Grid Synchronization of Wind Based Microgrid

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Abstract-This paper is on the synchronization of a wind based microgrid with main grid. The wind power is generated using the permanent magnet brushless DC generator (PMBLDCG) and the MPPT (Maximum Power Point Tracking) is executed with P&O (perturb & Observe) approach to extract the maximum power from the wind generation. This power is fed to the AC load using a voltage source inverter (VSI) through the battery bank (BSS) at DC link. The control algorithm operates in standalone mode and grid connected mode. It can switch in islanded and grid connected modes seamlessly according to the wind conditions. In standalone mode, this wind power is fed to the load through a VSI, during low wind conditions, the battery discharges itself to fulfill the load demand. After that, the grid is connected to give power to the load during low wind conditions, and for this, control algorithm operates in grid connected mode. Therefore, the control algorithm switches from voltage control to current control mode to provide smooth synchronization and vise versa at de-synchronization. A MATLABI Simulink model is developed to simulate the system performance during wind variations, and during synchronization and desynchronization.

Keywords-Microgrid; PMBLDCG; Standalone; Synchronization; Grid; VSI; Voltage Control; Current Control

I. INTRODUCTION

Modern advanced civilization is standing on the feet of electrical energy. This energy is generated mainly from the conventional resources based on fossil fuels. However, in this world of technical advancement and development only conventional energy resources are not sufficient. Therefore, renewable resources have also been explored and research on these fields is also getting maturity [1-2]. The local demand of energy is fulfilled with distributed energy generation, and microgrid is one of such ways that consists of resources like wind, solar, hydro, and biogas etc. [3-5]. These sources increase energy efficiency, reduce losses, enhance the robustness of such sources [6]. They can also feed the extra power to the utility grid through power electronics converters. Therefore, the converters of these microgrid systems have to work in both standalone and grid connected modes.

Various control algorithms for standalone system have been used in previous literature to improve the power quality, stability and performance of such systems [7-9]. The control algorithms of grid connected system are also defined in [10- 1 1]. These control algorithms generate the PWM pulses for the switching of the converter according to the operating mode. These converters are being used for smooth transition between grid connected and standalone modes to transfer the energy coming from the distributed generation or microgrids. It must be transients free during transfer. Some work in this field is reported in the literature [12- 15].

These control algorithms are based on voltage control and current control approach. In [12], a thorough control description is given on grid connected, standalone and rectifier modes for multifunctional PWM converter. It is given with the PLL (Phase Lock Loop) approach to extract grid angle. An indirect current control method is used for seamless transfer of distributed generation system for intentional islanding in [13]. It is also provided LCL filter design. Karimi [14] has introduced universal integrated synchronization and control (UISC) for single phase converter operation in both modes of operation and also reduced the requirement of PLL. In [15], a control strategy is explained with single control structure including both the modes of operation and smooth transition without PLL approach.

In this work, the control algorithm switches in two modes in voltage and current control modes according to the availability of wind. The microgrid works in standalone mode when sufficient wind power is available and excess power is stored in battery during high winds. When wind generation is small and demand is increased the battery starts exhausting and if the grid is available the synchronization process takes place seamlessly. Now the converter starts operating in current control mode from the voltage control mode. Here SOG! (Second Order Generalized Integrator) based PLL (Phase Lock Loop) is used to extract the grid angle.

II. SYSTEM CONFIGURATION

The proposed microgrid consists of PMBLDC (Permanent Magnet Brushless DC) generator based wind system, connected to the DC link through DC-DC boost converter to provide MPPT to the wind power as shown in Fig.l. A diode bridge rectifier is used at generator terminals to convert wind power into DC power. This boosted power comes to the battery bank at DC link

A VSI is used to transfer the DC power to AC load during islanding mode. This system is connected with the utility grid when grid is available through STS (Static Transfer Switch). Linear/ nonlinear loads, interfacing inductor (Lf) and filter capacitor (C) are connected at point of common coupling (PCC).

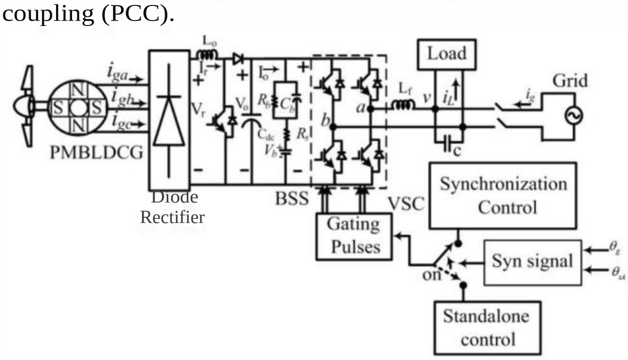


Fig. 1: Schematic diagram of wind based microgrid with utility grid

III. CONTROL STRATEGIES FOR MICROGRID SYNCHRONIZATION WITH UTILITY GRID

The control of the inverter needs to change according to the various operating modes. In standalone mode it operates in voltage control mode and in grid operating condition it works in current control mode. During synchronization and de-synchronization process this control algorithm has ability to switch between both the modes. This swift between two control algorithms must be very smooth to avoid grid current and voltage transients.

A. *Control for Standalone Mode of Operation*

In standalone mode of operation, the microgrid VSI PWM pulses are generated from voltage control algorithm as shown in Fig.2 (a). The reference sine voltage is generated with reference voltage magnitude and frequency (V^*, ω_0) and is compared with feedback voltage to generate PWM pulses for voltage source inverter.

B. *Control for Grid Connected Mode of Operation*

In grid connected operation the control algorithm works on indirect current control algorithm with power factor correction (PFC) mode as shown in Fig. 2 (a). The fundamental load current component for phase (ia) is extracted using SOG! (Second Order Generalized Integrator) filter as shown in Fig. 2 (b). This is used to estimate active power component (ILp). To keep ILf in phase with its respective voltage, quadrature template (uq) is given as input to a zero crossing detector (ZCD). The in-phase (up) and quadrature components (Uq) of the grid voltage are derived according to Fig. 2 (c). The current signal iL is input signal for sample and hold circuit (SHC) and triggering pulse comes from output of ZCD. The active power component of the iLa is extracted as an output. The reference current component is derived as,

$$i_g^* = I_{Lp} u_p \quad (1)$$

The reference grid current (i_g^*) and sensed grid current (ig) are compared to generate PWM pulses for the switching of VSC in grid connected mode.

C. *Transition from Standalone to Grid Synchronization*

For the smooth transition from standalone to grid connected mode, the load voltage magnitude, frequency and phase must be within the range according to IEEE 1547 standard [16]. Once these parameters match the microgrid is connected to the utility grid through STS. The steps of synchronization are explained as,

1. When the grid is present in normal operating condition.
2. Check the voltage magnitudes at PCC and grid. If the difference is less than 10% according to IEEE 1547 standards upto 500 kVA in distributed generation.
3. Calculate the in-phase (up) and quadrature (Uq) template of grid voltage and load voltage using SOG! as shown in Fig. 2 (c). Match up with load voltage in-phase template as shown in Fig. 2(d). For smooth synchronization the angle difference sin (8g- 8SA) = (8g- 8SA) = a, is taken less than 2°, which is within the limits provided by the IEEE standard 1547.
4. Now a signal is generated to switch on the STS for grid synchronization of microgrid. Simultaneously, the control mode switches from the voltage control mode to current control mode.

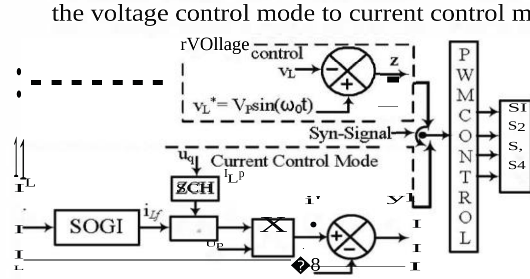


Fig. 2: (a) Voltage and Current Control for Grid Connected Operation

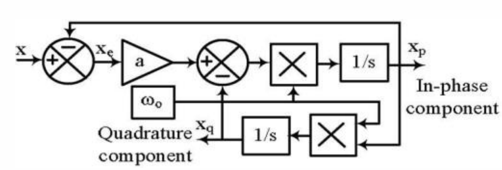


Fig. 2: (b) SOG! (Second Order Generalized Integrator)

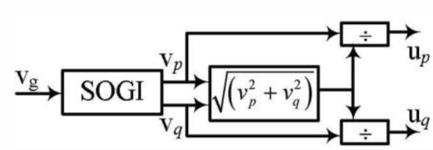


Fig. 2: (c) In-phase and Quadrature Components of Grid Voltage

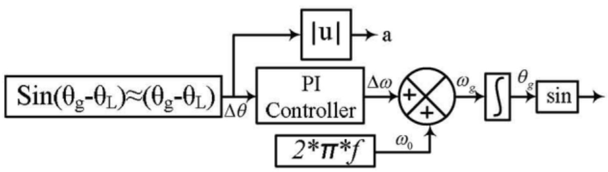


Fig. 2: (d) Phase Angle Matching using PI Controller

D. Transition from Grid Synchronization to Standalone Operation

When the grid is not available or wind power is sufficient to supply load demand. The microgrid appears back to standalone mode of operation. The necessary steps for de-synchronization are explained as,

1. The grid is unavailable.
2. At this time the voltage difference between PCC and grid voltage becomes large.
3. De-synchronization signal is produced.
4. The control mode changes to voltage control mode and simultaneously the STS switches off
5. To avoid sudden jump of the angle, the initial value of the angle at the instant of control mode change is kept same as that of during synchronization.

E. Maximum Power Point Tracking (MPPT) Algorithm

For wind power extraction, a perturb and observe (P&O) technique is used for MPPT [17]. It is a simple and commonly used technique. The generated wind power is converted into DC power using a rectifier. The rectified output voltage (Vr) and current (Ir) are sensed to calculate the output power P= IrxVr where P is a function of current Ir. For MPPT LlPILlw= LlPILlIr= 0. The variable Ir is perturbed with small step size and the output power is observed. According to the change in power with the current, the next step size direction is decided.

IV. RESULTS AND DISCUSSION

A MATLAB/Simulink model of a 3.7 kW, 50 Hz, 230 V autonomous wind based microgrid is developed and simulation results are presented for standalone and grid connected modes and during synchronization and de-synchronization operating conditions with variable wind and nonlinear loads.

A. Microgrid Operation with Linear Load

Microgrid operation with linear load is described in standalone, grid connected, synchronization and de-synchronization mode.

1) *Standalone mode ofoperation*

In standalone operation, the microgrid operates in voltage control mode for PWM pulse generation. Fig.3 depicts the load voltage (VL), grid voltage (Vg), grid current (ig), load current (iL), inverter current (iinv), inverter angle and grid angle (8SA & 8g), battery current (Ibl) and wind speed (Vw in standalone mode of operation.

It depicts that at t= 1 s, the wind speed is decreased, simultaneously battery current is reduced to feed the load demand. The load voltage, load current and inverter current are sinusoidal but grid current is zero as the grid is not available. The inverter and grid angles are with their phases.

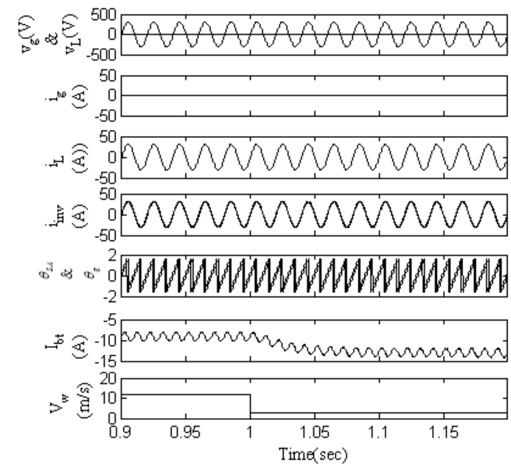


Fig. 3: Standalone Mode of Operation

2) *Synchronization ofwind based microgrid*

Figure 4 illustrates that with normal grid condition when grid voltage is available. The magnitudes of grid and load voltage (Vg & VL) are within the limit and the phases (8SA & 8g are matched. With these conditions, the synchronization process takes place within 2 cycles after grid recovery and the control changes from voltage control to current control mode. With grid recovery, voltage vg appears in Fig. 4 and with synchronization ig starts increasing and iinv starts decreasing and the Ibl is approached to zero because now the power is coming from the grid. The wind speed remains constant. Theta angles of inverter and grid are almost same at the instant of synchronization.

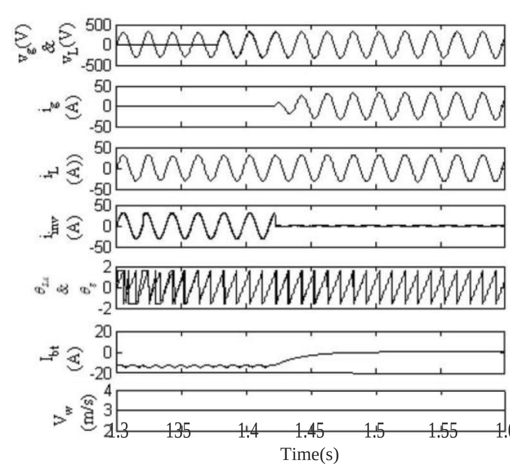


Fig. 4: Synchronization of Microgrid

3) *De-synchronization ofwind based microgrid*

Figure 5 depicts the de-synchronization process for microgrid. At the instant when de-synchronization takes place, the control switches from current control to voltage control mode. During this the grid voltage (vg) and grid current ig are disappeared. The load demand (iL) is constant and an inverter current (iinv) is increased to fulfill the demand. The difference of grid angle and inverter angle is increased and battery starts discharging with low wind speed.

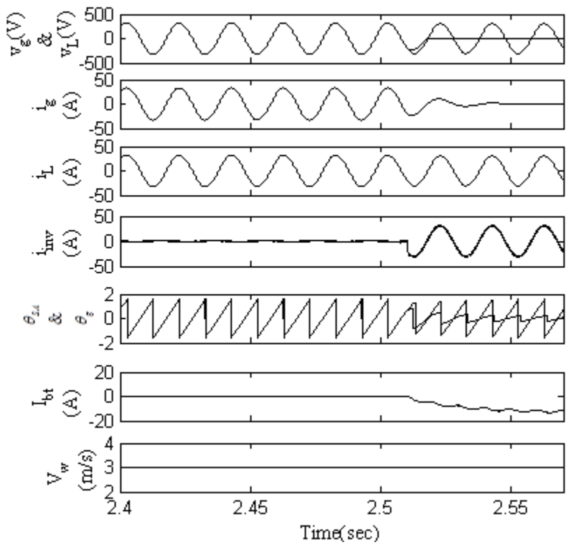


Fig. 5: De-synchronization of Microgrid

B. *Microgrid Operation at Nonlinear Load*

The microgrid operation at nonlinear load in all the four domains of operation which are shown in the following section. The results are showing the satisfactory performance of the control.

J) *Standalone mode ofoperation*

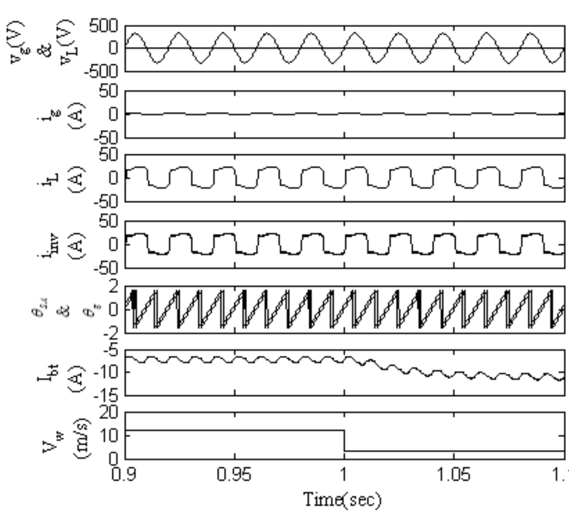


Fig. 6: Standalone Mode of Operation under Nonlinear Load

Figure 6 illustrates sinusoidal grid voltage and grid current at a nonlinear load. Both the voltages are with their own angles. With the decrease in wind speed from 12 m/s to 3 m/s the battery system starts discharging to provide load leveling.

2) *Synchronization ofwind based microgrid*

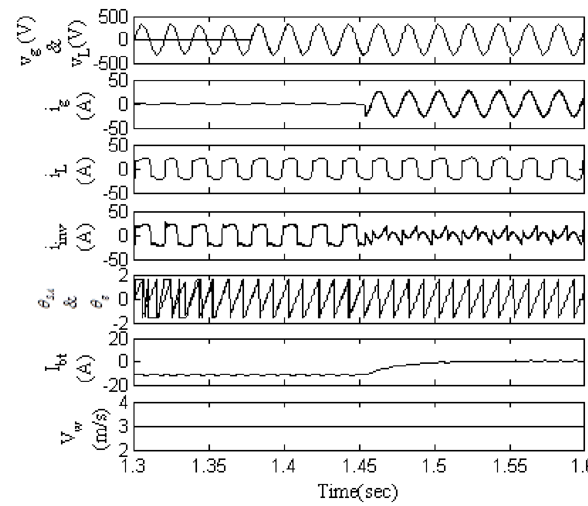


Fig. 7: Synchronization of Microgrid under Nonlinear Load

Figure 7 shows the results of synchronization process when voltages and angles are within the range according to IEEE 1547 standard. It is illustrated that with the mode change the i_{grid} current increases without any spike and voltage also remains transient free. The compensating current changes its shape as it provides the harmonic current injection. The i_{grid} feeds power to the load so the battery is coming in idle state. The load current is nonlinear in nature but the i_{grid} current is unaffected with harmonics and voltages are sinusoidal.

3) *De-synchronization ofwind based microgrid*

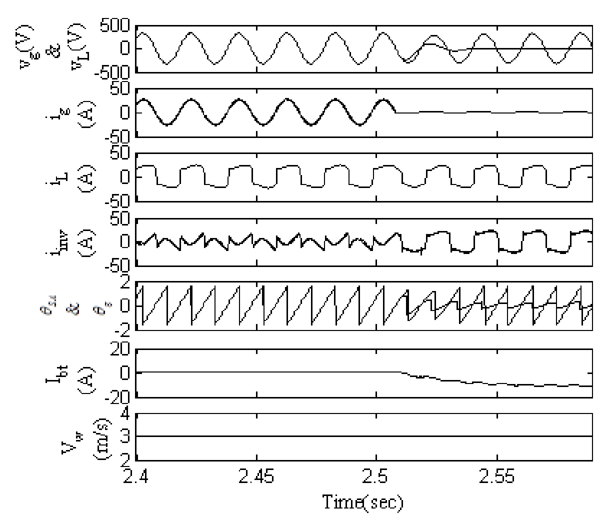
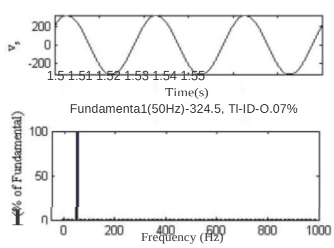


Fig. 8: De-synchronization of Microgrid under Nonlinear Load

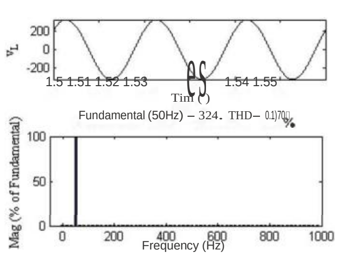
Disconnection of grid is shown in Fig. 8. At the instant de-synchronization comes in picture due to grid loss. The control switches from current control to voltage control mode. During this the grid voltage (vg) and grid current ig become zero. The load current (iL) and inverter current (iinv) are non-sinusoidal and iinv is increased with mode change. The gap between angles is increased, and battery supplies power to the load during low wind conditions.

C. *Steady State Performance of Microgrid in Both the Modes ofOperation*

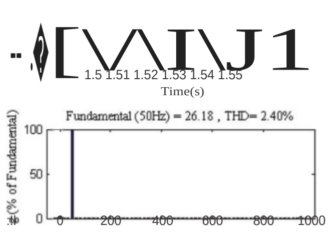
The steady state performance of microgrid for standalone and grid connected operation are illustrated in Figures 9 (a-d) during grid connected mode. In Figs. 9 (a-b), the grid and load voltages are sinusoidal and THD (Total Harmonic Distortion) is 0.07%. The grid current is maintained sinusoidal with 2.4% THD while the load current is highly distorted with THD 35% shown in Figs. 9(c-d). Such results show the satisfactory performance of current controller. Figs. 9 (e-f) show the microgrid performance in standalone mode of operation. The load voltage is with 1.52% THD with highly nonlinear load. The THDs of PCC voltage and grid current are under 5%, which is permissible according to standard IEEE 519.



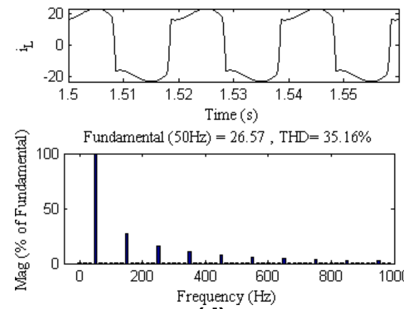
(a)



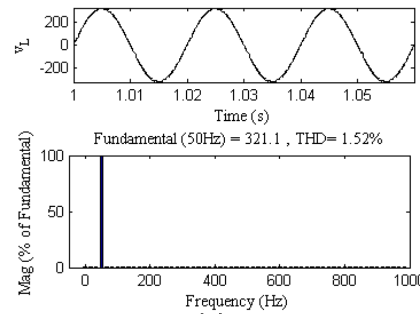
(b)



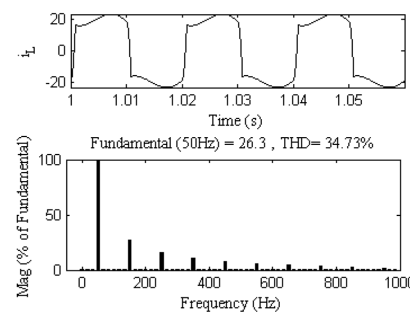
(c)



(d)



(e)



(f)

Fig. 9: (a-f) Voltage and Current Waveforms of Grid and Load Side with their Harmonic Spectra

All these results in dynamics (synchronization and de-synchronization) as well as steady state (standalone and grid connected) are showing the smooth and satisfactory performance of the controls for microgrid.

V. CONCLUSION

A wind based microgrid has been modeled and its performance is simulated in MATLABI Simulink using Sim Power System. The microgrid has worked in standalone environment with wind availability. When the grid fault is recovered and wind speed reduces the microgrid synchronizes with the utility grid and when fault appears the grid abnormal condition is detected and the control transfers from voltage control to current control mode. The synchronization and de-synchronization process are achived seamlessly. The obtained results have been depicted to justify the performance of the microgrid. During both the modes of

operation, the system steady state and transient responses are observed satisfactory.

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APPENDICES

PMBLDCG Rating: 3-phase, 3.7kW, 230V, 1430rpm, 13A.

Battery bank: Vb=360V, Cb= 1125 F, Rb=IO k!1, Rs=O.1.

C. Gains for voltage PI controller: kp= 1.5, and ki= 0.1. D. Interfacing inductance Lf=5mH, capacitance C=20IIF.

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