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Coordinated MPPT and DPC Strategies for PMSG based Grid Connected Wind Energy Conversion System

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Abstract

This paper presents a novel control strategy employing the maximum power point tracking (MPPT) and direct power control strategy (DPC) for permanent magnet synchronous generator (PMSG) based wind energy conversion system (WECS). The WECS adopts medium voltage source converter with AC-DC-AC configuration. The 10 MW wind farm is implemented in this paper which consists of 2 MW PMSG's wind systems. The PMSG's of the wind farm is connected to the DC collection grid through a DC/DC rectifier topology. The DC collection system is connected to the AC grid using single DC/AC inverter thus providing simple control technique which controls the number of PMSG generators. The output power fluctuations are compensated using direct torque control based maximum power point controller and direct power control. The DC link voltage and the active power injected to AC grid is controlled using grid side controller and the maximum power is extracted using the machine side controller of the wind turbine. Pitch angle control strategy is also used in order to reduce the turbine speed during high wind speed condition. The proposed controller provides aneffective solution for grid integration and constant power flow from the generator system to thegrid system. Simulation results are presented and analyzed the performance of the control strategies implemented in the system.

*Keywords:*Permanent magnet synchronous generator (PMSG); Maximum Power Point Tracking (MPPT); grid side controller (GSC); machine side controller (MSC); Direct power controller (DPC);Pitch angle controller.

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1. Introduction

In recent years the need of renewable based power generation is growing exponentially due to high energy demand and carbon emission issue. At present, most of the power utilized is generated using the fossil fuel based generation which leads to excessive carbon emission in theatmospherewhich increasesglobal warming. Renewable energy sources such as solar, wind, tidal are the future of the power production in order to overcome the demand-supply gap and global warming [1]. Wind based power production is gaining more interest among the existing renewable based generation due to technological development, faster payback of initial installation cost and abundant availability which makes wind energy economically balanced. PMSG and doubly fed induction generator (DFIG) are most preferred wind generators for wind energy systems. PMSG based power generation is mostly preferred for small WECS, as they have an advantage of no requirement of gear box thus less maintenance. When parameters such as robustness, reliability, and efficiency related to power quality are given importance then PMSG based generation is mostly preferred solution [2].

The regular approach to integrating WECS to the grid is by using power electronics converters. The AC/DC/AC based topology is used to as the basic configuration for WECS.The diode rectifier is generally used in the small-scale WECS to convert the AC power generated from the generator to DC power which is further transferred to the DC/DC converter to obtain the desired voltage level through DC link voltage in order to remove the distortion. The system with DC/DC converter will have one degree of freedom for implementation of themaximum power point tracking (MPPT) technique. Though, they are most preferred since they reduce the torque ripple produced by the converter and enhance the controllability of the system [3].

Recently, many innovative control strategies have been utilized to increase the power output and to limit the system speed to obtain an optimized power [4]. For wind speed above the rated value, pitch angle control strategy is implemented to optimize the speed to the nominal value. Pitch angle controller limits the turbine speed to the optimal value so as to protect it from sudden gust [5]. The MPPT strategy is implemented to track the maximum available power from wind speed and generate an appropriate duty cycle which is fed to the machine side converter (MSC) power converter. The active and reactive power of grid connected WECS is controlled using the grid side control (GSC) strategy. The major research area in wind energy includes grid integration and power stability [6].

This paper proposes a simplistic and efficient coordinated control strategy for tuning MSC and GSC connected to PMSG based wind energy conversion system. Importantly, the additional control technique is implemented to enhance grid connectivity variable speed 2 MW PMSG based WECS in MATLAB/Simulink. The performance of the wind system is analyzed for 10 MW wind farm control strategy where five 2 MW PMSG generators are connected to the DC microgridThe proposed controller is used to stabilize the output DC link voltage using direct power control technique which also controls the active power of the system to maintain the grid stability in GSC. The maximum power is extracted using the DTC control strategy which is implemented in MSC. Additional pitch angle control technique is implemented in the WECS which reduces the aerodynamic torque when the wind system is subjected to higher wind speed. The single inverter is incorporated to the DC bus. This system satisfies the desired performance of grid integrated system.

2. Mathematical modeling of wind energy conversion system

The topology implemented in this study is shown in Fig. 1. As shown in Fig. 1, in this configuration PMSG is connected to the boost converter through diode bridge rectifiers do not require magnetizing current [4]. The diode bridge rectifier is used to convert the generated AC to DC in order to eliminate the harmonics produced due to nonlinearity in wind speed. The DC voltage obtained from the diode bridge rectifier is connected to the boost converter to control the generated torque and to obtain maximum power using DTC control strategy. A smoothing capacitor CDC is used to remove ripple present in DC voltage [6]. Similarly, five WECS is connected to the DC bus to form a DC microgrid of 10 MW rating.

A single inverter is used to connect the entire DC microgrid to the AC grid system. The IGBT based high voltage switching device is used for converting the rectified DC voltage to AC voltage for grid integration. The NPC based inverter is generally used for medium voltage grid capacity. The modeling of the wind turbine and PMSG is considered same as [6].

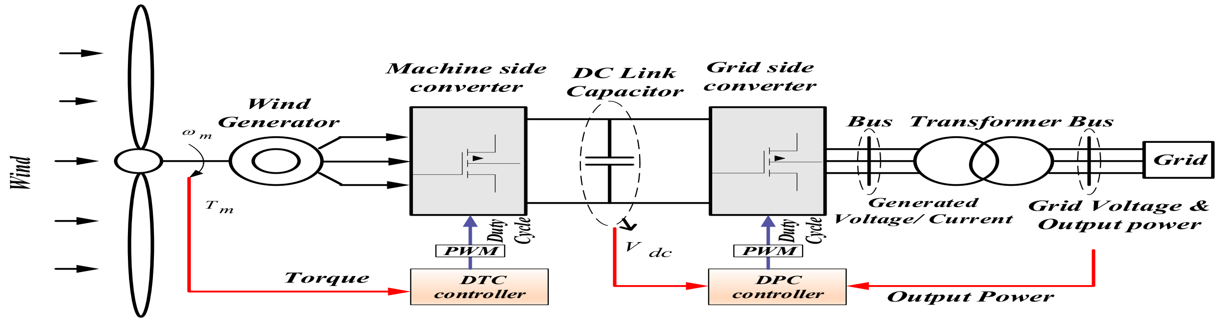

Fig. 1. Overall schematic of grid connected PMSG based WECS

3. Control strategy of DC grid based wind energy system

The control strategy of the wind farm and the DC collection grid is explained in this section. The Coordinate control strategy employing MPPT in machine side converter and DPC in grid side converter is briefly stated. The proposed system has two control strategy associated with it to provide sufficient support to the grid and also to maintain thestability of the system during faults. The control strategy is used to generate a duty cycle for the MSC and GSC. The boost converter tracks the maximum available power by analyzing mechanical speed and generator torque of the wind turbine and inverter regulates the active and reactive power injected to thegrid.

3.1. Machine side converter

The MSC controls the speed of the PMSG to attain a variable speed operation with MPPT control. Direct torque control (DTC) technique is used in this paper. They are mainly applied for low power wind turbine. In the proposed controller the electromagnetic torque is controlled directly. The major advantages of DTC are the independent of machine parameter, no requirement of rotor position sensor faster torque response and no need of current regulation loop which in turn gives faster computation time [6].The optimum rotation speed of wind turbine rotor is given by

$$\omega_{m-opt} = \frac{v\lambda_{opt}}{R} \tag{1}$$

The maximum mechanical output power ($P_{Max\_Turbine}$) obtained from the wind turbine is expressed as,

$$P_{Max\_Turbine} = \frac{1}{2}\rho A C_{P\,max}\left(\frac{R\omega_{m-opt}}{\lambda_{opt}}\right)^3 \tag{2}$$

Thus by controlling the turbine speed, the maximum power can be obtained. For each PMSG, the machine side converter is implemented with diode rectifier and DTC controller which chooses appropriate stator current vector from the converter.The DTC control strategy is based on the difference between reference torque, actual torque, and flux linkage value. As a result, the desired torque is achieved alongwith stator reference frame trajectory which rotates the stator flux linkage vector. The machine side control strategy works as a driver which controls the rotor speed in order to obtain the maximum power. The control topology of individual PMSG system is shown in Fig. 4. The DTC control strategy consists of two control loop, an outer loop which regulates the speed of the system and inner current control loop which is used to control the generator current (i_d and i_q). The stator flux linkage and electromagnetic torque are estimated using the following equations (3) and (4) respectively [6].

$$\theta_s = tan^{-1}\left(\frac{\psi_q}{\psi_d}\right) \tag{3}$$

$$T_e = p\left(\psi_d i_q - \psi_q i_d\right) \tag{4}$$

DTC determines the PMSG to operate in optimal rotor speed by deriving a torque reference based on MPPT strategy which is given as the reference for the outer speed control loop. Thus the quadrature current reference is generated and the voltage feedback compensation is added. The main advantage of DTC control is its capability to overcome the non-linearity of system and robust in design.

3.2. Grid side converter

The proposed topology consists of five 2 MW PMSG's connected to common DC collection grid. As stated earlier, each PMSG is connected to DC bus system through rectifier and DC/DC converter. The DC collection bus is connected to the AC grid system using only one DC/AC inverter. The grid side converter or inverter feeds the generated power to the grid. The grid side converter control strategy is used to maintain the DC bus voltage constant and also to regulate the active power and reactive power delivered to the grid when the system is subjected to high wind speed variations [7]. Thus to regulate the grid side converter, direct power control (DPC) is implemented in this study. The DPC is implemented to regulate instantaneous values of active and reactive power. The DPC consists of two control loop, inner control loop controls the active and reactive power of the system whereas, the outer control loop optimizes the DC bus voltage.

The voltage balance across inductor in *dq* reference frame is given by,

$$L_f \frac{di_{d-f}}{dt} = e_d - R_f i_{d-f} + \omega L_f i_{q-f} - V \tag{5}$$

$$L_f \frac{di_{q-f}}{dt} = e_q - R_f i_{q-f} - \omega L_f i_{d-f} \tag{6}$$

WhereL_f and R_f are the inductance and resistance of filter. e_d and e_q are the voltage component of inverter *d* and *q* axis respectively. e_d and e_q are the voltage component of inverter *d* and *q* axis respectively and v_d and v_q are the grid voltage component of *d* and *q* axis respectively. The capacitance (*C*) of filter is determined by,

$$C\frac{dU_{dc}}{dt} = \frac{3}{2}\left(\frac{v_d}{U_{dc}} i_{d-f} + \frac{v_q}{U_{dc}} i_{q-f}\right) - i_{dc} \tag{7}$$

where, U_{dc} and i_{dc} are the dc bus voltage and current respectively.
The instantaneous active and reactive power of grid is given by,

$$P = \frac{3}{2} V i_{d-f} \tag{8}$$

$$Q = \frac{3}{2} V i_{q-f} \tag{9}$$

The power feedback loop is defined as follows,

$$P_0 = K_P\left(P_{ref} - P\right) + K_I \int \left(P_{ref} - P\right) dt \tag{10}$$

$$Q_0 = K_P\left(Q_{ref} - Q\right) + K_I \int \left(Q_{ref} - Q\right) dt \tag{11}$$

Where, P_{ref} and Q_{ref} is the rated reference active and reactive power. P_{ref} maintains the constant output voltage *and* Q_{ref} maintains the power factor of the grid system.

The implementation of MSC and GSC for PMSG based grid connected system is presented in next section. The parameters of thewind turbine and PMSG used for the study are also specified with satisfactory results to determine the performance of the controllers. The analysis of DPC control strategy is considered as the system is designed in [7]

4. Results and discussions

In this section, the design and simulation wind energy conversion system based on DTC and DPC coordinate control is performed using MATLAB/Simulink software based on the parameters stated in [6]. The 10 MW wind farm which consists of five 2 MW PMSG is connected to the common DC collection grid. The voltage at the dc link capacitor is considered as 7 kV and the grid is considered as unity power factor.

To test the proposed control strategy, highly non-linear wind speed is considered in this study as shown in Fig. 2. The wind speed alters the power and voltage of the wind system. Thus a frequent fluctuation in wind energy conversion system is not considered for grid integration.

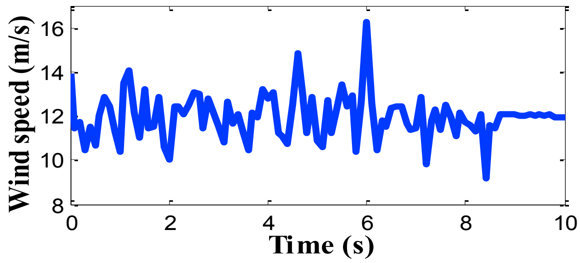

Fig. 2. Wind speed pattern

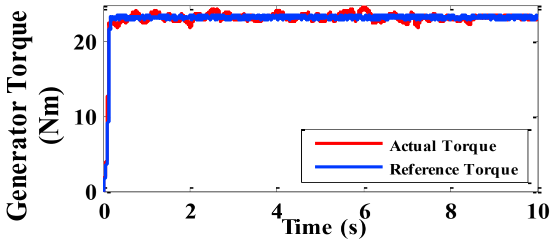

Fig. 3. Generator torque of PMSG

The electrical speed of the proposed system for proposed system is 25 rad/sec. Direct Torque Controller (DTC) is implemented to extract maximum power from the available power. The generated torque of the system is shown in Fig. 3. When the wind speed increases, DTC increases the generator speed reference thus produces the electrical torque opposite direction in order to accelerate the machine. The mechanical torque is built by the wind when the mechanical speed reaches to the reference speed the electrical torque is built to the same level to bring the generator to the steady-state condition. The diode bridge rectifier causes distortion in the generator current. This can be mitigated using AC filters and the major advantage of the proposed system is the high inertia of the wind turbine.

The grid side controller controls the DC link voltage and active power supplied to the grid. When the turbine speed changes based on the wind speed there is a change in DC link voltage and the power supplied to the grid. When the generator speed attains the reference speed the mechanical torque reaches the maximum limit, electrical torque also reaches for steady state analysis and the active power is transferred to the grid. This causes voltage swell in the DC link which is compensated by the DPC strategy as shown in Fig. 4. The active and reactive power of grid for 2 MW systems is shown in Fig. 5. and Fig. 6. respectively. The variations in the power are mostly stabilized using the DTC controller. But for grid integration, the grid code must be followed thus in order to reduce the fluctuation the DPC strategy is used.

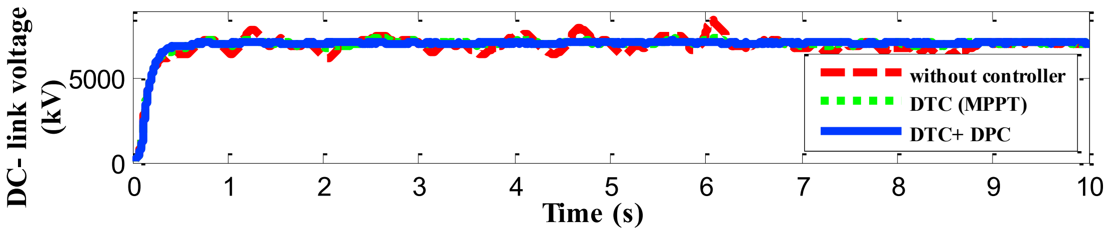

Fig. 4. DC link voltage

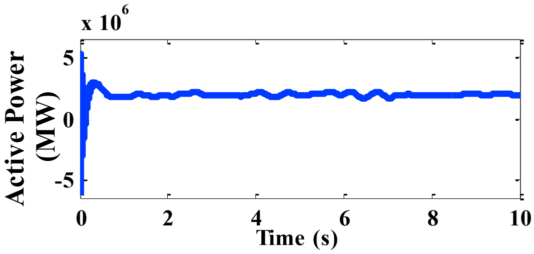

Fig. 5. Active power of grid side inverter

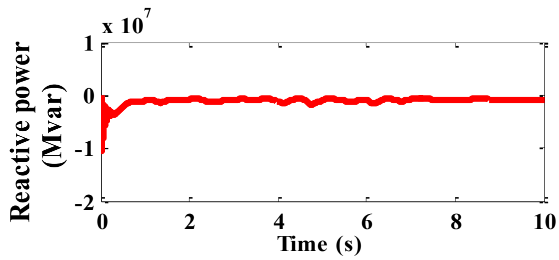

Fig. 6. Reactive power of grid side inverter

From the results, it is determined that the coordinate control strategy is the suitable solution to extract the maximum power from the available wind and to reduce the torque fluctuation in the generator. The control strategy is efficient technique to integrate the WECS to the grid by overcoming the nonlinearity of the system and better stability of grid voltage and power.

5. Conclusion

The proposed configuration presents a coordinate control of DTC and DPC control strategy for MPPT and GSC for PMSG based WECS. The output active power fluctuation is smoothened and DC link voltage is controlled using the DPC control strategy for grid side inverter. The maximum power is extracted using the DTC based MPPT technique which is implemented in boost controller. Both the control strategy provides duty cycle for MSC and GSC. The proposed methodology provides stable voltage and power smoothing technique. The proposed methodology is tested using MATLAB/Simulink which consists of PMSG based WECS. The disturbance in DC link voltage and speed response of generator have been analyzed and reduced with the optimal parameters. Stable operation of WECS is achieved during system fault using DPC control strategy. From the simulation results, it can be analyzed that the proposed strategy provides asuitable solution for grid integration and can be considered for further advancements in future research.

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