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Impact of load dynamics and load sharing among distributed generations on stability and dynamic performance of islanded AC microgrids

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ABSTRACT

Microgrids comprising of inverter-interfaced distributed generation (IIDG) units can be subjected to a high penetration level of dynamic induction motor (IM) loads and rectifier interfaced active loads, which may act as constant power loads. Constant power loads present a negative incremental resistance leading to the degradation of stability. Whereas, the highly non-linear IM load, which couples voltage, supply frequency, active power and reactive power dynamics, challenges the stability of islanded AC microgrids (ACMGs). Further, the stability of these microgrids is also affected by the load sharing among IIDG units. To address the aforementioned difficulties, this paper investigates the impact of load dynamics and load sharing among IIDG units on the stability and dynamic performance of islanded ACMGs. To explore this, a full dynamical non-linear state-space model of a studied islanded AC microgrid with both static and dynamic IM loads has been developed in synchronous (DQ) reference frame. The developed non-linear state-space model is linearized around its steady-state operating point to analyze the small-signal stability. Selective modal analysis and time-domain simulation results have been presented to observe the impact of load dynamics as well as load sharing among IIDG units on the stability and dynamic performance of islanded ACMGs.

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1. Introduction

Renewable energy sources (RESs) based distributed generation (DG) units have received remarkable interest due to continuous exhaustion of fossil fuel reserves and environmental concerns [1]. However, these RESs based DG units produce fluctuating active power due to their intermittent nature. Further, the output of these DG units is either a DC or a variable frequency AC. Therefore, these DG units will be interfaced to the distribution network or the local loads through a front-end inverters. A recently evolved concept is to group a few of these inverter-interfaced distributed generation (IIDG) units and a cluster of loads together to form a small local power system, called an inverter-based or AC microgrid [2–18]. These AC microgrids (ACMGs) can be operated either in an island mode or in a grid connected mode of operation. Stability of ACMGs is not a critical issue in grid connected mode of operation as the stiff grid would be responsible for its stable operation. However, in the island mode of operation, it is an important concern due to the intermittent and low-inertia nature of IIDG units.

Stability of islanded ACMGs is considerably influenced by load dynamics due to the presence of low inertial IIDG units and poor damping of low-frequency modes associated with the droop controllers [2–18]. Therefore, the impact of resistive (R) and/or inductive (RL) load dynamics has been studied in [2–9]. It was found that the dominant low-frequency modes are very sensitive to the power-sharing controller parameters and network configuration, whereas, the medium and high-frequency modes are mainly affected by the inner loop controllers, network dynamics and load dynamics. The impact of constant power load (CPL) and rectifier interfaced active load (RIAL), individually, revealed that the presence of RIAL caused an increase in the low-frequency modes, whereas, the ACMG is destabilized due to the CPL dynamics [10–13].

The impedance mismatch between IIDG units and induction motor (IM) loads, addressed in [14,15], showed that the presence of IM load causes medium frequency instabilities in the range of tens to a few hundreds of Hz. The impact of multiple types of static loads including the combination of CPL and RIAL together, studied in [16–18], unveiled that the interaction between the control loops

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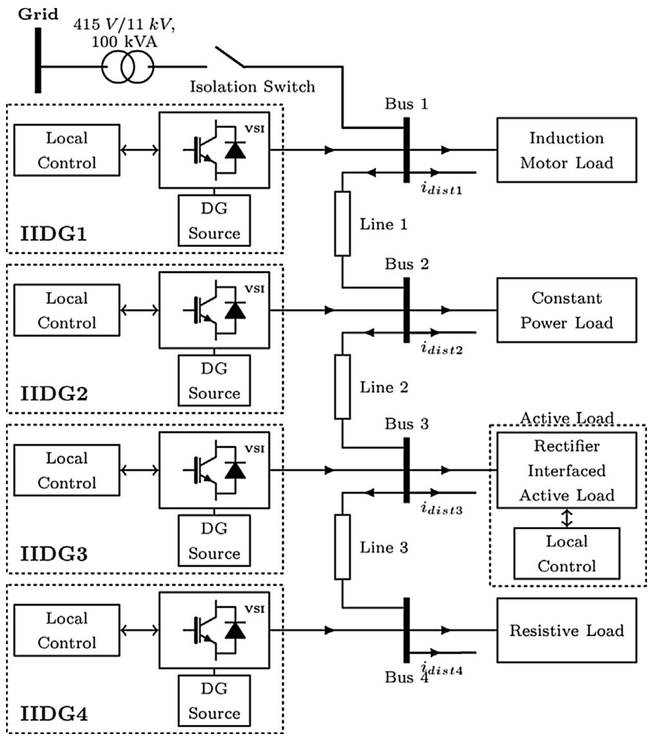

Fig. 1. Schematic diagram of the studied AC microgrid system.

of RIAL and the IIDG units cause instability in these ACMGs. Apart from multiple types of static loads, the dynamic induction motor (IM) load may also be present in ACMGs. Moreover, the above studies have not investigated the impact of load sharing among IIDG units on the stability and dynamic performance of these ACMGs. Therefore, this paper aims to present the impact of load dynamics as well as load sharing among IIDG units on the stability and dynamic performance of the islanded ACMGs.

To examine the aforementioned objectives, a studied islanded ACMG system feeding various static loads and dynamic induction motor (IM) load, as shown in Fig. 1, has been considered. To analyze the small-signal stability, a full dynamical non-linear state-space model of the islanded ACMG, represented in synchronous (DQ) reference frame, has been developed and linearized around its steady-state operating point. Based on the linearized and non-linear models, selective modal analysis and time-domain simulation, respectively, have been performed to observe the impact of load sharing among IIDG units and load dynamics on the stability and dynamic performance of islanded ACMGs. The impact of load sharing has been studied by considering the two cases (i) when all the IIDG units are of equal power ratings (ii) when all the IIDG units are of unequal power ratings.

The rest of the paper is organized as follows. In Section 2, the full dynamical non-linear state-space model of the studied islanded ACMG system, represented in synchronous (DQ) reference frame, has been developed and linearized around its steady-state operating point. Section 3 presents selective modal analysis and time-domain simulation results as well as discussions. Conclusions are drawn in Section 4.

2. Dynamic model of AC microgrid with static and dynamic loads

Fig. 1 shows a schematic diagram of a studied AC microgrid (ACMG) system operating at a frequency of 50 Hz and voltage of 230 V (per phase RMS). The ACMG system includes four inverter-interfaced DG (IIDG) units, three lines and locally connected loads viz. resistive (R)/inductive (RL), rectifier interfaced active load (RIAL), passive model of RIAL i.e., constant power load (CPL) and dynamic induction motor (IM) load. Each IIDG unit is represented by a DG source, which may be a photo-voltaic, micro-turbine or a fuel cell generator, etc., a voltage source inverter (VSI) and a local controller, which is composed of power sharing, voltage and current controllers. The microgrid is interfaced to the main utility grid bus through an isolation switch and a 415-V/11-kV step-up transformer at its point of common coupling (PC), which is bus-1. The ACMG can be operated either in the islanded mode or the grid-connected mode based on the status of isolation switch. Islanded operation is realized by opening the isolating switch, which disconnects the microgrid from the main grid, as shown in Fig. 1. In the island mode of operation, IIDG units are responsible for maintaining the system frequency and voltage along with meeting the total power demand. The parameters of the studied ACMG system are given in Appendix A. The inverter parameters are referred from [2,3], while, the RIAL parameters are refereed from [12,13]. The parameters of 400 V, 10 hp, 7.5 kW dynamic induction motor load have been referred from [19]. The active power droop gains, m_{P1}, m_{P2}, m_{P3} and m_{P4}, have been obtained considering the maximum and minimum allowable frequencies to be 50.5 Hz and 49.5 Hz, respectively. Whereas, the reactive power droop gains, n_{Q1}, n_{Q2}, n_{Q3} and n_{Q4}, have been obtained assuming the minimum and maximum allowable voltages to be 225 V and 235 V (per phase), respectively.

The complete dynamical non-linear model of the studied ACMG system has been developed in a synchronously rotating frame (dq) from the generalized modeling given in [3]. This modeling divides the whole ACMG system into three sub-modules i.e., generation sub-module, network sub-module and load sub-modules (passive, active and dynamic), virtually. The transformation used to convert from the ABC reference frame to the DQ reference frame is a variant of the Park-Clark transformation [20], as shown in (1). It is the power invariant and the D-axis is plotted on the horizontal axis of a two axis plot.

$$[T_{dq} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos(\omega t+\theta) & \cos\left(\omega t+\theta-\frac{2\pi}{3}\right) & \cos\left(\omega t+\theta+\frac{2\pi}{3}\right) \\ -\sin(\omega t+\theta) & -\sin\left(\omega t+\theta-\frac{2\pi}{3}\right) & -\sin\left(\omega t+\theta+\frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (1)$$

The IIDG unit model consists of power processing and local control sections. The power processing section includes a three-leg VSI,

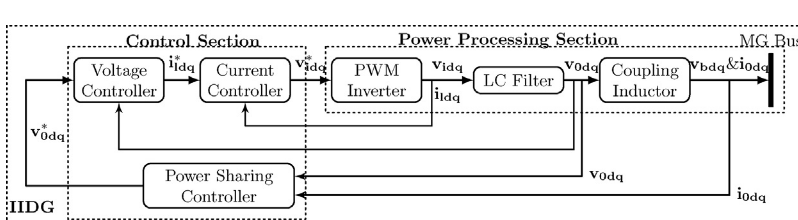

Fig. 2. Power processing and control sections of IIDG unit.

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