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Model Predictive Control of Back-to-Back Converter in PMSG Based Wind Energy System

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Abstract - *The PMSG wind energy connected to the grid using a bidirectional power flow back to back converter. Model predictive control was a efficient control model controlling of wind energy system. It predicts the behavior of control variable based on mathematical model of system. It performs predefined cost function. This paper presents control of back to back converter in wind energy turbine system based on MPC algorithm. The proposed method is presented in detail. For the effectiveness of proposed method several simulations are presented.*

Key Words: ***PMSG, model predictive control, back to back converter, Cost function minimization, Synchronous Generator Side Converter, Grid Side Converter.***

1.INTRODUCTION

The installed power capacity and penetration of wind power generation has been growing significantly over the last decade. Due to its increasing penetration, distributed generation has been included into the grid overall control system, to ensure the reliability and efficiency of the power system. The Grid Connection Requirements (GCRs) for conventional and distributed generation are set by the power system operators. The current GCRs, require the wind generators to remain connected to the grid during disturbances, as for conventional generators, condition known as the low voltage ride-through (LVRT) requirement. In this trend towards the diversification of the energy market and the satisfaction of the global energy demands, wind energy is one of the most promising and growing renewable energy sources[1]-[2].

Considering the large wind turbines installed worldwide, they are typically classified into two types: one is with a geared generator concept, such as those equipped with doubly-fed induction generators (DFIGs) and the other is based on a direct drive mechanism such as those using permanent magnet generators. Each of them has advantages and disadvantages, as discussed in . Their comparison in general was given in. The direct drive wind energy conversion system (WECS) based on permanent magnet synchronous generators (PMSGs)[3] is one of the promising wind power generation systems. Its advantages include higher reliability, better thermal characteristics, lower mass per kilowatt output power, lower weight, and a smaller generator size. A typical PMSG wind power system configuration is illustrated in Figure 1. The wind turbine converts the kinetic energy of the wind into mechanical energy and the mechanical energy is converted into electrical power through the PMSG. The output of the PMSG is connected to the grid through a full-scale back-to-back converter. This converter system is composed of both the generator side converter and the grid side converter. It is an AC/DC/AC converter.

The current controllers of the SGSC and the GSC become a key part of the control of the PMSG based wind energy system[4], since the achievement of the new grid codes requirements specified by national standards on its performances[5]. To this purpose, several control methods based on different current control algorithms have been studied and developed for both SGSC and GSC [7].Among them, we can quote the Field Oriented Control (FOC) and Direct Torque Control (DTC) for the SGSC control, and the Direct Power Control (DPC)[8] and the DPC-SVM[9] for the GSC control. For (DTC and DPC)[10] algorithms, the current control part is based on nonlinear hysteresis controllers associated to a switching table. For FOC and DPC-SVM algorithms, the current control part is based on linear PI controllers associated to a Space Vector Modulation (SVM) process[7].

Model Predictive Control (MPC), is a set of predictive control techniques based on the dynamic model of the process to be controlled and a time horizon[6]. Among the different MPCs applied to power converters, Finite Control Set MPC (FCS-MPC) is particularly attractive as it takes advantage of the limited switching states of the converter for solving the optimization problem from a discrete model of the system. The switching action that minimizes a given quality function is directly applied to the power converter. Thus, no modulator is needed. An optimization task is then performed based on a predefined cost function that selects the switching signals combination that minimizes it. This last is defined so that minimal error between the stator current reference vector in the SGSC (respectively the grid current reference vector in the GSC) and the predicted one is obtained.

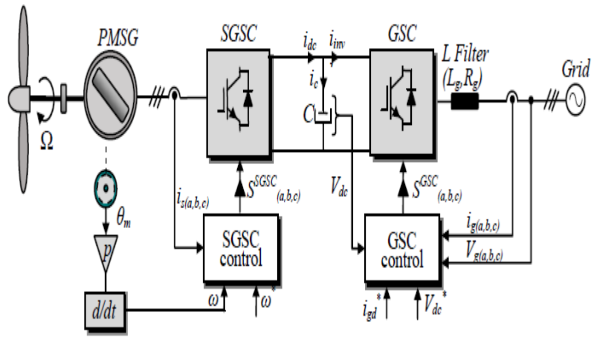

Fig.1. PMSG Wind turbine energy system

2. SYSTEM MODELLING

2.1 PMSG Model

The voltage, flux linkage equations of PMSG are as follows:

$$V_{sd} = R_s i_{sd} + \frac{d\varphi_{sd}}{dt} - \omega_{dq}\varphi_{sq} \quad (1)$$

$$V_{sq} = R_s i_{sq} + \frac{d\varphi_{sq}}{dt} - \omega_{dq}\varphi_{sd} \quad (2)$$

$$\varphi_{sd} = L_{sd} i_{sd} + \varphi_{rd} \quad (3)$$

$$\varphi_{sq} = L_{sq} i_{sd} \quad (4)$$

The electromagnetic torque is expressed as:

$$T_e = \frac{3}{2} p\left(\varphi_{sd} i_{sq} + \varphi_{rd} i_{sq}\right) \quad (5)$$

$$J\frac{d\omega}{dt} = T_e - T_L - f\omega \quad (6)$$

Where

i_{sd} *and* i_{sq} : *dq axis of stator current*

V_{sd} *and* V_{sq}: *dq axis of stator voltage*

φ_{sd} *and* φ_{sq} : *dq axis flux linkage of staror*

φ_{rd} : *d axis permanent magnet flux linkage*

ω_{dq}: *dq axis electrical angular rotor speed*

ω : *rotational speed*

p: *number of poles*

L_{sd} *and* L_{sq} : dq axis stator inductance

R_s : stator resistance

f : friction coefficient

J : inertia coefficient

T_e : electromagnetic torque

2.2 GSC model

From fig.1 where an L filter is interface between the grid and the converter. where L_g represents inductor and R_g represents serial resistance. The mathematical model of the GSC in dq axis is characterized as follows:

$$\frac{di_{gd}}{dt} = \frac{1}{L_g}\left(V_{gd} - R_g i_{gd} + \omega_g L_g i_{gq} - V_{convd}\right) \quad (7)$$

$$\frac{di_{gq}}{dt} = \frac{1}{L_g}\left(V_{gq} - R_g i_{gq} - \omega_g L_g i_{gd} - V_{convq}\right) \quad (8)$$

$$p = V_{gd} i_{gd} + V_{gq} i_{gq} \quad (9)$$

$$Q = V_{gq} i_{gd} + V_{gd} i_{gq} \quad (10)$$

Where

$\frac{di_{gd}}{dt}$ *and* $\frac{di_{gq}}{dt}$: d and q axis grid current deviation

L_g *and* R_g : inductance and resistance

i_{gd} *and* i_{gq} : dq axis grid current

V_{gd} *and* V_{gq} : dq axis grid voltage

V_{convd} *and* V_{convq} : dq axis of converter output voltage.

3. MODEL PREDICTIVE CONTROL FOR SGSC

A cascade control were used in SGSC is as shown in fig.2. In one side, a PI speed controller controls the rotor speed externally. from other side, MPC controls a stator currents in dq axis internally. The d axis reference stator current i_{sd}^{*} is set to zero to obtain maximum torque at minimum current, where as q axis reference i_{sq}^{*} is obtain from the external speed controller.

Here, the conversion from abc to dq is required. The conversion of the stator voltage components in dq reference frame determined by the application of rotation operation by angle. The speed controller is based on controller parameters that is proportional gain and integral gain.

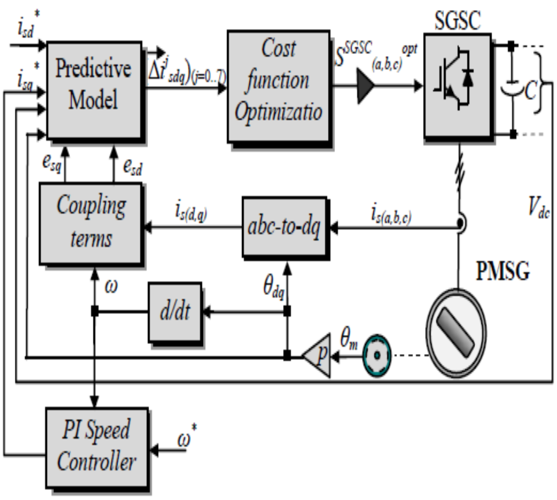

Fig.2. Model Predictive control for SGSC

The equations (1) and (2) can be deduced and are expressed for different possibilities of d and q stator voltage and vector voltage are as follows

$$\left(i_{sd}^{j}[k+1] = \frac{T_s}{L_{sd}}\left(V_{sd}^{j}[k] - e_{sd}[k]\right) + \left(1 - \frac{T_s}{T_{sd}}\right) i_{sd}[k]\right)_{(j=0.7)} \quad (11)$$

$$\left(i_{sq}^{j}[k+1] = \frac{T_s}{L_{sq}}\left(V_{sq}^{j}[k] - e_{sq}[k]\right) + \left(1 - \frac{T_s}{T_{sq}}\right) i_{sq}[k]\right)_{(j=0.7)} \quad (12)$$

Where $\left(i_{sd}^{j}[k+1]\right)_{(j=0.7)}$ and $\left(i_{sq}^{j}[k+1]\right)_{(j=0.7)}$: dq axis stator current at $(k+1)^{th}$ sampling period.

T_s: *sampling time*

V_{sd}^{j} *and* V_{sq}^{j} : k^{th} *sampling period*

e_{sd} *and* e_{sq} : *d and q coupling*

The current error is the difference between the stator current reference at k^{th} sampling period and the predicted one at $(k+1)^{th}$ when stator coil voltage $\left(\vec{V}_{sdq}^{j}[k]\right)_{(j=0.7)}$ is applied.

$$\left(\Delta i_{sd}^{j}[k+1] = i_{sd}^{*}[k] - i_{sd}^{j}[k+1]\right)_{(j=0.7)} \quad (13)$$

$$\left(\Delta i_{sq}^{j}[k+1] = i_{sq}^{*}[k] - i_{sq}^{j}[k+1]\right)_{(j=0.7)} \quad (14)$$

From (11),(12),(13)and(14), a cost function g_s is applied to obtain stator current error and the cost function is defined as shown in below

$$\left(g_s^{j} = \left|\Delta i_{sd}^{j}[k+1]\right| + \left|\Delta i_{sq}^{j}[k+1]\right|\right)_{(j=0.7)} \quad (15)$$

This is applied in finally optimization procedure. which leads to minimal cost function.

4. MODEL PREDICTIVE CONTROL FOR GSC

A Cascade control were used is as shown in fig.3. In one side, PI controller the dc-link externally. On other side grid current of dq axis .the d axis is connected to grid voltage.

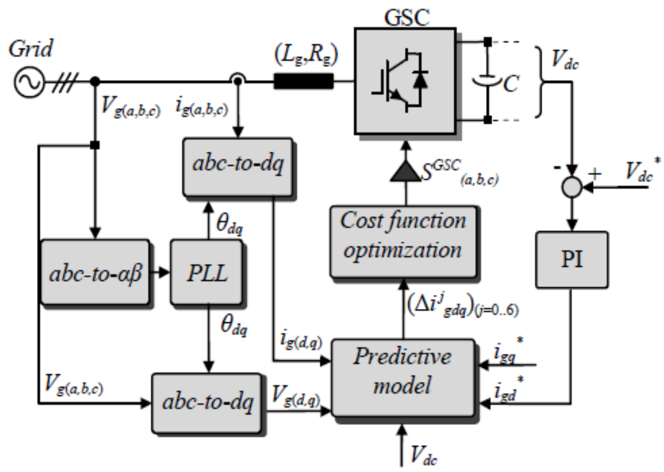

Fig.3. Model predictive control for GSC

where q axis of grid current is set to zero to obtain a unit power factor, whereas the d axis grid current is obtain by PI controller of the dc-link voltage loop.

The equations (7) and (8) are deduced as(16) and (17) is expressed as

$$\left(i_{gd}^{j}[k+1] = a_0\left[V_{gd}[k] - V_{convd}^{j}[k]\right] + a_1 i_{gd}[k]\right)_{(j=0.6)} \quad (16)$$

$$\left(i_{gq}^{j}[k+1] = a_0\left[V_{gq}[k] - V_{convq}^{j}[k]\right] + a_1 i_{gq}[k]\right)_{(j=0.6)} \quad (17)$$

Where $a_0 = \frac{T_s}{L_g}$ and $a_1 = \left(1 - \frac{R_g T_s}{L_g}\right)$

The grid current error is expressed as

$$\left(\Delta i^{j}_{gd}[k+1] = i^{*}_{gd}[k] - i^{j}_{gd}[k+1]\right)_{(j=0.6)} \quad (18)$$

$$\left(\Delta i^{j}_{gq}[k+1] = i^{*}_{gq}[k] - i^{j}_{gq}[k+1]\right)_{(j=0.7)} \quad (19)$$

From (16), (17), (18) and (19), a cost function is applied to obtain grid current error. The cost function is defined as

$$\left(g^{j}_{s} = |\Delta i^{j}_{gd}[k+1]| + |\Delta i^{j}_{gq}[k+1]|\right)_{(j=0.7)} \quad (20)$$

5. SIMULATION RESULTS

The simulation test is developed under *Matlab/Simulink* 11a to show the performance of SGSC and GSC of the PMSG wind energy system. The following conditions are taken as

-The reference q axis grid current was set to zero.

-The reference d axis stator current was set to zero.

Fig.4 and Fig.5 are obtain simulation results for SGSC. In Fig.4 the reference speed of PMSG was set to 250 rad/sec. Then, the small variation occurs due to load torque. Fig.5 represents that stator current increases when load torque increases.Fig.6 Initially charge the dc-link capacitor to 500V and set the dc-link voltage reference to 600V. Fig.7(a) simulation result shown the grid current response. Fig.7(b) the simulation result shown the performance of dc-link voltage for 50% drop of grid current. Fig.8 represents shown sinusoidal waveforms of grid current and grid voltage.

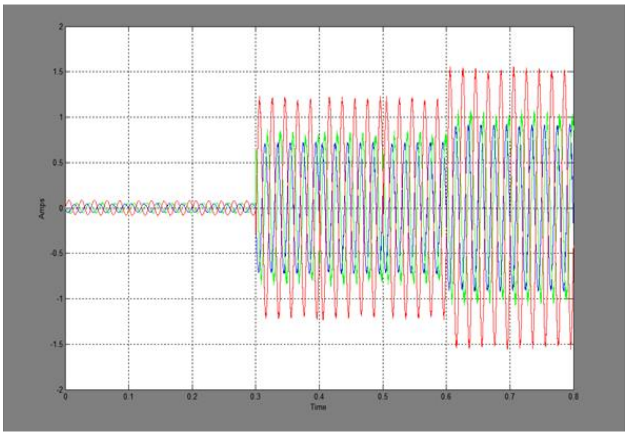

Fig.5. Three phase Stator Currents response of PMSG.

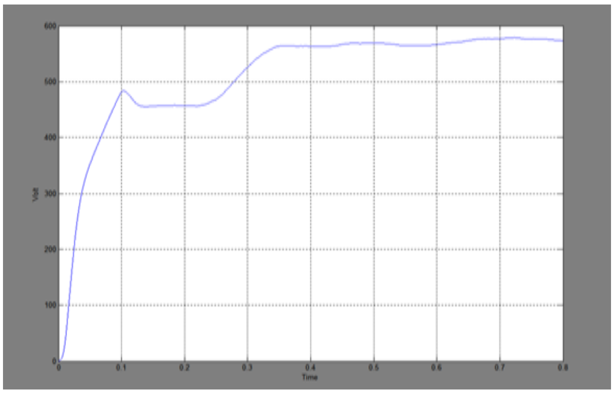

Fig.6. Step reference of 600v applied to dc-link voltage response.

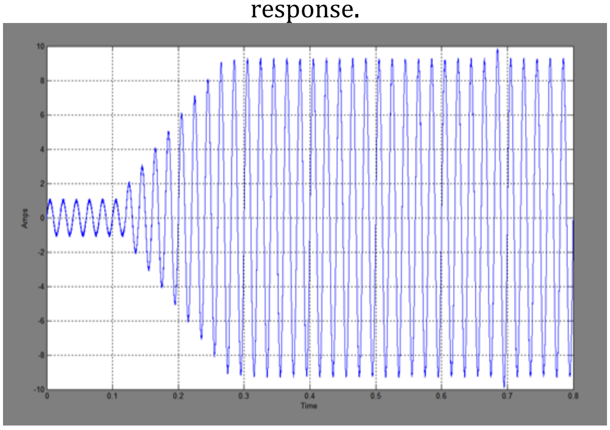

Fig.7. (a) Grid current response

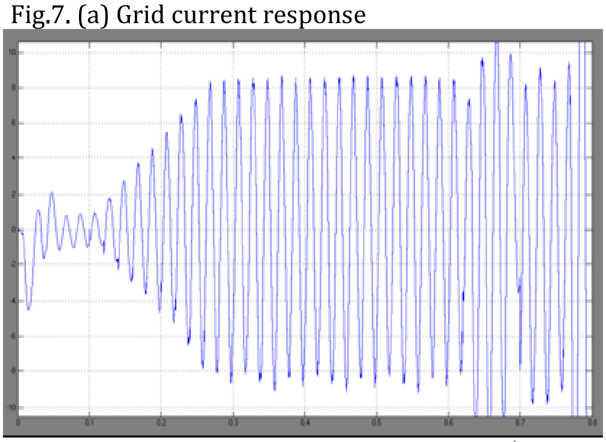

Fig.7. (b) Grid current response with $\Delta L = 50\%$

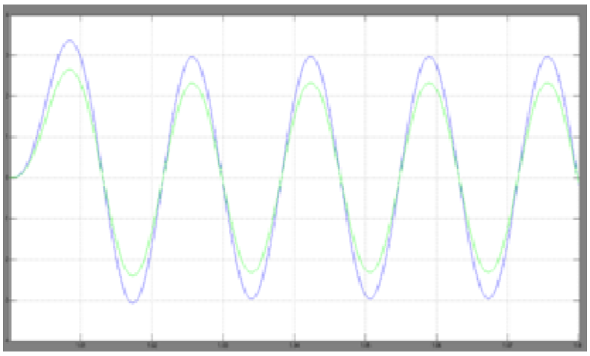

Fig.8. Sinusoidal grid current i_{ga} and voltage V_{ga}

6.CONCLUSION

Using back to back converter the whole system decreases output harmonic and improving power capacity of whole equipment, and reduces the equivalent switching frequency and the voltage stress of switch. The simulation results shows that SGSC has maximum wind power tracking, and make the generator operates efficiently by using two closed control loop based on MPC current controller. The GSC has decoupling control of active and reactive power. While the grid feed-in has high quality of electrical energy and it also improves the whole system utilization.

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