Control and Operation of a Dc Grid-Based Wind Power Generation System in a Micro Grid

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Abstract - The design of a dc grid-based wind power generation system in a poultry farm. The proposed system allows flexible operation of multiple parallel-connected wind generators by eliminating the need for voltage and frequency synchronization. A model predictive control algorithm that offers better transient response with respect to the changes in the operating conditions is proposed for the control of the inverters. The design concept is verified through various test scenarios to demonstrate the operational capability of the proposed micro grid when it operates connected to and islanded from the distribution grid, and the results obtained are discussed.

Keywords - —Wind power generation, dc grid, energy management, model predictive control

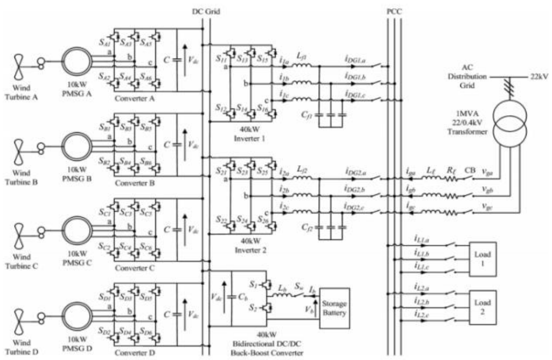
I. INTRODUCTION

POULTRY farming is the raising of domesticated birds such as chickens and ducks for the purpose of farming meat or eggs for food. To ensure that the poultries remain productive, the poultry farms in Singapore are required to be maintained at a comfortable temperature. Cooling fans, with power ratings of tens of kilowatts, are usually installed to regulate the temperature in the farms [1]–[3]. Besides cooling the farms, the wind energy produced by the cooling fans can be harnessed using wind turbines (WTs) to reduce the farms' demand on the grid. The Singapore government is actively promoting this new concept of harvesting wind energy from electric ventilation fans in poultry farms which has been implemented in many countries around the world [4]. The major difference between the situation in poultry farms and common wind farms is in the wind speed variability. The variability of wind speed in wind farms directly depends on the environmental and weather conditions while the wind speed in poultry farms is generally stable as it is generated by constant-speed ventilation fans. Thus, the generation intermittency issues that affect the reliability of electricity supply and power balance are not prevalent in poultry farm wind energy systems. However, failure of the bidirectional converter will result in the isolation of the dc micro grid from the ac micro grid. An alternative solution using a dc grid based distribution network where the ac outputs of the wind generators (WGs) in a poultry farm are rectified to a common voltage at the dc grid is proposed in this paper. The most significant advantage of the proposed system is that only the voltage at the dc grid has to be controlled for parallel operation of several WGs without the need to synchronize the voltage, frequency and phase, thus allowing the WGs to be turned ON or OFF anytime without causing any disruptions. Many research works on designing the controllers for the control of inverters in a micro grid during grid-connected and islanded operations is conducted in [13]–[15]. A commonly adopted control scheme which is detailed in [13], [14] contains an inner voltage and current loop and an external power loop to regulate the output voltage and the power flow of the inverters. In [15], a control scheme which uses separate controllers for

The inverters during grid-connected and islanded operations are proposed. Although there are a lot of research works being conducted on the development of primary control strategies for DG units, there are many areas that require further improvement and research attention. These areas include improving the robustness of the controllers to topological and parametric uncertainties, and improving the transient response of the controllers.

II. SYSTEM DESCRIPTION AND MODELING

The overall configuration of the proposed dc grid based wind power generation system for the poultry farm is shown in Fig. 1. The system can operate either connected to or islanded from the distribution grid and consists of four 10 kW permanent magnet synchronous generators (PMSGs) which are driven by the variable speed WTs. The PMSG is considered in this paper 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 (i.e., converters A, B, C and D), 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 two inverters (i.e., inverters 1 and 2) with each 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.



$$P_{\mathrm{wt,opt}} = k_{\mathrm{opt}}(\omega_{r,\mathrm{opt}})^3 \quad (1)$$

$$k_{\mathrm{opt}} = \frac{1}{2}C_{p,\mathrm{opt}}\rho A\left(\frac{R}{\lambda_{\mathrm{opt}}}\right)^3 \quad (2)$$

$$\omega_{r,\mathrm{opt}} = \frac{\lambda_{\mathrm{opt}} v}{R} \quad (3)$$

where kopt is the optimized constant, ωr,opt is the WT speed for optimum power generation, Cp,opt is the optimum power coefficient of the turbine, ρ is the air density, A is the area swept by the rotor blades, λopt is the optimum tip speed ratio, v is thewind speed and R is the radius of the blade. When one inverter fails to operate or is under maintenance, the other inverter can handle the maximum power output of 40 kW from the PMSGs. Thus the proposed topology offers increased reliability and ensures continuous operation of the wind power generation system when either inverter 1 or inverter 2 is disconnected from operation. An 80 Ah storage battery (SB), which is sized according to [24], is connected to the dc grid through a 40 kW bidirectional dc/dc buck-boost converter to facilitate the charging and discharging operations when the micro grid operates connected to or islanded from the grid.

III. PI CONTROLLER

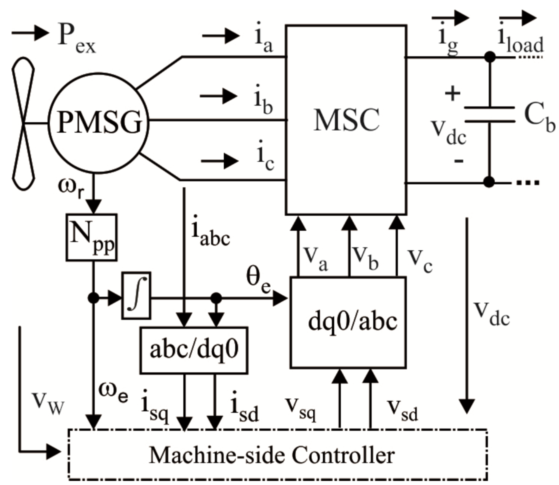
A proportional integral-derivative is control loop feedback mechanism used in industrial control system. In industrial process a PI controller attempts to correct the error between a measured process variable and desired set point by calculating and then giving corrective action that can adjust the process accordingly. The PI controller calculation involves two separate modes the proportional mode and integral mode. The proportional mode determine the reaction to the current error, integral mode determines the reaction based recent error. The weighted sum of the two modes output as corrective action to the control element. PI controller is widely used in industry due to its ease in design and simple structure. PI controller algorithm can be implemented as

$$output(t) = K_p e(t) + K_I \int_0^t e(\tau)d\tau$$

Where e(t) = set reference value – actual calculated

The drive consists of speed controller, reference current generator, PWM current controller, position Sensor, the motor and MOSFETs based current controlled voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in proportional- integral (PI) speed controller.
e(t) = ωref-ωm(t)

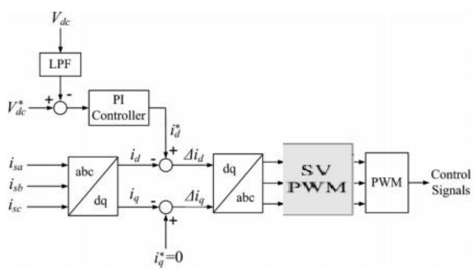
ωm(t) is compared with the reference speed ωref and the resulting error is estimated at the nth sampling instant as.
Tref(t) = Tref(t-1) + Kp[e(t) - e(t-1)] + K1 e(t)



The concepts of the control have been developed in [5]and in the present paper new theoretical evidences that confirm the previous analysis were included.The block diagram for the control system is shown in Fig.5. The dc-link voltage control loop generates the requiredPMSG speed reference (_r*). The output of the dc-link
compensator generates the current reference, which is treatedto generate a toque reference. The turbine model is saved into
a look-up table which considers the wind speed and the turbinetorque as input while _*r** comes in its output. The bus voltage
loop considers the blocks from *ig** to *ig* as unity gain. Thisassumption is valid once this inner system (machine speed and currents loops) works around ten times faster than the voltageloop dynamics. The generator control follows the

speed reference threating the turbine torque (*Twg*) as a disturbance.The resulting current (*ig*) from the generator inverter feeds andregulates the dc-link voltage.The generator speed and current control loops areimplemented through Field Oriented Control (FOC) in the dq0
synchronous reference frame according to Fig. 6.

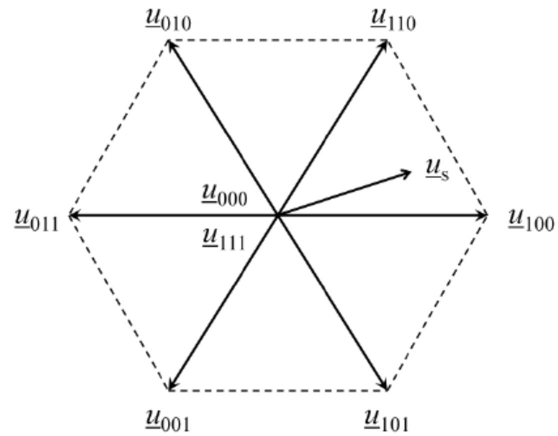
IV. PROPOSED CONTROLLER



Space vector pulse width modulation is an algorithm for the control of pulse width modulation (PWM). in which the reference signal is sampled regularly; after each sample, non-zero active switching vectors adjacent to the reference vector and one or more of the zero switching vectors are selected for the appropriate fraction of the sampling period in order to synthesize the reference signal as the average of the used vectors. The topology of a three-leg voltage source inverter is Because of the constraint that the input lines must never be shorted and the output current must always be continuous a voltage source inverter can assume only eight distinct topologies. Six out of these eight topologies produce a nonzero output voltage and are known as non-zero switching states and the remaining two topologies produce zero output voltage and are known as zero switching states. It is used for the creation of alternating current (AC) waveforms; there are variations of SVPWM that result in different quality and computational requirements. One active area of development is in the reduction of total harmonic distortion (THD) created by the rapid switching inherent to these algorithms.

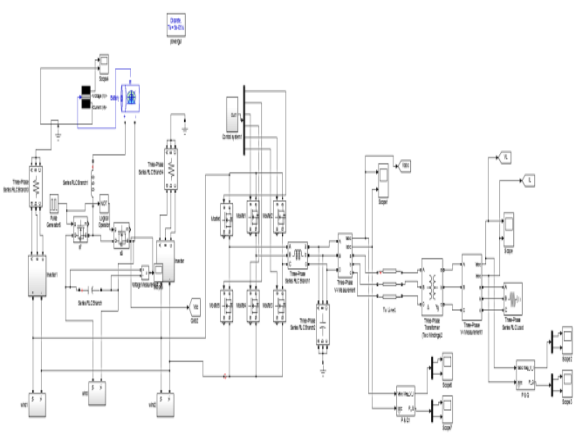
Pulse-width modulation (PWM) uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. The simplest way to generate a PWM signal is the interceptive method, which requires only a saw tooth or a triangle waveform (easily generated using a simple oscillator) and a control wave. When the value of the reference signal is more than the modulation waveform, the PWM signal is in the high state, otherwise it is in the low state. The inverter output voltage is determined in the following:

- When Vcontrol > Vtri, VA0 = Vdc/2
- When Vcontrol < Vtri, VA0 = −Vdc/2

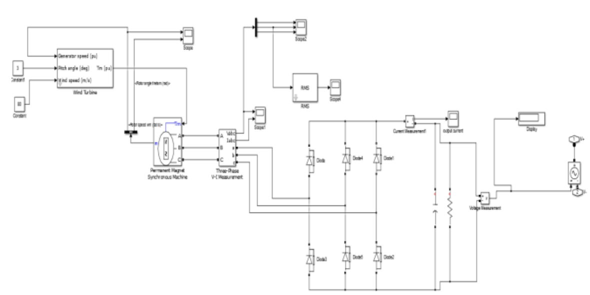


V. SIMULATION RESULTS

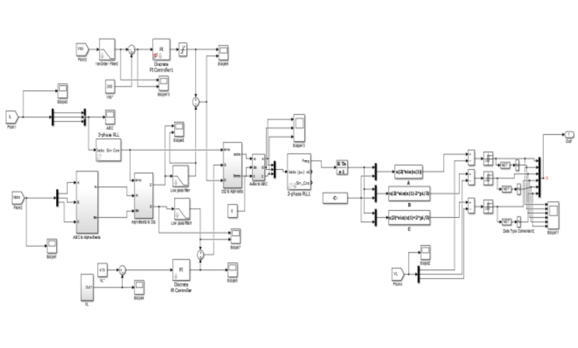
Simulation work:



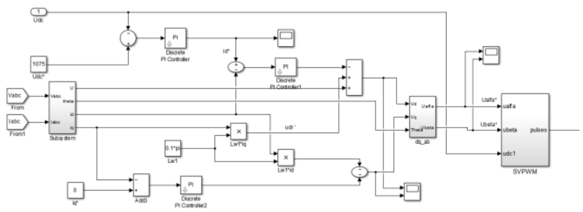
WIND TURBINE:



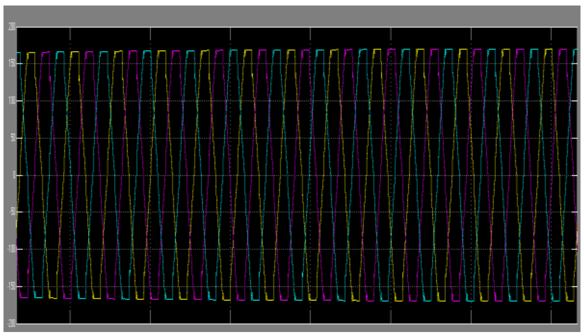
DC-AC CONTROL TECHNIQUE:



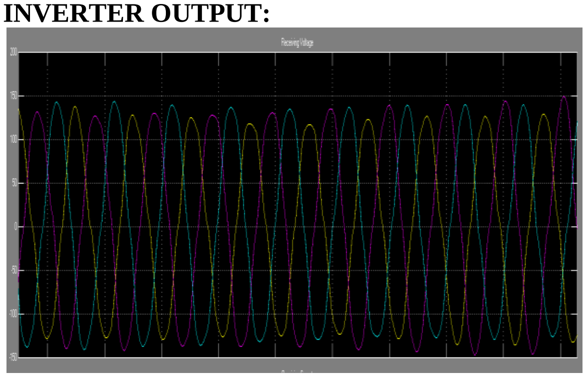
MACHINE SIDE CONTROLLER:



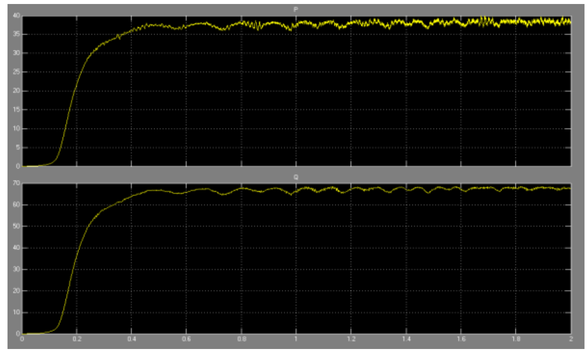
WIND OUTPUT:



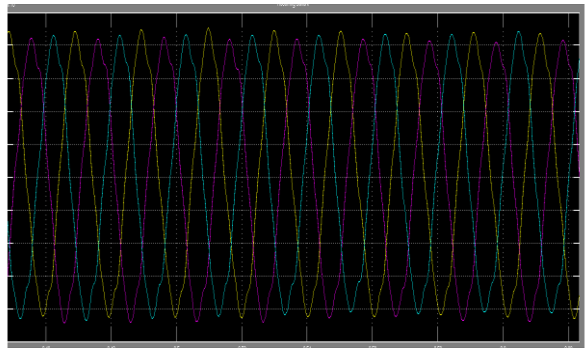
INVERTER OUTPUT:



REAL AND REACTIVE POWER:



LOAD CURRENT:



VI. CONCLUSION

In this paper, the design of a dc grid based wind power generation system in a micro grid that enables parallel operation of several WGs in a poultry farm has been presented. As compared to 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. The design concept has been verified through various test scenarios to demonstrate the operational capability of the proposed micro grid and the simulation results has shown that the proposed design concept is able to offer increased flexibility

VII. REFERENCES

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