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Intelligent control strategy in the islanded network of a solar PV microgrid

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ABSTRACT

In the islanded mode of MG network, due to the lack of inertia and under performance of PI based inverter control, variation in power and frequency level can be expected more during the transient conditions as compared to the grid connected mode. Thus, in this study, a Particle Swarm Optimization (PSO) algorithm with the proposed cost function was implemented in the Grid-support grid-forming (GsGfm) type Voltage Source Inverter (VSI) of the DG sources (solar PV and battery unit) for the islanded photovoltaic (PV) based MG model (built in Matlab-Simulink software environment) to reduce the variation in power and frequency level. The islanded MG model was also implemented with a reverse droop based on virtual impedance control strategy for the VSI and power management control strategy to ensure better power sharing among DG sources with regulation of frequency level and power balance with co-ordinated control operation of DG sources. Implementation of PSO based intelligent control strategy for the inverters of DG units, showed substantial improvement in the performance of controller in terms of reduced settling time and overshoot in power level along with the significant reduction of the power variation and frequency variation during the transient conditions (change in load and change in solar irradiance of PV units). Also proposed PSO control strategy ensured the frequency level to be within the acceptable operating range (Australian network standard) in the islanded MG network.

1. Introduction

MG provides secure and reliable energy supply to the facilities of critical load and promotes energy independence for the community. MG can be operated in either grid connected or islanded mode of operation [1,2]. In either mode of operation, it is required to maintain power balance and regulation of frequency level in the MG network [3]. As compared to the grid connected mode of MG operation, maintaining power balance and regulation of frequency level is a big challenge in the islanded mode [4,5]. A coordinated control operation with equal sharing of power among DG sources and power balance with regulation of frequency level in islanded MG network can be ensured by means of implementing appropriate power sharing and power management control strategies in the MG power system [3]. Similarly as compared to the grid connected mode, variation in power and frequency level can be expected more in the islanded MG network. This is due to the lack of inertia and under performance of PI based controller of DG sources during the transient conditions in the islanded MG network [3]. In such a scenario, implementation of PSO based intelligent control strategy can be considered for the MG model to minimize the variation in power and frequency level during the transient conditions in the islanded MG network. PSO control technique is widely used for MG control applications and most of the research works [6–10] have been focused on optimizing control parameters of the inverter controller to get an optimized power flow, regulation of voltage and frequency level, improving dynamic response and stability of the MG system. Also some of the research works have been done by using multi objective PSO (MOPSO) [11] and advanced or modified PSO (MPSO) algorithm [12] applied for solving the problem constraints in relation to the energy and operation management of MG.

In most of the research works [13–17], for power sharing among the DG sources in low voltage (LV) MG network, the reverse droop with virtual impedance control was implemented with either grid feeding (P–Q or current control) or grid forming type (voltage control) VSI of DG sources. However in this study, a reverse droop with virtual impedance (resistor) control has been implemented with GsGfm type VSI for the DG sources in MG model (built in the

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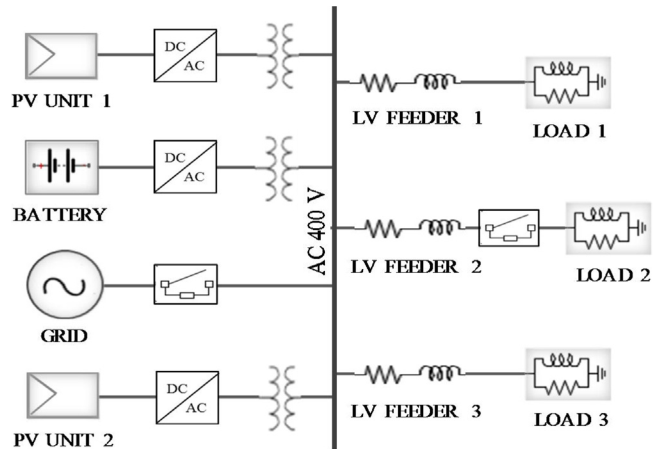

Fig. 1. Typical MG model configuration.

Table 1
Specification details of DC and AC equipment.

DC equipment	Voltage (V)	Power (KW)
PV unit 1	500	210
PV unit 2	500	210
PV-DC boost converter	280/500	300
Battery storage	300	100/h
Battery-DC buck-boost converter	260/500	200
AC equipment	**Rating (MVA)**	**Voltage (KV)**
PV inverter	0.3	0.26
PV inverter interfacing transformer	0.3	0.26/0.4
Battery inverter	0.3	0.26
Battery inverter interfacing transformer	0.3	0.26/0.4

MATLAB-SIMULINK), since this type of VSI is more flexible and has the ability to be operated in either mode of MG operation without modifying its control configuration. Another novelty in this work is that the PSO algorithm with proposed cost function was also implemented to optimize the power flow and power variation from the DG units and minimize the frequency variation during the transient conditions. The PQ factors in the islanded MG network has been analyzed with the transient conditions like change in load and change in solar irradiance level of the PV units, since both the scenarios are the important factors that could be frequently encountered in a real time MG network and they could cause negative impact over the PQ factors in the islanded MG network.

This paper is organized as follows; Section 2 describes the detail of MG model configuration, control configuration of the VSI, proposed power management control strategies for the MG model, and detail of allowable operating frequency range as per the Network standard, Section 3 outlines the method of optimization which includes the formulation of cost function, setting parameters and process steps of the proposed PSO algorithm, Section 4 demonstrates the optimization analysis, results and discussion, and Section 5 concludes the outcome of this study.

2. MG model configuration

The configuration of a typical AC MG network model which is operating at voltage and frequency level of 400 V and 50 Hz is shown in Fig. 1. The specification details of each element which are used in the proposed MG model is given in Tables 1 and 2 respectively.

Table 2
LV feeder and load details.

LV feeders	P-Load (KW)	Q-Load (KVAR)	Impedance ratio (R/X)
Feeder 1	70	9	6.37
Feeder 2	110	19	6.37
Feeder 3	270	30	6.37

2.1. *Control configuration of Voltage Source Inverter (VSI)*

In this proposed MG model, Grid-support grid-forming (GsGfm) type VSI has been considered for both the PV units and battery storage. GsGfm type VSI acts as a droop controlled voltage source that adjusts voltage and frequency reference, according to the measured active (P) and reactive (Q) power level in the MG network [18,19]. Control configuration of VSI which is shown in Fig. 2 includes three main control loops namely; droop control loop, virtual impedance control with voltage control loop, and current control loop. Considering the resistive nature (R/X ratio 6.37) of LV network in the proposed MG model, a reverse droop control strategies, expressed as per Eqs. (1) and (2) [13,20] have been considered for VSI droop control of DG units.

$$\omega** = \omega_n + K_Q(Q* - Q) \tag{1}$$

$$E** = V_n - K_P(P* - P) \tag{2}$$

$$K_P = \frac{\Delta(\omega)_{max}}{P_{max}} \tag{3}$$

$$K_Q = \frac{\Delta(V)_{max}}{Q_{max}} \tag{4}$$

where P and Q are the actual active and reactive power, P^* and Q^* are the active and reactive power reference, ω_n and V_n are the nominal value of angular frequency (rad/s) and voltage amplitude (v), ω^{**} and E^{**} are the reference angular frequency and voltage magnitude, K_P and K_Q are the droop coefficients of active and reactive power, $\Delta\omega_{max}$ and ΔV_{max} are the maximum angular frequency and voltage deviations, P_{max} and Q_{max} are the maximum real and reactive power delivered by the DG sources.

In this study, in order to improve the power sharing accuracy, a virtual resistor has been implemented in virtual impedance control loop and the voltage drop across the virtual impedance (resistor) loop can be expressed as per Eq. (5) [13,18,20]. The value of virtual resistor (R_D) is determined in such a way to ensure minimum voltage drop (less than 5% of nominal value) [20].

$$V_{O=}i_{d*}R_D \tag{5}$$

where V_O is the voltage drop across virtual resistor, R_D is the virtual impedance (resistor), and i_d is the inverter output current. The expression of modified reference voltage signal can be written as per Eq. (6) and the expression of output reference currents from the voltage controller can be written as per Eqs. (7) and (8) respectively.

$$V_{ref(M)} = (E^{**} - V_O) \tag{6}$$

$$I_{d\text{-}ref} = (V_{ref(M)} - V_d)(kp + \frac{Ki}{s}) \tag{7}$$

$$I_{q\text{-}ref} = -(V_q - V_O)(kp + \frac{Ki}{s}) \tag{8}$$

where $V_{ref(M)}$ is the modified voltage reference signal, $i_{d\text{-}ref}$ and $i_{q\text{-}ref}$ are the output reference current components (d–q axis), V_d and V_q are the voltage components (d–q axis), Kp and Ki are the proportional and integral gain of PI controller. As per the control configuration of current control loop with the inclusion of feed forward voltage and inverter reference current feed forward facility, output voltage signals from the current control loop of VSI can be