, much of FL may be viewed as a methodology for computing with words rather than numbers. Although words are inherently less precise than numbers, their use is closer to human intuition. Furthermore, computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution. Another basic concept in FL, which plays a central role in most of its applications, is that of a fuzzy if-then rule or, simply, fuzzy rule. Although rule-based systems have a long history of use in Artificial Intelligence (AI), what is missing in such systems is a mechanism for dealing with fuzzy consequents and fuzzy antecedents. In fuzzy logic, this mechanism is provided by the calculus of fuzzy rules. The calculus of fuzzy rules serves as a basis for what might be called the Fuzzy Dependency and Command Language (FDCL).

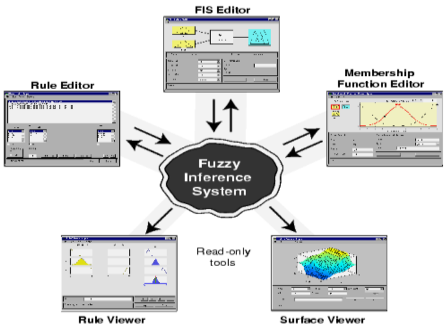
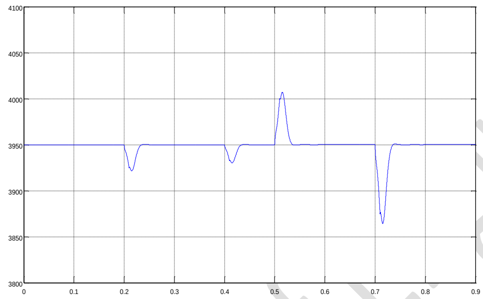
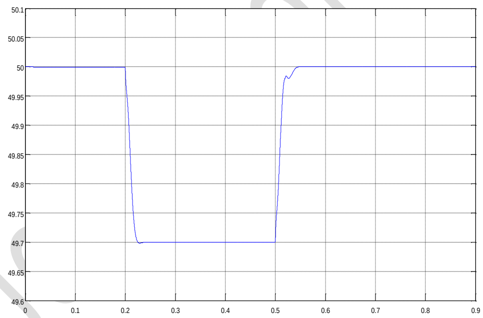


Fig.4 The Primary GUI Tools of the Fuzzy Logic Toolbox

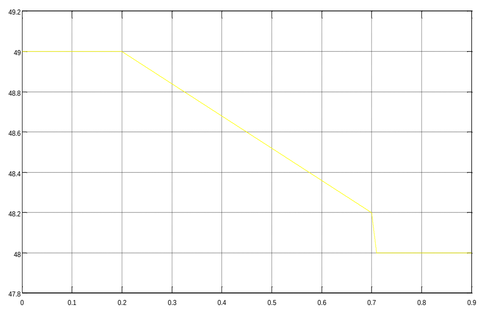
5. SIMULATION OUTCOMES



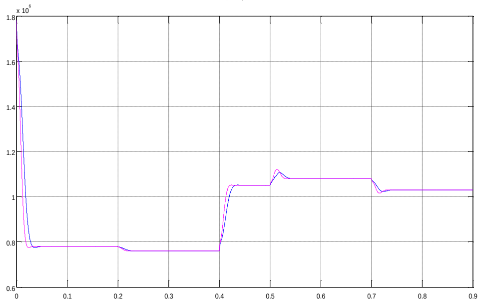
(a) Voltage



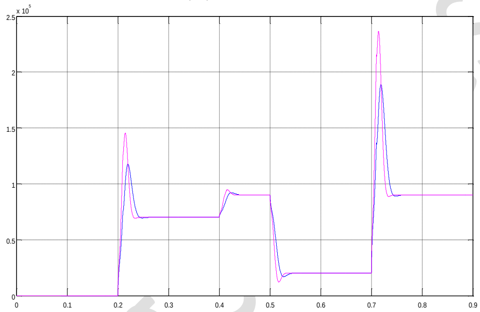
(b) Frequency



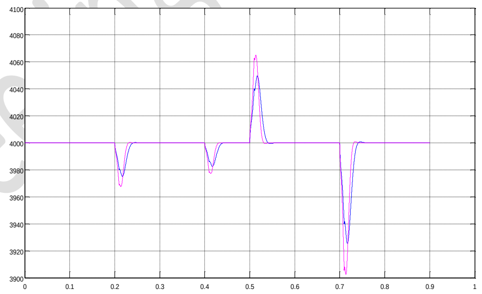
(c) SoC



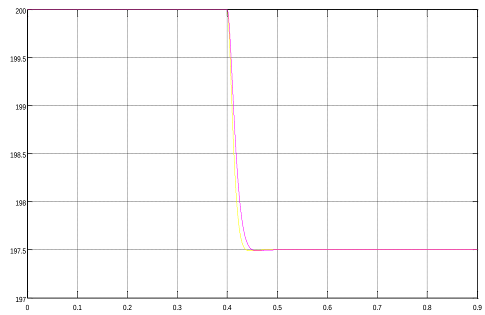
(d) Net Power



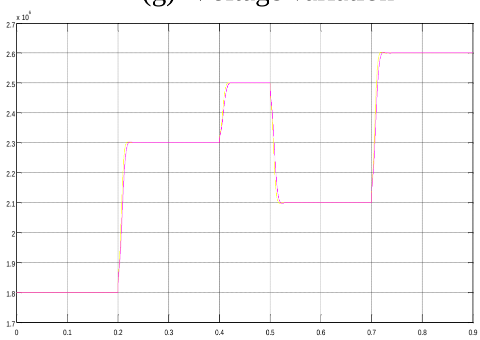
(e) Output Power



(f) DC link Voltage

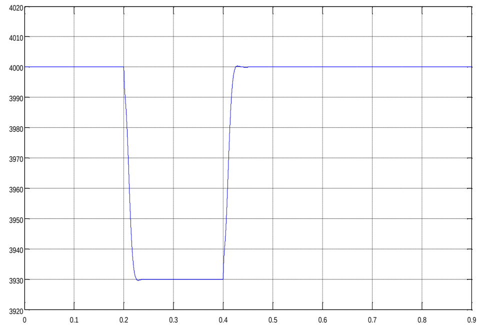


(g) Voltage variation

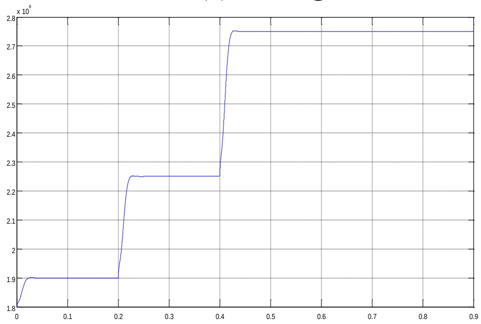


(h) VSC active power

Fig.5 Simulation results of the DC microgrid for case 1with fuzzy



(a) Voltage



(b) Power

Fig.6 Simulation results of DC bus #1 for case 2 with fuzzy

6. CONCLUSION

In this study, the suggested method of flexible voltage control is given better ability in DC distributed network for controlling the DES units. 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 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. The simulation outcomes rendered the fruitful response for improving the voltage stability in DC distributed network as compared to other existing techniques.

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Vol 11, Issue 1, Jan /2020
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