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A review of reactive power compensation techniques in microgrids

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ABSTRACT

Renewable energy based Distributed Generation (DG) has been the solution to researchers to combat the problem of increasing load. In DG based microgrids, the loads and generators are in the close vicinity to aid continuous power supply. However, the power electronic interfacing towards DG systems gives rise to some of the serious power quality problems, such as, the reactive power compensation and the generation of harmonics that pollutes the power distribution system. Reactive power compensation is becoming a challenging task to sustain an acceptable degree of power quality in microgrids due to tightly coupled generation and distribution. Therefore, current research is to cope up with the expanding microgrid system and mitigation of these concerned issues. Recent trends are geared towards the realization of multitasking devices to tackle several power quality problems simultaneously. Hence, the objective of this paper is to present an overview of a microgrid and its modeling utilizing the actual environmental data. Subsequently, the challenges and power quality issues faced in the microgrid are observed and succeeded by a review of compensation methods against these concerns using various control techniques, algorithms, and devices.

1. Introduction

Electrical practices for the entire power system industry are tremendously changing and these progressions will mark an evolution of new concepts and strategies in the future, particularly concerning the planning and operation of the power systems. The detrimental effects such as aging, hazardous atmospheric changes associated with conventional energy sources make renewable energy based distributed generation to take a lead in future power generation. Distributed generators like solar, the wind, biomass, fuel cells and microturbines will give significant momentum for power generation in the coming future. A microgrid (MG) is a small scale power network designed for a low voltage distribution system to provide a power supply for a small community/island [1,2]. The microgrid operates in two operating modes; grid connected (connected to the conventional grid to allow power exchange) and individual/islanded mode (independent of the conventional grid). The major elements of MG have DG units like PV and wind generators, storage devices, different loads, and power controllers. The interconnection of these DGs to the conventional grid is normally achieved by employing power converters. The use of power converters offers vast benefits like optimal operation and flexible control [3]. However, this power electronic interfacing creates a plethora of power quality problems [4–7]. Power quality problems in a microgrid are of a large variety such as voltage harmonics, voltage sags, voltage swells, voltage unbalance, current harmonics, reactive power compensation (RPC), current unbalance and circulation of neutral currents, impulse transients, and interruptions [8]. Among these, reactive power compensation is considered as a major concern in this paper.

The power system operates on AC system and most of the loads used in our daily life demand reactive power. Thus reactive power or VAR compensation is characterized as the administration of reactive energy to enhance the performance of the AC system. The issue of reactive power compensation is seen from two ways: load and voltage support. The aim is to achieve an improved power factor and real power balance from the load point of view, while the voltage support is primarily necessary to reduce voltage fluctuations at a given terminal of a transmission or distribution line. In both the cases, the reactive power that flows through the microgrid has to be effectively controlled and compensated.

In islanded operating condition, the microgrid has to maintain the reactive power balance independently due to the absence of an infinite bus. The firmly coupled generation and utilization along with the presence of non-dispatchable intermittent renewable power sources require reactive power support. Similarly, in a grid interconnected mode, the reactive power compensation is also found to be challenging due to linear and non-linear loads. This paper envisages reactive power issues of a microgrid in different conditions. In this regard, a microgrid is modeled and developed consisting of renewable energy sources such as PV and wind energy conversion system (WECS), and connected to a

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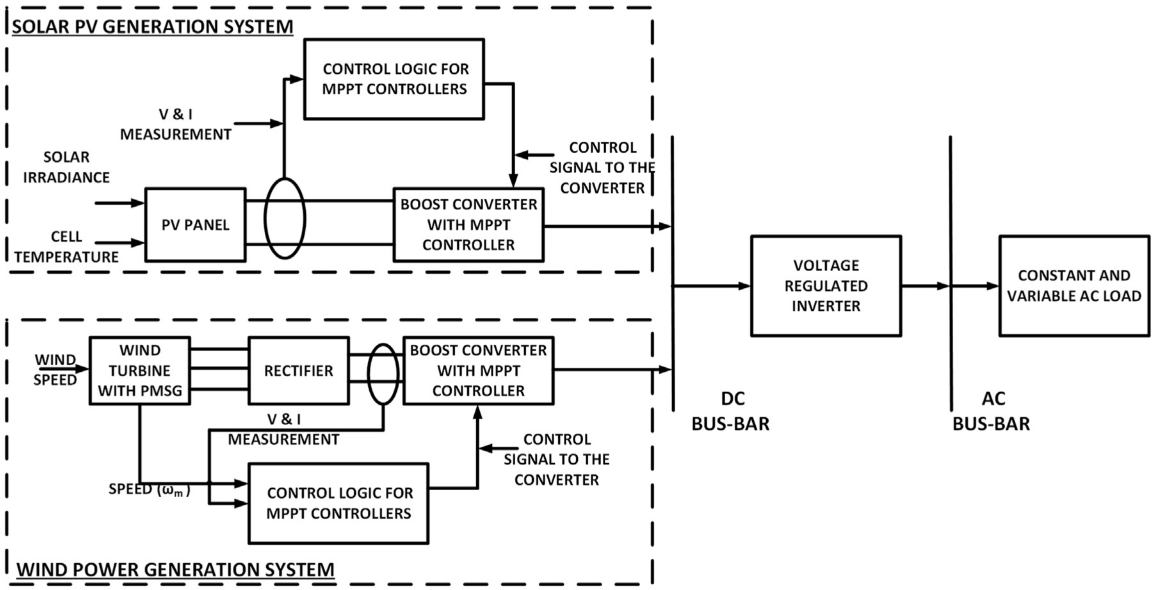

Fig. 1. Block diagram of microgrid.

load. Maximum power point tracking (MPPT) controllers are employed for both PV and WECS. The power quality problems of the microgrid, when subjected to supply and load variations, is observed and presented in the next section. Further, a review of compensation methods against these issues using various control techniques, algorithms and devices are discussed.

2. Microgrid and its power quality issues

A system containing a microgrid with two DG sources connected to a common AC bus is shown in the Fig. 1. The two DG sources include a wind generation source and a PV generation source respectively. In this DG network, linear and nonlinear loads are connected to the AC bus [9]. The modeling of the each DG source is described below:

2.1. Modeling of PV modules in microgrid

A PV cell based on the two-diode model is considered in the construction of MG. The two-diode solar PV model yields more accurate results as compared to other existing models, especially at lower illumination levels [9]. Hence the two diode model is considered as an appropriate model for PV cell where its voltage and current are related by:

$$I{=}I_{ph} - I_{S1}\left[e\left[\frac{V + R_s{*}I}{N_1{*}V_t}\right] - 1\right] - I_{S2}\left[e\left[\frac{V + R_s{*}I}{N_2{*}V_t}\right] - 1\right] - \frac{V + R_s{*}I}{R_P} \quad (1)$$

where, I_{s1}, I_{s2} are the reverse saturation currents of the two diodes, V_t is the module thermal voltage, photo-generated current is I_{ph}, N_1, N_2 are the quality factors of the two diodes D_1, D_2 used in the two-diode model. R_s, R_p are the series and shunt resistances. Based on Eq. (1), a two-diode model is developed with equation based implementation in MATLAB. The simulations are carried out and the results are validated using the extracted circuit parameters from the data sheet [9]. The behavior of I-V and P-V curves of the two-diode model of a PV cell, when simulated in MATLAB, are shown in Fig. 2 (a). The electrical parameters obtained at standard test condition (STC) from simulation of the two diode model of PV panel are compared with the electrical parameters of the manufacturer datasheet given in Table 1. It can be seen from this table that the simulated parameters and the actual parameters of the solar cell (as given by the manufacturer) fairly coincide with each other.

The model consists of 14 panels connected in series with each other. The MPPT voltage and currents are 30.5 V & 8.05 A respectively and generate the output power of 245 W. As the output voltage is quite low it is required to step up PV system output voltage to the desired value of 415 V using a boost converter. An MPPT algorithm is used to track the MPP to control the boost converter with a duty cycle to achieve continuous desired output voltage. Perturb & Observe (P & O) algorithm is used to control the duty cycle of the boost converter so that MPPT is achieved. The resultant power rating of the modeled PV generator is 3 kW with 14 panels, each having a power rating of 245 W maximum as described in Table 1. Similarly, a 3 kW, 415 V wind-based generator is developed and connected to the MG.

2.2. Modeling of wind generator in microgrid

A wind generator with Permanent Magnet Synchronous Generator (PMSG) is considered as the second DER in the construction of MG. The wind turbine output power [10] is given by (2)

$$P_0 = \frac{1}{2}\rho A V_{wind}^3 C_p(\lambda,\ \theta) \quad (2)$$

where P_o represents the turbine output mechanical power, C_p is turbine power coefficient λ represents the rotor blade's tip speed ratio, θ represents the pitch angle of the blade, ρ represents the density of air, A represents the area swept by the blades of the turbine, V_{wind} represents the wind speed. The considered wind turbine parameters are R=1.25 m, length of blade L = 2.5 m, $A = 19.63\ m^2$, ρ=1.225 kg/m^2. The wind energy conversion system (WECS) is modeled and developed by using these parameters. To keep the output voltage constant at a desired value of 415 V, an MPPT controlled boost converter is employed. The duty cycle of the boost converter is controlled by Hill Climb Search (HCS) MPPT algorithm for the WECS.

An MG containing PV-wind MG generating system is implemented in a Simulink / MATLAB environment by appropriately modeling the DG sources, MPPT controllers, Boost converters and the DC bus. The developed system along with its controllers has been investigated for the real-time data. The actual environmental data like solar irradiation and wind profile have been collected with the help of a weather monitoring system of Birla Institute of Technology and Science, Hyderabad Campus, India. The record of solar insolation and wind speed in a day is observed as shown in Fig. 2 (b) & (c). The variations in the output voltage, active and reactive power flow in each DG is

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