Control Strategy for a DC Micro-grid based Wind Power Generation System

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Abstract: This paper presents an improved control strategy for a DC Grid based multiple parallel wind generation system by eliminating the need for voltage and frequency synchronization. The PMSG is considered in this paper since it doesn't require a dc excitation framework that will expand the plan many-sided quality of the control equipment. Separate controllers are proposed for the inverter when grid is in grid-connected and islanded modes of operation. Model predictive control algorithm is used for the better transient performance with respect to the change in the operating condition for the inverter operation. A separate controller has been developed for the wind turbine to maintain the constant power and to mitigate the variation error. Performance of the proposed micro grid in islanded mode is also evaluated.

Keywords: *Model Predictive control, PMSG, islanded operation.*

I. INTRODUCTION

According to the recent analysis of the Energy storage devices, and increase within the form of dc loads and therefore the penetration of dc distributed energy resources (DERs) like solar photovoltaic and fuel cells [1]. Several analysis works on dc micro grids are conducted to facilitate the combination of varied DERs and energy storage systems [2], [3]. A dc micro grid based mostly power station design during which every wind energy conversion unit consisting of a matrix convertor, a high frequency electrical device and a single -phase ac/dc convertor is proposed [4]. However, the proposed design will increase the system quality as 3 stages of conversion are needed. In a dc micro grid based mostly power station design within which the WTs are clustered into teams of four with every cluster connected to a device is planned [5],[6]. However, with the proposed design, the failure of 1 device can lead to all four WTs of an equivalent group to be out of service [11],[12]. The analysis works conducted are focused on the event of various distributed management ways to coordinate the operation of varied DERs and energy [8],[10].

II. SYSTEM DESCRIPTION

The general design of the proposed dc network based breeze control age framework for the poultry cultivate is appeared in Fig.1. The framework can work either associated with or islanded from the conveyance network and comprises of four 10 kW perpetual magnet synchronous generators (PMSGs) which are driven by the variable speed WTs. The PMSG is considered in this paper since it doesn't require a dc excitation framework that will expand the plan many-sided quality of the control equipment. The three-stage yield of each PMSG is associated with a three-stage converter (i.e., converters A, B, C and D), which works as a rectifier to control the dc yield voltage of each PMSG to the coveted level at the dc framework [10]. The total control at the dc matrix is reversed by two inverters (i.e., inverters 1 and 2) with each appraised at 40 kW. Rather than utilizing singular inverter at the yield of each wind generator (WG), the utilization of two inverters between the dc lattice and the air conditioner framework is proposed.

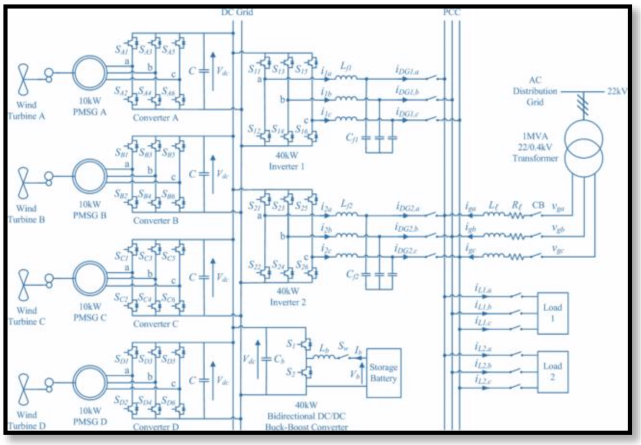

Fig.1.Proposed DC grid based wind power generation system in a microgrid

Instead of using individual inverter at the output of each WG, the use of two inverters between the dc grid and the ac grid is proposed [9]. This architecture minimizes the need to synchronize the frequency, voltage and phase, reduces the need for multiple inverters at the generation side, and provides the flexibility for the plug and play connection of WGs to the dc grid. The centralized EMS is also responsible for other aspects of power management such as load forecasting, unit commitment, economic dispatch and optimum power flow [22],[23]. During normal operation, the two inverters will share the maximum output from the PMSGs. The maximum power generated by each WT is estimated from the optimal wind power as follows:

$$Pwt, opt = kopt(\omega r, opt)3 ------(1)$$

$$kopt = \frac{1}{2}Cp, opt\, \rho A\left(\frac{R}{\lambda opt}\right)3 ----- (2)$$

$$\omega r, opt = \frac{\lambda opt\ v}{R} -----------(3)$$

where k opt is the optimized constant, $\omega_{r,opt}$is the WT speed for optimum power generation, $C_{p,opt}$ is the optimum power coefficient of the turbine, ρ is the air density, A i s the area swept by the rotor blades, λ_{opt} is the optimum tip speed ratio, v is the wind speed and R is the radius of the blade. The energy constraints of the SB in the proposed dc grid are determined based on the system -on-a-chip (SOC) limits given by;

$$SOC_{min} < SOC \le SOC_{max} ------(4)$$

III. SYSTEM OPERATION

When the micro grid is operating connected to the distribution grid [, the WTs in the micro grid are responsible for providing local power support to the loads, thus reducing the burden of power delivered from the grid. The SB can supply for the deficit in real power to maintain the power balance of the micro grid as follows:

$$P_{wt} + P_{sb} = P_{loss} + P_l ------- (5)$$

Where Pwt is the real power generated by the WTs, Psb is the real power supplied by SB which is subjected to the constraint of the SB maximum power Psb,max that can be delivered during discharging and is given;

$$P_{sb} \le P_{sb,max} --------- (6)$$

a) AC/DC Converter Modelling

Fig. 2 shows the power circuit consisting of a PMSG which is connected to an ac/dc voltage source converter. The PMSG is modelled as a balanced three-phase ac voltage source esa,esb,esc with series resistance R s and inductance Ls. The state equations for the PMSG currents isa,isb,isc and the dc output voltage Vdc of the converter can be expressed as follows:

$$L_s\frac{di_s}{dt} = -R_s i_s + e_s - KSV_{dc} ----- (7)$$

$$C\frac{dV_{dc}}{dt} = i_s^T S - I_{dc} --------- (8)$$

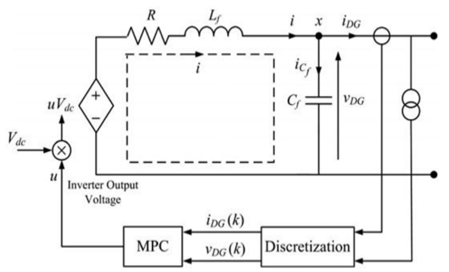

Fig.2.Three-phase dc/ac inverter single phase representation

b) DC/AC Inverter Modelling

The two 40 kW three-phase ac/ac inverters which connect the dc grid to the point of common coupling (PCC) are identical, and the single-phase representation of the three-phase dc/ac inverter is shown in Fig. 3.To derive a state-space model for the inverter, Kirchhoff's voltage and current laws are applied to loop i and point x respectively, and the following equations are obtained:

$$S_j = \begin{cases} 1, & S_j \text{ is ON} \\ 0, & S_j \text{ is OFF} \end{cases} \quad \text{for} \quad j = a,\ b,\ c \qquad (9)$$

where Vdc is the dc grid voltage, u is the control signal, R is the inverter loss, Lf and Cf are the inductance and capacitance of the low -pass (LPF) filter respectively, iDG is the inverter output current, i is the current flowing through Lf , iCf is the current flowing through Cf , and vDG is the inverter output voltage.

During grid-connected operation, the inverters are connected to the distribution grid and are operated in the current control mode (CCM) because the magnitude and the frequency of the output voltage are tied to the grid voltage. Thus, the discrete state-space equations for the inverter model operating in the CCM can be expressed with sampling time Ts as follows:

$$L_f\frac{di}{dt} + iR + v_{DG} = -uV_{dc} ----(10)$$

$$i_{DG} = i - iC_f --------- (11)$$

The exogenous input vg(k) can be calculated using state estimation. In this paper, the grid is set as a large power system, which means that the grid voltage is a stable three-phase sinusoidal voltage. Hence, when operating in the CCM, a three-phase sinusoidal signal can be used directly as the exogenous input.

During islanded operation, the inverters will be operated in the voltage control mode (VCM). The voltage of the PCC will be maintained by the inverters when the microgrid is islanded from the grid. As compared to Ts, the rate of change of the inverter output current is much slower. Therefore, the following assumption is made when deriving the state-space equations for the inverter operating in the VCM [33];

$$x_g(k+1) = A_g x_g(k) + B_{g1}v_g(k) + B_{g2}u_g(k) - - --(12)$$

$$y_g(k) = C_g x_g(k) + D_g x_g(k) ----(13)$$

Based on the above mentioned assumption, the discrete state space equations of the inverter model operating in the VCM can be expressed as follows;

$$\frac{di_{DG}}{dt} = 0 ---- -------- (14)$$

$$x_i(k+1) = A_i x_i(k) + B_i u_i(k) --(15)$$

$$y_i(k) = C_i x_i(k) -------- (16)$$

During islanded operation, the inverters are required to deliver all the available power from the PMSGs to the loads. Therefore, only the inverter output voltage is controlled and the output current is determined from the amount of available power

c) Control Design for the DC/AC Inverter

In order for the microgrid to operate in both grid-connected and islanded modes of operation, a model-based controller using MPC is proposed for the control of the inverters. MPC is a model-based controller and adopts a receding horizon approach in which the optimization algorithm will compute a sequence of control actions to minimize the selected objectives for the whole control horizon, but only execute the first control action for the inverter[15],[16]. To derive the control algorithm for the inverters, the state-space equations are transformed into augmented state-space equations by defining the incremental variables in the following format:

$$\Delta\xi(k) = \xi(k) - \xi(k-1) - - - - - - - - (17)$$

where ξ represents each variable in the inverter model, such as vDG, iDG, i and u as shown in Fig. By defining the incremental variables, the augmented state space model for the inverter model operating in the CCM during grid-connected operation can be expressed [17],[18]as follows:

$$X_g(k+1) = A_{g,aug}X_g(k) + B_{g1.aug}V_g(k) + B_{g2,aug}U_g(k) - - - - - - - - - - - - (18)$$

$$Y_g(k) = C_{g,aug}X_g(k) - - - - - - - - (19)$$

Similarly, the augmented state-space model for the inverter model operating in the VCM during islanded operation can be expressed as follows:

$$X_i(k+1) = A_{i,aug}X_i(k) + B_{i.aug}U_I(k) - (20)$$

$$Y_i(k) = C_{i,aug}X_i(k) - - - - - - - - - - - (21)$$

For the control of the two augmented models in the CCM and the VCM, the following cost function is solved using quadratic programming in the proposed MPC algorithm [33]:

$$J = (R_s - T_j)^T(R_s - T_j) - U_j^T Q U_j$$

Subject to the constraint

$$-1 \leq u_j(k) \leq 1$$

$$x_g(k+1) = A_g x_g(k) + B_{g1}v_g(k) + B_{g2}u_g(k) \quad (12)$$

$$y_g(k) = C_g x_g(k) + D_g v_g(k) \quad (13)$$

$$\frac{di_{\mathrm{DG}}}{dt} = 0. \quad (14)$$

$$x_i(k+1) = A_i x_i(k) + B_i u_i(k) \quad (15)$$

$$y_i(k) = C_i x_i(k) \quad (16)$$

IV. PROPOSED SYSTEM

The system can operate either connected to or islanded from the distribution grid and consists of two 10 kW permanent magnet synchronous generators (PMSGs) which are driven by the variable speed WTs. The PMSG is considered because it does not require a dc excitation system that will increase the design complexity of the control hardware. The three-phase output of each PMSG is connected to a three phase converter, which operates as a rectifier to regulate the dc output voltage of each PMSG to the desired level at the dc grid. The aggregated power at the dc grid is inverted by inverter rated at 40 kW. Instead of using individual inverter at the output of each WG, the use of two inverters between the dc grid and the ac grid is proposed. This architecture minimizes the need to synchronize the frequency, voltage and phase, reduces the need for multiple inverters at the generation side, and provides the flexibility for the plug and play connection of WGs to the dc grid. The availability of the dc grid will also enable the supply of power to dc loads more efficiently by reducing another ac/dc conversion.

The coordination of the converters and inverters is achieved through a centralized energy management system (EMS). The EMS controls and monitors the power dispatch by each WG and the load power consumption in the microgrid through a centralized server. To prevent excessive circulating currents between the inverters, the inverter output voltages of inverter is regulated to the same voltage. Through the EMS, the output voltage of inverter is continuously monitored to ensure that the inverters maintain the same output voltages.

The simulation model of the proposed dc grid based wind power generation system shown in Fig. 1 is implemented in MATLAB/Simulink for islanded operation of DC Grid as shown in Fig. 3. Also, the system parameters are utilised as per given in Table I. [1]

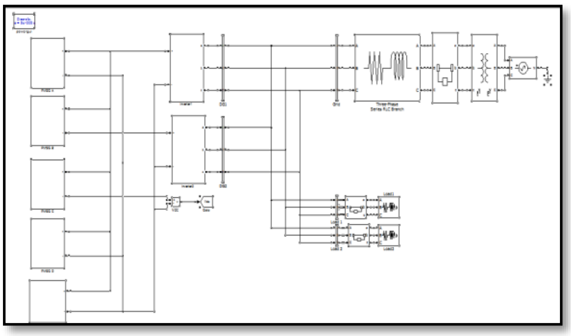

Fig.3. Simulink model for proposed scheme

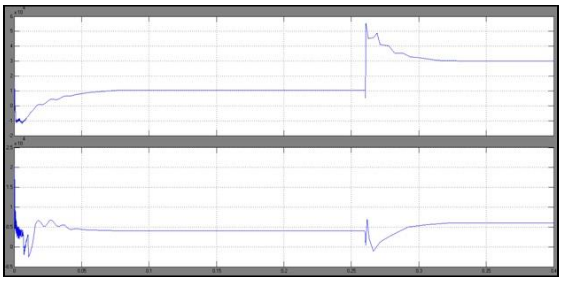

Fig.4. Real (top) and reactive (bottom) power delivered by inverter 1

When the microgrid operates islanded from the distribution grid, the total generation from the PMSGs will be insufficient to supply for all the load demand. Under this condition, the SB is required to dispatch the necessary power to ensure that the microgrid continues to operate stably. The third case study shows the microgrid operation when it islands from the grid.

The microgrid is initially operating in the grid-connected mode. Each inverter is delivering real power of 10 kW and reactive power of 4 kVAr to the loads as shown in Figs. 4 and 5. At t = 0.2 s, the microgrid is disconnected from the distribution grid by the CBs due to a fault occurring in the upstream network of the distribution grid. It can be seen from Fig. 6 that the CBs fully separate the microgrid from the grid in about half a cycle, resulting in zero real and reactive power supplied by the grid for $0.2 \leq t < 0.4$ s. With the loss of power supply from the grid, the power imbalance between the generation and load demand is detected by the EMS. To maintain the stability of the microgrid, the SB is tasked by the EMS to supply real power of 40 kW at $t = 0.26$ s as shown in Fig.6. At the same time, the real and reactive power delivered by each inverter is also increased by the EMS to 30 kW and 6 kVAr as shown in Figs. 4 and 5 respectively. Fig. 7 shows the dc grid voltage where slight voltage fluctuations are observed at $t = 0.26$ s. The initial voltage rise at $t = 0.26$ s is due to the power supplied by the SB while the subsequent voltage dip is due to the increase in power drawn by the inverters.

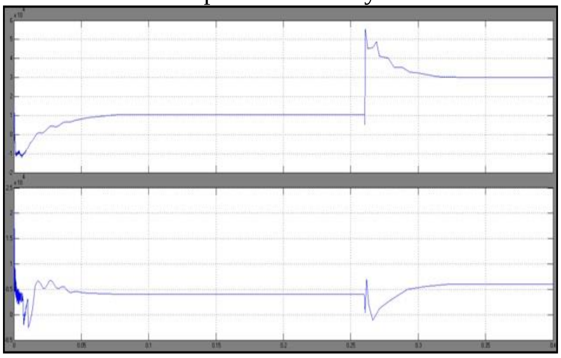

Fig.5. Real (top) and reactive (bottom) power delivered by inverter 2

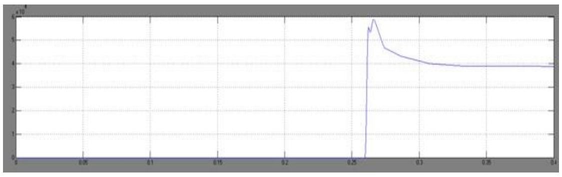

Fig.6. Real power delivered by Storage Battery

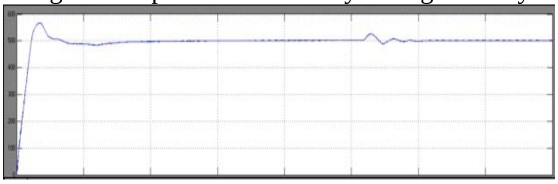

Fig.7. DC grid voltage.

V. CONCLUSION

This paper presents the operation of a dc grid-based wind power generation system that allows flexible operation of multiple parallel - connected wind generators by eliminating the need for voltage and frequency synchronization. The design of a dc grid based wind power generation system in a micro-grid enables parallel operation of several WGs has been presented in this paper. Compared to the conventional wind power generation systems, the proposed micro-grid architecture eliminates the need for voltage and frequency synchronization, thus allowing the WGs to be switched on or off with minimal disturbances to the micro-grid operation. In addition, MPC relies on the accuracy of model establishment; hence further research on improving the controller robustness to modelling inaccuracy is required. The simulation results obtained and the analysis performed in this paper serve as a basis for the design of a dc grid based wind power generation system in a micro-grid.

VI. REFERENCES

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