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Energy Management Strategy of Induction Machine in Wind Energy Production System Control for Industrial with Harmonic Optimization

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***Abstract*--This paper presents the energy management strategies of a doubly fed induction machine (DFIM), with using the control strategy for an induction generator in a grid-connected operation wind energy production systems (WEPS) has been extensively studied for variable speed wind turbines. However, this control of DFIM using improved repetitive control regulator with the rotor-side converter (RSC) and grid-side converter (GSC) controller for harmonic grid voltage optimization of the system. The improved repetitive control considering nonsinusoidal voltage sources on the stator and rotor sides of machine, with the larger magnitude response at the frequency for higher control. It is important to achieve enhance the transient stability of the DFIM based wind energy production and wind energy conversion from generator. Results of the steady-state control strategy performance by the improved repetitive controller regulator are discussed harmonic power grid voltage using MATLAB/Simulink program. Thus, simulation results are presented to shows the effectiveness of the improved repetitive control regulator is designed based on the conventional control, with the RSC and the GSC controller to increase the magnitude response can be ensure transient stability increasing.**

***Keywords*: Transient stability, doubly fed induction machine, energy management, harmonic power, control strategy.**

I. Introduction

THE output power quality of the energy generation system is essentially vulnerable to the grid voltage with harmonic distortion. Since the DFIM is directly connected to the power grid through the stator winding, the power grid operator would always require that the wind power generation system should inject sinusoidal current into the power grids [1]. The DFIM is a three-phase wound rotor induction machine fed from the stator and the rotor winding, the rotor winding is supplied with a voltage source of controllable amplitude and frequency via converter. The converter of the DFIM has the control ability to maintain stability at fault condition. The DFIM control under generalized harmonic voltage is selected as sinusoidal stator current, the comparison with the variable speed wind generators having full rated converter, and the DFIM is more vulnerable to grid fault or disturbances from the stability standpoint, stator windings are directly connected to grid while rotor windings are interfaced to grid via the RSC and the GSC that connected to back-to-back through a dc-link capacitor [2]. Harmonic studies in an electrical network with considerable wind power energy penetration are actually a necessity since resonance problem in the wind park network [3]. This paper proposed to improved repetitive control regulator-based DFIM control strategy under the generalized harmonic grid voltage to achieve the sinusoidal stator current injected into the power grid, and design based on the conventional control regulator to increase the magnitude response stability at the higher power harmonic frequency.

II. Energy Management Strategy

Strategies management refer to the process of analyzing the environment and the business critical data used in decision making. Implementation guidelines, and control organizational strategic performance in order to ensure that the organizational is able to operate in a consistent manner with the environment and circumstances. Thus, as well as being able to develop and compete in the industry effectively. Number research works have been published recently in the field of a new energy management system of the WEPS grid. Related recent research works are, the wind energy production systems studied in work includes a generator coupled to supply a load profile demand.

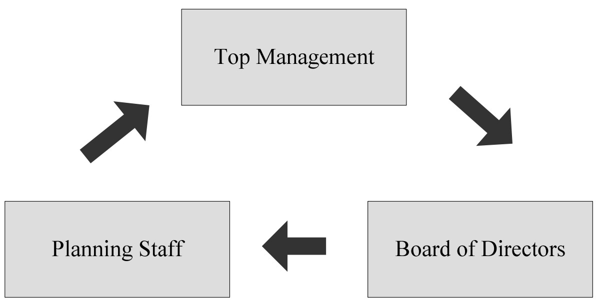

Fig. 1. Role in strategic management of production control system

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The different of the energy management strategies studied are described. In this paper, energy management strategies based respectively on inverter active power system control and on controllable loads using are proposed and compared to inverter ON/OFF system control strategy from simulation and experimental analysis. First, the control strategies studied are described followed by the models of the system' components used for simulation. Second, the experimental setup and case of study considered are displayed. The results from simulation experimental validation are present production system control and discussed. The conclusion is made strategies management as shown in Fig.1.

Whatever climate condition and load to production control system is expected to deliver with wind energy management without interruption at any time and ensure a stability of the system. This energy management strategy as shown in Fig. 2 aims to ensure reliable operation of the system, to maximize the turbine energy penetration by the inverter's active power control and to avoid operation of the DG under its minimal set point value especially during high generation and low loads periods.

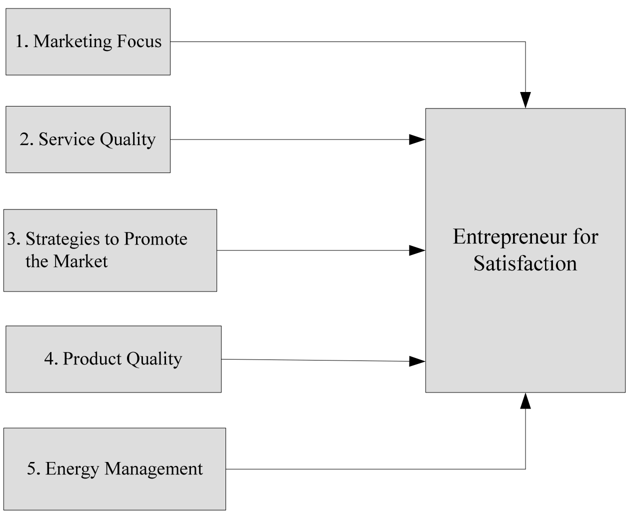

Fig. 2 The conceptual of the management strategies with production system

III. Speed Wind Turbines of the DFIM Control System

A. Wind Turbine Modeling

The turbine mechanical part dynamics is neglected due to small duration of the considered faults. The DFIM modeling is basically operation an induction generator control with the stator windings directly connected to grid and accessible rotor winding to the grid connected through the converter as shown in Fig.2. The model of DFIM under the generalized harmonic voltage, the commonly used mathematical relation for the mechanical power from the wind turbine, can be expressed as:

$$P_w = \frac{1}{2}\pi\rho R^2 V_w^3 C_p(\lambda,\beta) \tag{1}$$

where P_w is the extracted power from the wind turbine, ρ is the air density, R is the blade radius, V_w is the wind velocity, and C_p is the power coefficient which is a function of both the tip speed ratio λ and the blade pitch angle β ,and ω_r is the angular mechanical speed of the rotor winding is given by [2]

$$C_p(\lambda,\beta) = \frac{1}{2}(\lambda - 0.022\beta^2 - 5.6)e^{-0.17\lambda} \tag{2}$$

and
$$\lambda = \frac{\omega_r R}{V_w} \tag{3}$$

The wind turbine parameters used in this study, it can also be observed from in Table I. The wind energy available on the blade impact area, which can consider of the rotor slip power P_r system are defined as [3]:

$$P_r(V_\omega,\omega_t) = 55.12\rho A \frac{\dfrac{V_\omega}{R_{\omega t}} - 0.09}{exp\left(\dfrac{V_\omega}{R_{\omega t}} - 0.003\right)} V_\omega^3 \tag{4}$$

The power optimization and control of grid coupled WEPS composed on the squirrel-cage induction generator dynamics and a wind turbine (WT), assuming zero blade pitch angle, the turbine power is related to the wind power as:

$$P_t = \omega_t T_t = C_p(V_w,\omega_t)P_w \tag{5}$$

where T_t is the rotor torque, ω_t is the turbine speed, and C_p is the nondimensional power coefficient, which is a measure of the ratio of the turbine power to the wind power.

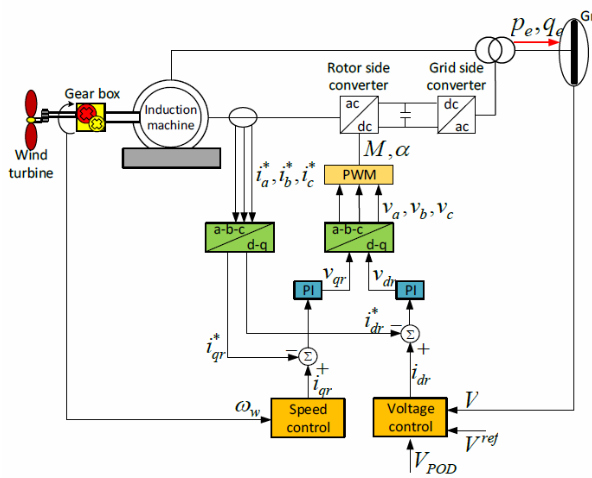

Fig.3. Block diagram of the DFIM in wind turbine control with RSC and GSC controller [3]

B. Model of DFIM Under the Generalized Harmonic Voltage

The DFIM works under the generalized harmonic voltage with fifth and seventh distorted grid voltage, when the 6n ± 1-order harmonic components of grid voltage are considered, the stator current and the rotor current references are linked to the optimal active and reactive power can be presented as [4]:

$$I_{sdq}^{+} = I_{sdq+}^{+} + \sum_{n=1}^{\infty}\left(I_{sdq(6n-1)-}^{(6n-1)-} e^{-j6n\theta_1} + I_{sdq(6n+1)+}^{(6n+1)+} e^{j6n\theta_1}\right) \quad (6)$$

and $$I_{rq\,ref} = -\frac{L_s}{L_m V_s} P_s \;,\; I_{rd\,ref} = \frac{V_s}{\omega_s L_m} \quad (7)$$

where I is current; subscripts d, q represent components at the dq synchronous rotating frame; subscripts s represent stator components of DFIM; superscripts +, (6n – 1) – and (6n + 1) + represent the reference frames rotating at the angular speed in the positive direction, and Ps is the stator power [].

The reference voltage of the DFIM from the rotor stationary frame is given by

$$E_{rdq}^{+} = \left(R_r I_{rdq}^{+} + j\omega_1 \sigma L_r I_{rdq}^{+}\right) + L_m\left(U_{sdq}^{+} - R_s I_{sdq}^{+} - j\omega_r \psi_{sdq}^{+}\right) / L_s \quad (8)$$

where R_s and R_r are stator and rotor resistance, subscripts r is represent rotor component of the DFIM control, ω_1 and ω_r are grid voltage angular speed and rotor angular speed, L_s and L_r are the stator and rotor inductance, and $\sigma = 1 - L_m^2 / L_s L_r$ is the leakage inductance coefficient, L_m is the mutual inductance of the electromagnetic.

C. Calculate the Torque by the Turbine Power

The load torque created by the spring-damper model of the shaft is defined as [1]:

$$T_L = K_s \bar{\theta} + B\left(\omega_t - \frac{\omega_r}{pn}\right) \quad (9)$$

where K_s is the stiffness coefficient value of the spring and B is the damping ratio, n is the gearbox ratio, p is the number of pole pairs of the induction generator, and the generator rotor angular speed value of a WEPS equals ω_r / p

The electromagnetic torque generated by the turbine power of the induction generator is

$$T_e = \frac{3}{2} p \frac{L_m}{L_r} (i_\beta \lambda_\alpha - i_\alpha \lambda_\beta) \quad (10)$$

where i_α and i_β are the stator currents value, λ_α and λ_β are the rotor flux linkages, and $L_r = L_{lr} + L_m$ is rotor inductance.

TABLE I
PARAMETERS FOR WIND ENERGY PRODUCTION OF THE DFIM SYSTEM

Generator characteristic	Value
Nominal power (P)	3.8 MW
Rated voltage (V)	650 V
Stator to rotor turns ratio	0.31
Rated frequency	60 Hz
Stator resistance (Rs)	0.0106 pu
Stator inductance (Ls)	0.104 pu (refined to stator)
Rotor resistance (Rr)	0.0122 pu.
Rotor inductance (Lr)	0.19 pu (refined to rotor)
Mutual inductance (Lm)	3.482 pu.
Grid voltage (RMS of phase to phase)	120 V

IV. CONTROLLER DESIGN OF DFIM SYSTEM USING IMPROVED REPETITIVE CONTROL REGULATOR

In the reactive power control strategy model to achieve the control target of sinusoidal DFIM system for stator current, it is prerequisite to guarantee the transient stability of the closed-loop regulation using improved repetitive control regulator.

The GSC controller scheme is given in Fig.3. It takes the dc link voltage E_{dc}, the rotor speed line reactive power Q_L as inputs and produces the necessary outputs. In Figs.3 and 4 [4], the parameters of the PI controllers are chosen such a way that they give the optimization performance for the system under consideration. Otherwise, there is a chance that the stability of the DFIM is likely to be compromised. A transfer function is used in the controllers so that the system takes shorter time to reach the normal operation. For the wind energy production systems studied in work includes a diesel generator coupled to supply a load profile demand, an induction generator in a grid-connected operation WEPS, and will additional phase leading unit is needed with the improved repetitive control regulator of RSC controller as shown in Fig. 4.

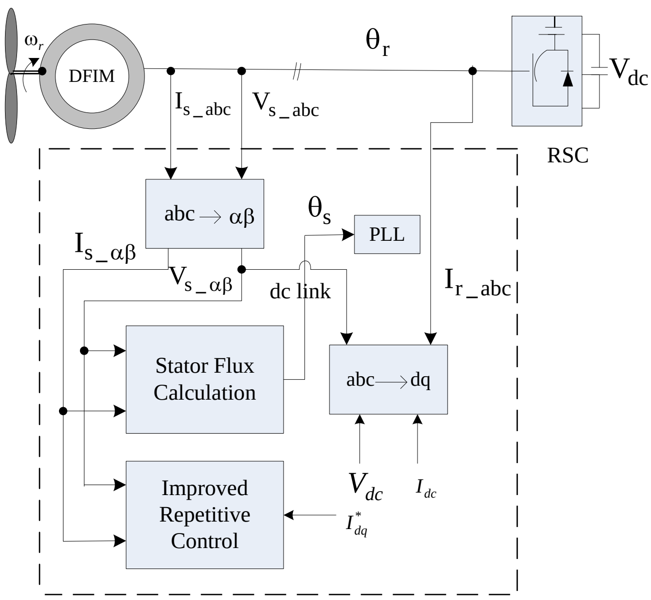

Fig. 4. Block diagram of the DFIM for wind energy production control

V. Simulation Results

This paper presents to control strategy for stability increase of 3 phase induction machine of 2160 HP, 3 phase balanced voltage source of 2500 V [5], 60 Hz was applied in the stator. Simulation result that compares the response of the design with the closed-loop regulation using improved repetitive control regulator in wind speed of 3 phase system as shown in Fig .5, the wind energy is assumed constant as the duration of fault is too short for the wind speed to make any noticeable effect. The DFIM was operating normally when temporary faults were applied to the most vulnerable point of time step used for the study is 10 sec. In Fig. 6 shows the curves result of active and reactive power of the stator machine based, the machine voltage goes very low right after the faults initiation and goes even lower till the breaker open. The result of higher generator slip is less stable for power oscillation than the lower slip [6], this proposed magnitude response compensation is capable of increasing the magnitude response [7], at the higher harmonic control frequency. In Fig. 7 shows the comparison result of the control strategies management of the two systems, there are noticeable differences between them, the new simplified DFIM gave a faster response due to the rotor field dynamics model. Table II shows result of the improved repetitive control with the stator current under grid voltage are 5^{th}-, 7^{th}-, 11^{th}-, 13^{th}-order harmonic analysis of the DFIM.

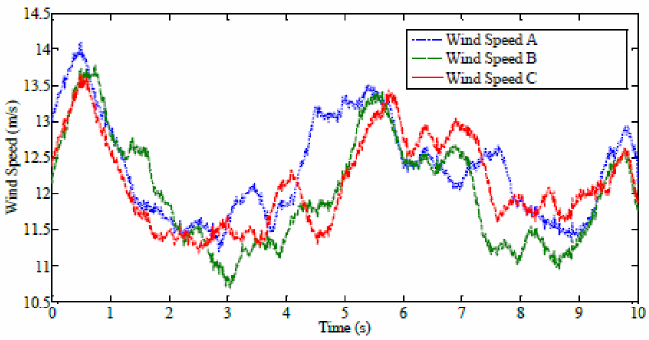

Fig. 5. Result of wind speed response of DFIM for temporary fault occurs

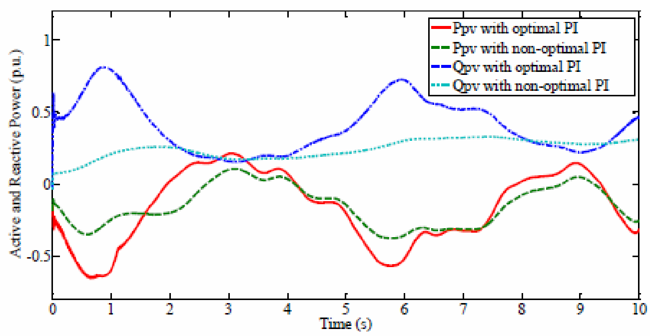

Fig. 6. Result of active and reactive power response in the DFIM with PI

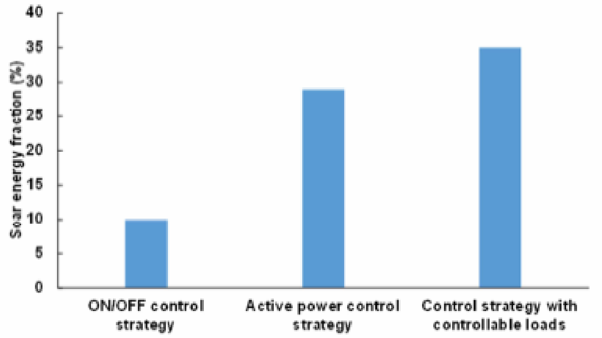

Fig. 7. Result of control strategy comparison with management system

TABLE II Result of The Stator Current for Order Harmonic Power

Level	Grid voltage	Stator current when no RC*	Stator current for connect RC	Stator current for improved RC
5th	3.30 %	3.58 %	2.06 %	1.98 %
7th	3.68 %	4.22 %	2.19 %	2.13 %
11th	3.50 %	3.15 %	1.74 %	1.76 %
13th	3.79 %	2.84 %	1.52 %	1.35 %

*RC is repetitive control regulator

VI. Conclusions

The power optimal utilization for wind energy presupposes variable rotor speed with energy management, all wind energy production system, which have established themselves in the marked are using frequency converter, and magnitude response compensation is increasing the magnitude response at the higher harmonic frequency, and the purpose of eliminating the stator current harmonic components in under the generalized harmonic voltage of DFIM using improved repetitive control. Simulation results are presented to show the effectiveness of the improved repetitive control regulator is designed based on the optimal conventional control regulator with RSC and GSC controller to increase the magnitude response stability at the higher power harmonic frequency.

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