International Journal of Applied Engineering Research ISSN 0973-4562 Volume 15, Number 4 (2020) pp. 352-357

Islanded and Grid-Connected Control in a Microgrid with Wind-PV Hybrid

Lucas O. Mogaka[1], George N. Nyakoe[2] and Michael J. Saulo[3]

[1]*Electrical Engineering, Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI) P.O. Box 62000-00200, City Square Nairobi, Kenya.*

[2]*Electrical Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT) P.O. Box 62000-00200, City Square Nairobi, Kenya.*

[3]*Electrical Engineering, Technical University of Mombasa (TUM) P. O. Box 90420, Mombasa, Kenya.*

Abstract

Microgrid (MG) operation and use of renewable energy sources (RESs) in power systems has received a lot of attention in the recent past as grids evolve towards smart grid operation. This is because they can operate either in grid-connected or islanded mode and ensure critical loads are supplied with power without interruption in case of a contingency. However, this concept comes with its associated challenges like timely and accurate islanding detection and proper control of voltages and frequency within islanded MG. This paper designs and analyzes a control scheme for an islanding operation of a MG supplied by RESs that can operate in grid connected mode and Islanded mode. The RESs controller system will detect an islanding situation and switch to a voltage control mode when the MG is cut off from the main grid. In grid connected mode, the interface control is designed to provide constant active and reactive power to the grid. When the grid is disconnected, an islanding detection algorithm will transfer the inverter into voltage control mode after proper resynchronization without affecting the critical loads. The performances of presented controller have been simulated and verified in the MATLAB/Simulink platform.

Keywords: Renewable energy sources, Grid connected mode, Islanded mode, Microgrid

1. INTRODUCTION

The gap between the generation and demand of the power provided by conventional sources of power is fast increasing due to increasing population and industrial development. The transmission capacity is also inadequate, the loads and generating centers are non-uniformly distributed. This calls for the embracing of available and potential distributed generation (DG) to meet the steadily increasing power demand [1] [2]. Among the DG sources, RESs are preferred due to most governments' policy to reduce greenhouse gases by adopting green sources of energy. Distributed Generation refers to any electric power production technology that is integrated within distribution systems, close to the point of use [3].

A MG is formed when DGs together with storage sources continue supplying loads within islanded section of the power grid. This enhances the reliability and quality of power supply, reduce the costs of transmission capacity expansion, relieve congestion on transmission facilities among many other advantages. Despite these merits, this approach has associated technical, design, integration, protection, social, policy and sustainability challenges [4]. These include ensuring stable operation of the MG, seamless switching between islanded and grid connected modes and the supply of quality power during a contingency. This calls for sophisticated design of converters that can seamlessly switch between the two modes in case of a contingency.

Additionally, there are some challenges that comes with the change in power grid paradigm from the conventional centralized power stations to the deregulated structure. One of the major concerns in this regard is islanding. Islanding is a condition in which a part of distribution network is supplied by a DG when the main grid is disconnected and isolated from the system. Controlled islanding can improve the reliability of the power system considerably. Moreover, in a system with high DG penetration, the disconnection can create several power quality problems. Hence in order to maximize the benefits from DG, it is advisable to go for intentional islanding. IEEE 1547 states that one of its tasks for future smart grid consideration is the implementation of intentional islanding. To implement a successful intentional island, the system should detect the islanding event, as soon as the grid gets disconnected. An efficient islanding detection algorithm is needed for this task.

Many works have been reported in the literature regarding the interface and control of the DG systems in grid connected and islanding modes. However, the choice of appropriate control strategy is important so as to meet the operation requirements of a given system [5] [6]. For seamless transition between grid connected and islanded mode, an additional converter is used as dispatch unit (DU) in [7]. In [8], a fuzzy logic-based intelligent control technique was proposed to maintain the frequency and DC (direct current)-link voltage stability for sudden changes in load or generation power in a standalone microgrid with RES based DGs and local loads. Two PLLs are used in [9] for smooth transition between the modes of operation by minimizing the error between the phases of the PLL. In [10], Linear Quadratic Regulator theory based bumpless transfer scheme is used to achieve smooth transition between the islanded mode and grid connected mode. A method for coordination of a single-phase MG composed by a number of sources using power line signaling (PLS) was proposed in [11]. In reference [12], the authors proposed a hybrid system for rural electrification for a load specification of 20 rural houses in Sandakan. Most RESs technologies that can be installed in a MG are not suitable for direct connection to the electrical network due to the characteristics of the energy produced. Therefore, power electronic interfaces are required. Inverter control is thus the main concern in MG operation [13]. One of the main challenges for smooth operation of MGs is the ability to transition seamlessly from grid connected mode to islanded mode and vice versa [14] [15]. Reference [16], discusses an islanding operation of VSCs. The switching between grid connected and islanded modes should be fast and seamless in order to protect the loads within the island.

This paper presents a control strategy for grid connected as well as islanding modes of operation in a MG supplied by photovoltaic (PV) and DFIG hybrid. The proposed control technique is designed such that, it can be operated in grid connected mode, islanded mode and seamlessly switch between the two modes when necessary. In grid connected mode all the DGs will connect as a constant power sources, here the MG voltage is maintained by the main grid [17]. In case of any fault in the main grid, then the MG will be disconnected from the main grid and operate in islanded mode.

The rest of this paper is organized as follows. Section 2 discusses the problem formulation while section 3 explains the proposed control strategy for the controller. Section 4 presents the simulation results and their discussions. Section 5 summarizes and concludes the paper.

2. PROBLEM FORMULATION

If the RESs like PV and Wind turbines are installed into utility grids directly then they can cause a variety of problems such as voltage rise and protection problems in the utility grid. In order to mitigate these challenges, the MG concept was introduced in power system [18]. MGs can operate in either grid-connected mode or islanding mode. This ability makes them suitable in the provision of emergency power to the connected loads during a contingency hence improving power delivery within the island. The main problem of MGs supplied with RESs includes the ability to quickly and accurately detect islanding condition occurrence, control the RESs in the islanded power system to stabilize the frequency and voltage so as to supply quality power to the connected loads and ability to seamlessly switch between grid-connected and islanded modes of operation.

In grid-connected operation mode, the RESs are normally operated in current controlled mode. The voltages and currents are controlled by the main grid. However, this is not the case for weak grids where terminal voltages of DGs do fluctuate. In this case, phase locked loop (PLL) is needed to evaluate the correct phase angle in order to avoid coupling effect between the system active and reactive power. This coupling effect is caused by the voltage fluctuations due to the weakness of the grid. Generally, the maximum active power that can be transferred to or from the grid in this mode is through a distribution line is minimal to maintain the system voltages within limits. When connection to the main grid is lost, the RESs supplying the islanded MG are supposed to operate in voltage control mode. The DGs should control both voltage and frequency within the region and supply power to the loads within the island.

3. PROPOSED CONTROL STRATEGY

Figure 1 shows the single line diagram of the proposed control strategy in a MG. The system consists of PV generator equipped with a Maximum Power Point Tracker (MPPT) and doubly fed induction generator (DFIG) wind RESs. Located at the Point of Common Coupling (PCC), is a static transfer switch (STS) that is controlled by the DG controllers. A battery is used to supply real and reactive power within pre-specified limits since the RESs produce power intermittently.

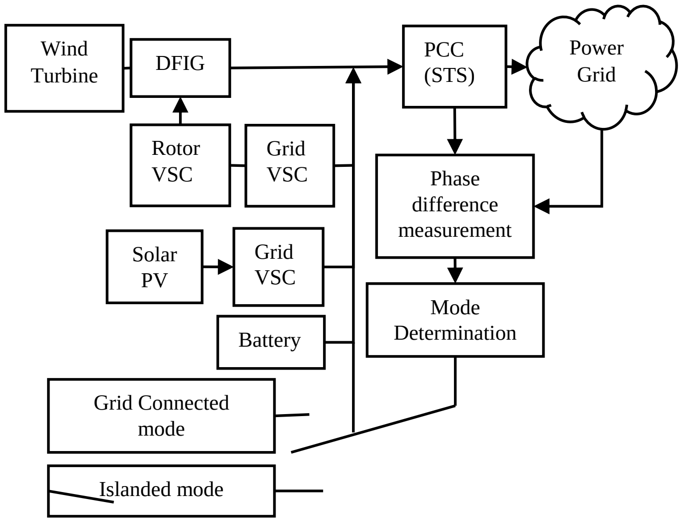

Figure 1: Proposed Control Strategy

During normal operating condition, the MG is operated in grid connected mode. However, in case of a contingency upstream, the MG is isolated from the main grid by opening the STS. When the fault is cleared, the islanded MG is re-synchronized to the main grid by operating STS. The RESs in the MG has a voltage source converter (VSC) connected with low pass filter L_f, R_f and C at its ac output side. The dc side is connected to the RES. Equation 1 and 2 below shows the dynamic equation of a DFIG RES.

$$\frac{J}{n_p}\frac{d\omega_r}{dt} = T_m - T_{em} \tag{1}$$

$$T_{em} = n_p L_m\left(i_{qs}i_{dr} - i_{ds}i_{qr}\right) \tag{2}$$

Where L is the inductance, T_m is the mechanical torque and T_{em} is the electromagnetic torque. Figure 2 below is an equivalent diagram of a PV cell [19].

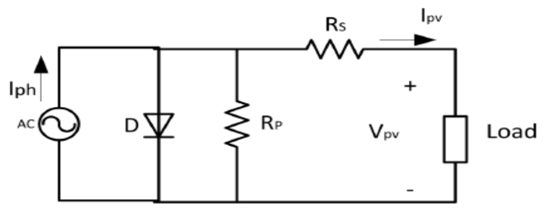

Figure 2: Equivalent diagram of PV cell

The output current generated from a PV array can be expressed by equation 3 below.

$$I_{pv} = n_p I_{ph} - n_p I_{sat} * \left[exp^{\left(\left(\frac{q}{AKT}\right)\left(\frac{V_{pv}}{n_s}+I_{pv}R_s\right)\right)-1} \right] \quad (3)$$

Where n_p is the number of parallel cells, I_{ph} is the photocurrent, I_{sat} is the module reverse saturation current, q is the electron charge, A is the ideality factor, K is the Boltzman constant, T is the surface temperature of the PV, n_s is the number of cells in series and R_s the series resistance of a PV cell.

3.1 Grid connected mode

This mode is activated whenever the fault is cleared in the main grid. Before switching to grid connected mode, the MG voltage is resynchronized with the main grid voltage first before closing the STS. The RESs supplies the constant active and reactive power to the main grid which is the current control mode in stiff synchronization with the grid. The voltage and frequency are controlled from the main grid at the PCC. The real and reactive power in this case is represented by the following equations;

$$P = \frac{3}{2} V_{gd} i_d \quad (4)$$

$$Q = -\frac{3}{2} V_{gd} i_d \quad (5)$$

Where *id* and *iq* are the components of the current in the dq axis and *Vgd* is the maximum value of the voltage at the PCC.

3.2 Islanded Mode

In this case, the main grid is lost and hence voltages and frequency are not externally controlled. The controller then automatically switches to voltage control mode to ensure quality power is supplied to the connected loads within the island. The wind and solar RESs actively participates in voltage and frequency regulation.

3.3 Synchronization and Transfer between grid connected and islanded modes

The phase difference between the MG and the main power grid is measured at this stage. An islanded condition is detected when the phase difference exceeds the set threshold. On the other hand, when the fault is cleared and the MG need to be grid connected, the MG need to be synchronized to the main power grid before reconnection. This is achieved by first measuring the PCC voltage and frequencies. Synchronization starts when the voltage magnitude differences between the main grid and the islanded MG is zero. Figure 3 below is a sketch of the synchronization controller [16].

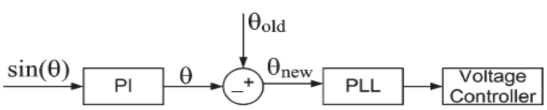

Figure 3: Synchronization Controller

The phase difference θ between the voltages of the grid and inverter can be expressed by equation 6 and 7 below.

$$\theta = \angle V_G - \angle V_I \quad (6)$$

$$\sin(\theta) = \frac{\frac{4}{3}g + \frac{2}{3}k}{\sqrt{3}} \quad (7)$$

Where

$$k = \frac{3}{2}\cos\theta \quad (8)$$

and

$$g = \frac{3}{4}\left[-\cos\theta + \sqrt{3}\sin\theta\right] \quad (9)$$

Figure 4 below shows the proposed flow chart for this approach.

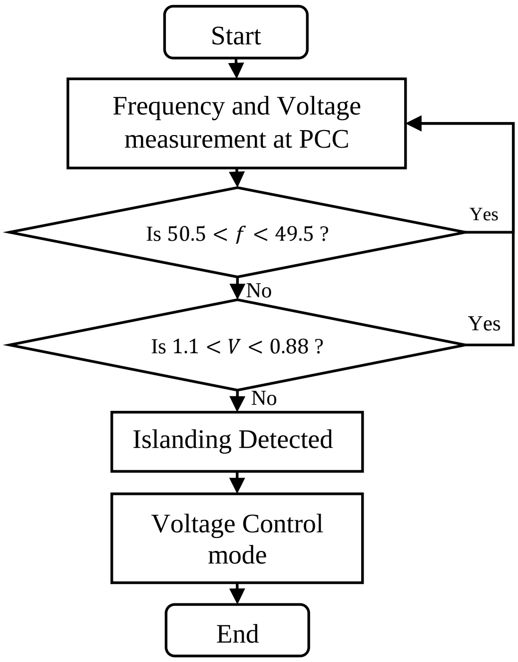

Figure 4: Proposed Flow Chart

Both frequency and voltage magnitudes are used in islanding condition detection in this study. The signal is then sent to the controller to switch the inverter to the suitable interface control mode.

4. SIMULATION RESULTS AND DISCUSSION

The performance of the system in grid connected and islanding mode of operation is analyzed using the simulated system in MATLAB/SIMULINK platform. The simulated system is shown in Figure 5. The inverter is operating with unity power factor while delivering power to the load. A parallel RLC load is connected to the system. The rest of the system parameters are given in table 1.

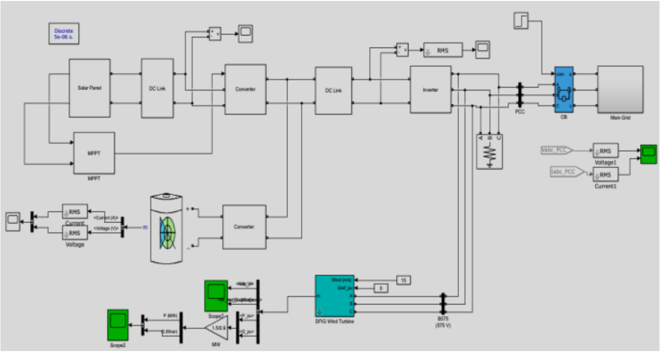

Figure 5: Simulated System

Table 1: System Parameter Settings

	Parameter	Value
1	System Voltage	415V (L-L)
2	Solar PV Rating	20 kVA
3	DFIG Rating	1.5 MVA
4	Line Impedance	1.334 Ohm, 3 mH
5	LC Filter (L_f, R_f and C)	6mH, 0.15Ω, 50µfarads
6	DC bus voltage of each DG	1150 V
7	Switching Frequency of each RES	3150 Hz

The DFIG wind generator settings was set as shown in table 2 below.

Table 2: Wind turbine parameter settings

Parameter	Value (p.u)
Rotor resistance (R_r)	0.016
Stator resistance (S_r)	0.023
Rotor leakage reactance (X_{lr})	0.160
Stator leakage reactance (X_{ls})	0.18
Magnetizing reactance (X_m)	2.90
Cp, max	0.43

The simulation was initially operated in grid-connected mode without a contingency upstream. The simulation was done for 0.3 seconds and the grid is disconnected at 0.15 seconds. The simulated results are shown in Figures 6-12.

Figures 6 and 7 shows the voltages and currents measured at the PCC before and after grid disconnection. The voltage profile at PV and DFIG converters is shown in figure 9 and 12 respectively.

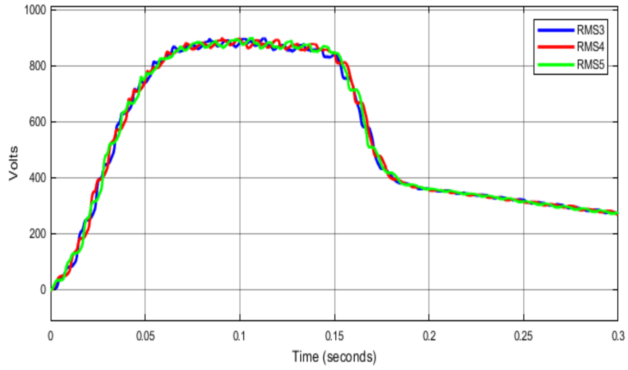

Figure 6: PCC Voltage

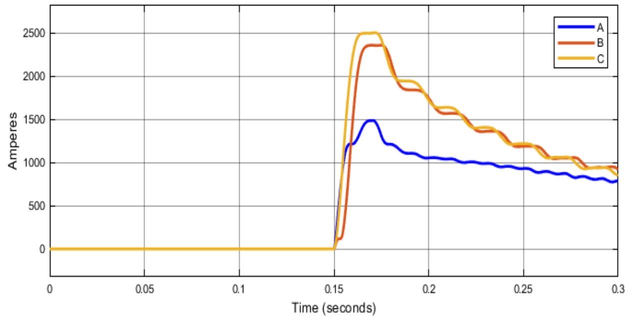

Figure 7: PCC Current

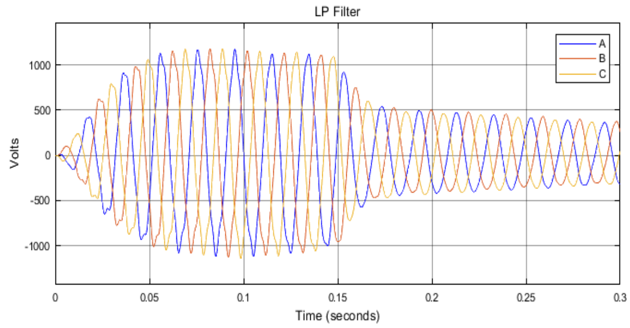

Figure 8: Low Pass Filter Voltage Measurement

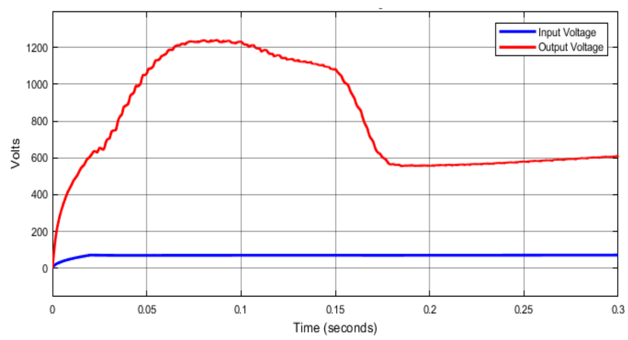

Figure 9: PV Converter Voltages

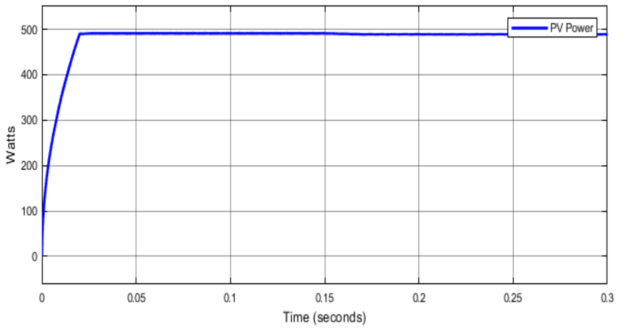

Figure 10: PV Power

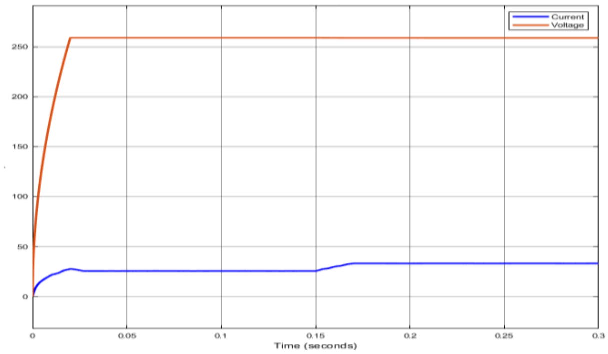

Figure 11: Battery Output

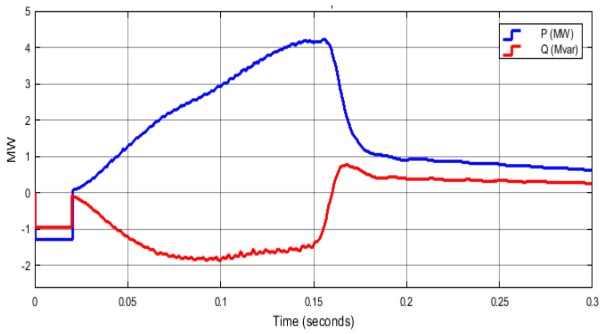

Figure 12: DFIG Output

Islanding detection algorithm continuously monitors the variations in the frequency and voltage at the PCC. After the grid gets disconnected at 0.15sec, the converter automatically switches to voltage control mode. As it can be observed from the results above, the control strategy changes from current controlled form of voltage Controlled form during islanding condition. The voltage deviates from its standard allowable values immediately the islanding condition was detected. Throughout this condition the control mode changes.

In grid connected mode, the converter operates in the current mode and supply constant power to the grid. The system voltage and frequency were controlled by the utility grid. In this mode the PV power is 495W while that of DFIG generator varies up to 4 MW. This is shown in figure 10 and 12 above.

For a constant preset current output, once islanding occurs, the output power and voltage becomes a function of the load. It is also observed that, the performance of constant power-controlled interface during islanding operation is different from the constant current controlled interface.

5. CONCLUSION

In this paper, a system controller that can smoothly and seamlessly switch between grid-connected and operation modes was designed and simulated. The performance of proposed MG under disturbances, during grid connected mode, islanded mode and resynchronization of the MG to main grid was tested. It is shown that the response of the proposed control schemes is capable of maintaining the voltages and currents within permissible levels during grid connected and islanding operation modes for a MG supplied with PV-DFIG hybrid.

ACKNOWLEDGEMENT

This research was supported by the Pan African University Institute for Basic Sciences, Technology and Innovation in the form of a postgraduate student research funding.

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