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Mathematical modeling and stability analysis of DC microgrid using SM hysteresis controller

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ABSTRACT

The use of dc microgrids in the residential and commercial complexes are increasing due to the high reliability, high efficacy, and easy integration with renewable energy sources. This paper presents the voltage stability of dc microgrid based on decentralized control architecture. Droop controllers cascaded with proportional integral (PI) controllers are being used for stability of dc microgrid. Droop control is not effective due to the error in steady state voltages and load power variations. Additionally, PI controllers cannot ensure global stability. It exhibits slower transient response and control parameters cannot be optimized with load power variations. To address the aforementioned limitation, sliding mode hysteresis control is proposed in this paper. Main advantages are high robustness, fast dynamic response and good stability for large load variations. To analyze the stability and dynamic performance of the proposed scheme, a system model is derived and its controllability, observability and stability are verified. Modeled dynamics are graphically plotted and presented. Detailed simulations are carried out to show the effectiveness of SM controller and results are compared with droop controller. The transient behavior on step load is also investigated and presented which shows the good performance of the proposed controller. A scaled down experimental setup of a source is also presented in the Appendix A.

1. Introduction

In the 19th century, the discussion between dc and ac distribution system had started [1–4]. The advantages of ac system were remained dominant up to 20th century. But due to depleting threat, high prices and ecological fear of burning fossil fuels and apprehensions over climatic changes, necessitates that a significant amount of power to be produced through renewable sources. Generating power close to the end power user reduces power losses associated in transmitting and hence increases system efficiency [1–3,5–13]. This inspires that microgrid is an effective way of power generation and consumption. In the near future, the distribution system will consist of some interconnected microgrids which will locally generate, store and consume power [9–14].

Solar, wind and fuel cell technologies are playing an important role in electric power generation among various renewable sources. Most of these sources are inherently designed for dc or dc friendly. In ac microgrid, the distribution system is ac. Therefore, a conversion stage is required to interconnect these sources with ac microgrid. The losses associated with these conversions decrease overall system efficiency. On the load side, many electrical loads are inherently designed for dc. A final conversion stage is required for these loads in ac microgrid. This conversion stage can be avoided if these loads are powered directly by dc. Electronics, lighting and variable frequency drives (VFDs) based load convert ac to dc before consuming it. Hence, efficiency can be improved if these loads are directly powered by dc. Resistive loads will operate at same output power if the root mean square (rms) value of ac supply is same as dc. Resistive loads can be powered both on ac and dc. Hence most of the loads can be directly powered by dc.

Growing demand of renewable sources and unavailability of the main supply grid necessitates energy storage. Normally used energy storage devices are battery and flywheel. The operation and control of these devices require dc power. An extra conversion stage is required to interface these devices with ac microgrid. This is not required if these devices are powered by dc.

Due to the above mentioned reasons, dc microgrids are becoming popular in the residential complex, data centers [15] and commercial buildings [16]. It is expected that the efficiency of dc

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distribution is to be 10–22% high than ac distribution [17]. Furthermore, reactive power compensation and frequency synchronization circuits are not required in dc distribution which is prominent in ac distribution. Due to the advantages mentioned above, dc microgrid is an attractive subject for the researchers [1–18]. DC microgrid faces certain problems for practical realization which are; (1) financial cost associated with the replacement of ac distribution lines with new dc lines (2) it is difficult to protect from dc because zero crossing is absent in dc system.

A generalized dc microgrid configuration [10] connecting different sources and loads is shown in Fig. 1. Sources and loads with dissimilar electrical characteristics are interconnected through power electronic converters (PECs). Main utility grid can be interconnected to dc microgrid through ac to dc PEC with bi-directional power flow ability. DC microgrid can be operated in two modes: (i) Grid connected mode: In this mode, shortfall of power in dc microgrid is shared by utility grid. The role of batteries can be considered idle because utility grid is responsible for maintaining stable bus voltage within the limits [11,14]. This mode is relatively simple because there is no need of complex bidirectional dc to dc controller to make decisions according to the state of charge (SOC) of batteries. Cost and maintenance cost of the batteries is also eliminated in this mode. (ii) Stand-alone Mode: In this mode of operation, utility grid is no more available. Batteries role for both power balance and voltage stability is very important in this case. The control objective of the battery interface converter is to maintain voltage stability and make decisions on the bases of battery's SOC [11,14]. If there is shortage of power and batteries are at low level, a non-renewable dc source is available for backup supply. For faraway sites, stand-alone microgrids can be cost effective.

Sources and energy storage are coordinated to provide consistent power to the loads. Normally, coordination control is divided in centralized and decentralized control. In centralized control, the controller collects system information using communication link, schedule the tasks based on the collected information and directs control decisions [1,9–10,12]. However, if the communication link is failed, it will degrade the system performance and reliability. This constraint can be avoided in decentralized control (droop control) [12,14]. Significant benefits are relaxed scalability and lesser cost. In this type of control, PEC operates on locally measured quantities. In [19–23], droop control stability is reported for ac microgrids. Extensively used droop control in conventional ac power system inspires its use in dc microgrid [24–27].

Linear controllers are used in cascaded connection with droop control for stability of dc microgrid. One of the main reasons to use these control techniques is easy implementation of tuning method in industrial applications. These are proportional integral (PI) type controllers. Regardless of the easiness in implementation of P controller it suffers steady state errors for the change in desired reference. Further, PI controlled converter suffers poor load power sharing due to the integral action where in most of the cases PI controllers do not attain stability [28,29]. PI controller also exhibits slower transient response.

The linear controller parameters are calculated using current specifications of the system [30,31]. These parameters vary with load and sources apply to the system. Hence it becomes difficult to optimize controller parameters for different operating conditions. Linear controllers cannot ensure global stability of the desired equilibrium state. Hence to use linear controllers for voltage stability is not feasible.

Sliding mode control (SMC) is proposed for voltage stability of dc microgrid in this paper. SM is used for the control of variable structure systems (VSSs) [32]. Properties of the SM include insensitive to the matched disturbances and robustness against model uncertainties. Furthermore, the implementation of SM controller is comparatively easy with the other methods used for nonlinear controller design. These properties attract its use in the dc microgrid application. Hence SMC is proposed for stability and better dynamic response [33].

Section 2 deals with the dc microgrid architecture. System dynamics are derived in Section 3. Further, controllability and observability is verified in Section 4. Section 5 deals with the lim-

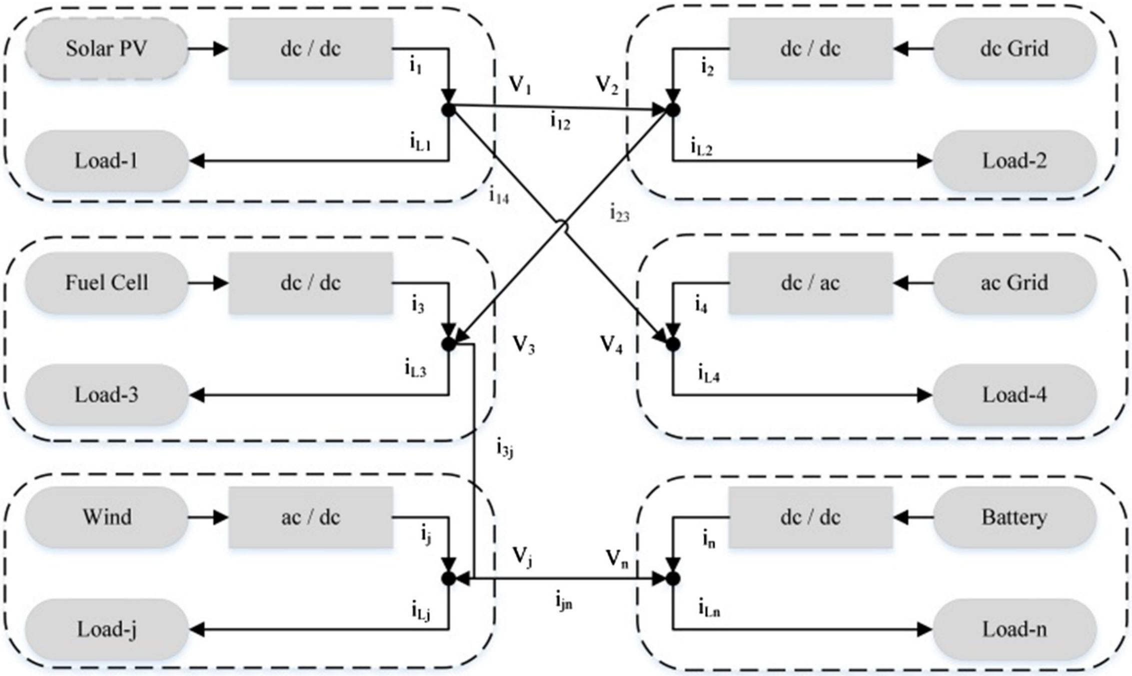

Fig. 1. Generic dc microgrid architecture.