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VECTOR CONTROL STRATEGY TO CONTROL DC BUS VOLTAGE AND GRID SIDE REACTIVE POWER OF WIND ENERGY CONVERSION SYSTEM

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Abstract: In this paper the most effective vector control scheme is applied for the accurate control on grid side of a grid integrated power conversion system. Here three-phase AC-DC bidirectional grid side voltage source converter employees vector control strategy to assure that the dc link voltage follows the reference and controls the flow of active and reactive power . A design procedure for converting 3 phase grid voltages into 2 phase stationary reference frame and then transforming into synchronous frame of reference that rotates at grid frequency is explained. A simple algorithm for unit-vector generation is presented. Matlab simulation has been performed on proposed converter model and Simulink results are presented .

Keywords—*grid side converter, vector control, synchronous frame of reference, dqo reference frame, space vector pulse width modulation, wind energy conversion system.*

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I INTRODUCTION

With the increase in demand for electrical energy along with gaining interest environmental concerns and decreasing fossil fuels supply, a need has been realized to focus on increased utilization of clean and renewable energy sources. Few of such energy source are wind, solar, tidal wave, biomass or fuel cell. Wind energy conversion system is gaining more interest because of its simple nature. Increasing penetration of wind energy in existing conventional energy systems necessitate better power quality and control. The present advanced power electronics facilitate rapid and accurate control. WTs can operate either with a fixed speed or a variable speed. The variable speed concept is used by mainly two configurations that are dominant in market, Type C and Type D. Owing to power limitation considerations, the variable speed concept is used in practice today only together with a fast-pitch mechanism. Type C uses variable speed Doubly Fed Induction Generator (DFIG) with partially rated converter interface whereas Type D uses variable speed generators (either Squirrel cage Induction Generator (SCIG) or Synchronous generator) with full rated converter (FRC) interface [1-2]. WECSs using doubly fed induction generator (DFIG) and squirrel cage induction generator (SCIG) both types of WECSs are using similar kind of the control strategage. Vector control strategy to decoupled control of active and reactive power is applied in this paper. Linear PI controller is used for controlling purpose. Grid voltage-oriented vector control strategy is performed at Grid Side Convertor. Various type of control strategy has been used like direct torque control, direct power control, vector control etc.[3]. Vector control strategy was first proposed by F. Blaschke. Vector control strategy provides less harmonic distortion and lower power ripple. Vector control strategy using PI controller has been carried out in this paper. Grid Side Convertor controls volt grid side reactive power. Unity power factor operation is implemented by providing reactive power reference at grid side to be zero. Grid voltage is aligned with reference direct axis component. This alignment provides decoupled control of active and reactive power.

The paper is organized as follows: section I presents an introduction along with the objectives of the present work followed by the system description in section II. Vector control scheme and method of unit generation has been discussed in Section III and results are discussed in section IV Sections V summarize the significant findings.

II SYSTEM DESCRIPTION

The system consists of a WT coupled to generator through a gearbox. The stator terminals of the generator are connected to the grid through back to back connected voltage source converters and coupling inductors as given in fig1

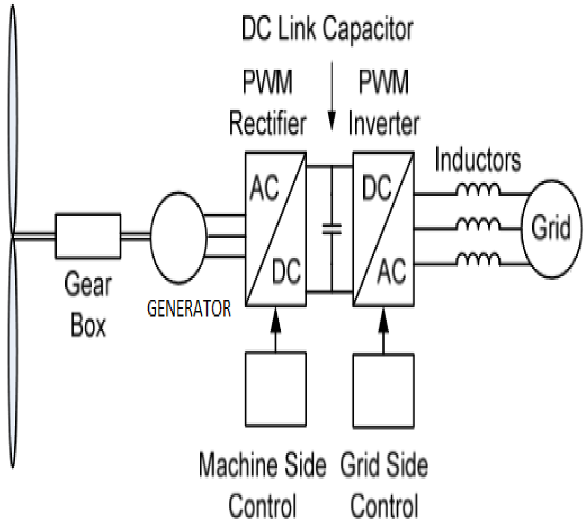

Fig1: block diagram of WECS

Control system consist of two types,

1. Control of Grid Side Convertor
2. Control of Rotor Side Convertor

In this paper we deal with control of grid side converter

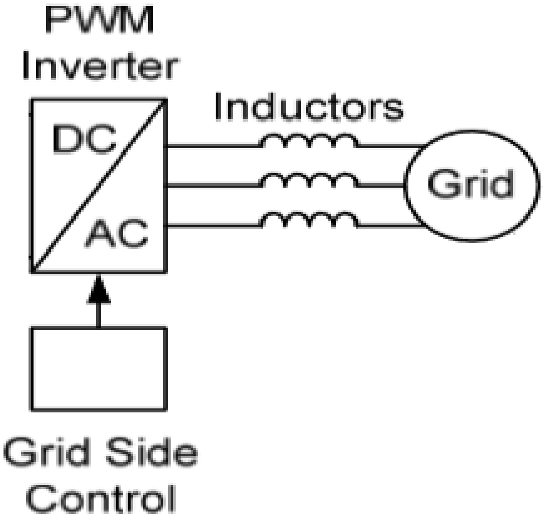

Fig2: block diagram of at grid side

A vector control strategy having reference frame oriented with the supply voltage vector is used to independently control the active and reactive power flow between grid side converter and the grid.

Grid Side Converter Control

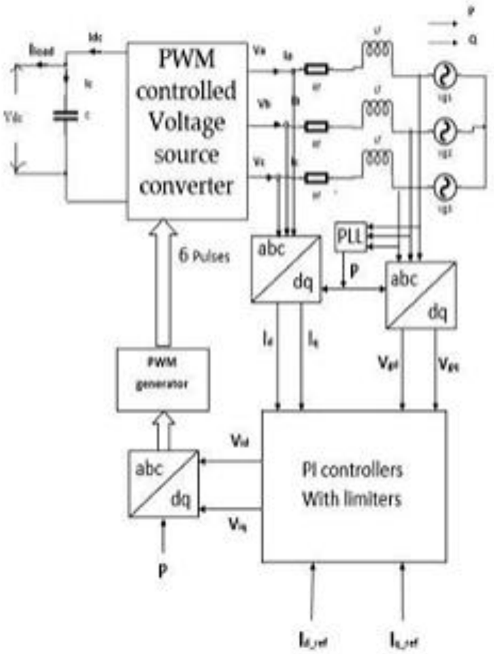

Fig 3: Block diagram of Vector control of grid side converter

Fig 3 presents the grid side converter (GSC) where the output of dc-link voltage controller sets the d-axis reference current, Id and reactive power (Q) controller creates the q-axis reference current, Iq. Using the phase angle of the grid voltages provided by a PLL system [4-7], the three current references are created. Each of them is compared with the corresponding measured GSC output current, and the error goes into the current controller.

The source voltages and the line currents are transformed into d-q reference frame and are used as feedback variables for the controllers as shown in the fig 4. The vector controller has an outer voltage loop to control Vdc. The voltage controller sets the reference to the inner d-axis current controller. The d-axis current loop controls the flow of real power P, since Id is a measure of active power. There is an independent loop for the control of Iq, which controls reactive power. It can also be operated as a Static Compensator (STATCOM) by setting an appropriate Iq current reference to produce leading or lagging reactive power. Grid voltage-oriented vector control strategy is performed at Grid Side Convertor in which direct axis component of grid voltage is aligned with direct axis component of synchronous reference frame. Because of this choice, direct axis grid voltage (v_{dg}), equal to stator voltage (v_s) and Quadrative axis voltage (v_{qg}) become zero. Grid Side Convertor, controls DC bus voltage and provide unity power factor operation by controlling reactive power to be zero. Therefore, grid side active power flow can be given by

$$P_g = \frac{3}{2} v_{dg} i_{dg} \quad \text{or} \quad P_g = \frac{3}{2} v_g i_{dg} \qquad (1)$$

Grid side reactive power

$$Q_g = -\frac{3}{2} v_{dg} i_{qg} \quad \text{or} \quad Q_g = -\frac{3}{2} v_g i_{qg} \qquad (2)$$

Therefore, it can be concluded that by controlling direct axis component of current, power flow balance at both side of convertor can be achieved. In same manner by controlling quadrature component of grid current reactive power control can be achieved.

vector control scheme

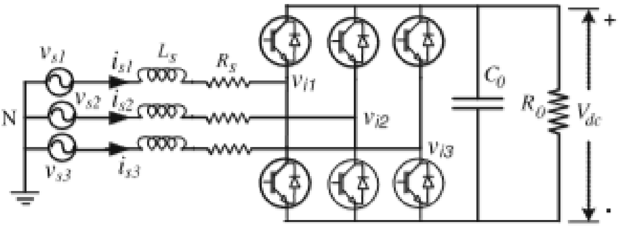

Fig 4: Schematic diagram of a grid side converter

For the converter shown in fig4 the power can also flow in either direction. The converter consists of a three-phase bridge, a high capacitance on the dc side and a three-phase inductor in the line-side. The voltage at the midpoint of a leg or the pole voltage vi is pulse width modulated (PWM) in nature. It is well known that the active power flows from the leading voltage to the lagging voltage and the reactive power flows from the higher voltage to the lower voltage. Therefore, both active and reactive power can be controlled by controlling the phase and magnitude of the converter voltage fundamental component with respect to the grid voltage

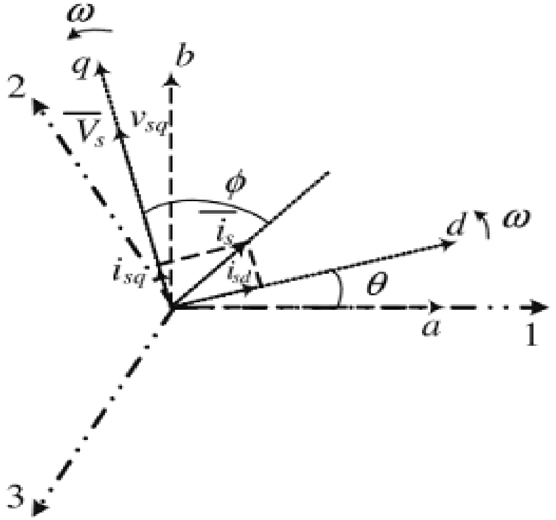

Fig: 5 Stationary and synchronously revolving frames of reference.

The grid side controller shown in fig 4 is fed from the ac mains. Mains voltages vs1, vs2 and vs3 are defined in (3), where Vs is the rms value of phase to neutral voltage. The three-phase voltages can be transformed into two-phase quantities vsa and vsb, which are the components of voltage vector Vs along a-axis and b-axis, respectively, in the stationary reference frame fig 5

$v_{s1} = \sqrt{2}Vs\ \cos\omega t$ (3)

$v_{s2} = \sqrt{2}Vs\ \cos(\omega t - 120^o)$

$v_{s3} = \sqrt{2}Vs\ \cos(\omega t - 240^o)$

$v_{sa} = 3/\ 2\ vs1 = 3/\ 2\sqrt{2}Vs\ \cos\omega t$. (4)

$v_{sb} = \sqrt{3}/\ 2(vs2 - vs3) = 3\ /2\sqrt{2}Vs\ \sin\omega t.$ (5)

These voltages can further be transformed into a synchronously revolving d–q reference frame, where q-axis is aligned with the voltage vector Vs and the d-axis lags the q-axis by 90◦ as shown in fig 5 This transformation is performed using (6 -7), where θ is the angle of the d-axis measured from the a-axis. The other three-phase quantities, namely line currents(i_{s1} ,i_{s2} and i_{s3})and the converter pole voltages (v_{i1},v_{i2} and v_{i3}),can also be similarly transformed to the d–q reference frame.

$v_{sq} = (-v_{sa}\sin\theta + v_{sb}\cos\theta)$ (6)

$v_{sd} = (v_{sa}\cos\theta + v_{sb}\sin\theta)$ (7)

The voltage equations of the grid side controller in the d–q reference frame are given by (8 -9), where Rs and Ls are the resistance and inductance, respectively, of the line inductor.

$R_s i_{sd} + L_s(di_{sd}/dt) - \omega L_s i_{sq} + v_{id} = 0$ (8)

$R_s i_{sq} + L_s(di_{sq}/\ dt) + \omega L_s i_{sd} + v_{iq} = v_{sq}.$ (9)

Unit vector generation

In order to transform any vector from stationary reference frame into d–q reference frame ,the quantities sinθ and cosθ, which are the components of a revolving unit vector are required (see equations 6 and 7). These quantities should have the same frequency as that of the system voltage.

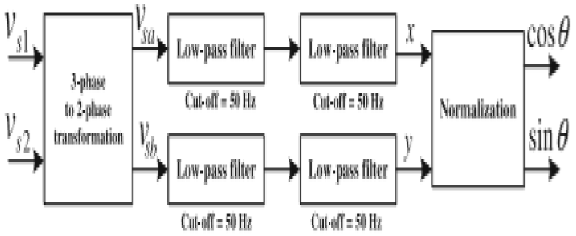

Fig : 6 unit vector generation block diagram

The voltage vector Vs is at an angle ωt (see equation (3)) with respect to the a-axis. The components v_{sa} and v_{sb} of the vector are as shown in equations (4 and 5). A low-pass filter, whose corner frequency equals the mains frequency, delays v_{sa} (or v_{sb}) by 45 ◦. Two such filters in cascade delay v_{sa} (or v_{sb}) by 90 ◦ as shown in (10 and11). Fig 6 illustrates such a filter arrangement followed by normalization as given by (12 and 13). Such filtering and normalization yields cosθ and sinθ, where θ is the angle between a-axis and d-axis required for the transformation in (6 and 7).

$$x = 3/4\sqrt{2}V_s \cos(\omega t - \pi/2) = 3/4\sqrt{2}V_s \cos\theta \qquad (10)$$

$$y = 3/4\sqrt{2}V_s \sin(\omega t - \pi/2) = 3/4\sqrt{2}V_s \sin\theta \qquad (11)$$

$$\cos\theta = x/\sqrt{(x^2+y^2)} \qquad (12)$$

$$\sin\theta = y/\sqrt{(x^2+y^2)} \qquad (13)$$

Vector control approach

The overall block diagram of a vector controlled converter is shown in figure 7.The mains voltages and the line currents are transformed into d–q reference frame, and are used as feedback variables for the controller as shown in the figure. The control calculations are performed in the d–q reference frame.

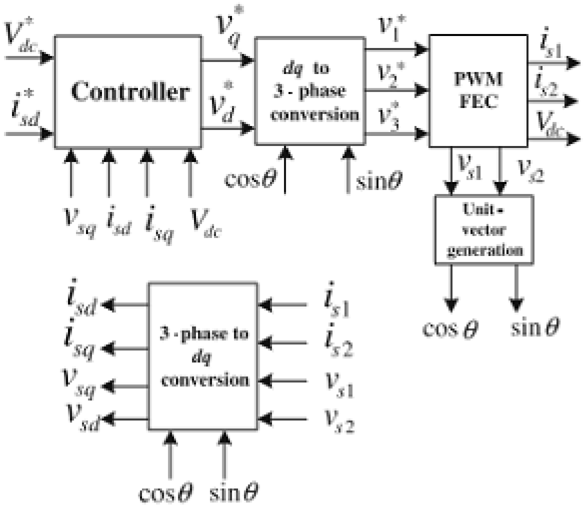

fig : 7 block diagram of control approach

Feed forward terms

A cross coupling exists between the d-axis and the q-axis quantities. To ensure decoupled control of i_{sd} and i_{sq}, feed forward terms v_{dff} and v_{qff} respectively, are added to the outputs of the d-axis controller (v''_{id}) and the q-axis controller (v''_{iq}) illustrated in fig 8

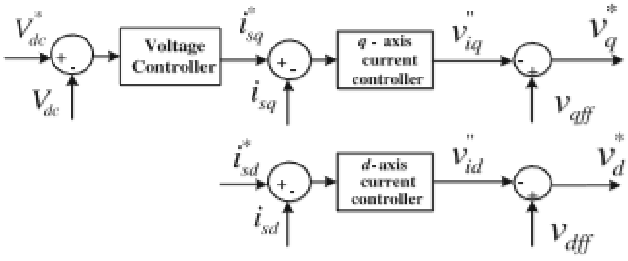

Fig : 8 voltage and current controls of grid side controller.

III RESULTS

Vector-controlled grid side converter is simulated with MATLAB/SIMULINK. The system parameters are

% Timing parameters %

Tsim = 1e-4; % Model step time

Td = 1e-6; % Dead time

Fclk = 150e+6; % controller clock frequency

Tinv=200e-6; % Inverter switching frequency

% References %

Vdc_ref=600; % Reference DC link voltage

Isq_ref=-1.5*2;

% Inductor and supply parameters %

Vph=(Vdc_ref*0.707)/(sqrt(3)); % Supply voltgae

f=50; % Supply frequency

w=2*pi*f;

Ls=30e-3; % Source inductance

Rs=1.25; % Source resitance

% Limits %

Vmax=1.5*Vph*sqrt(2); %Max voltage vector length

Idmax=5*1.5*sqrt(2); % Max Current vector length

Idcmax =Idmax;

Idlim=Idmax;

% Current controller parameters %

Ti=1e-3; % Current controller bandwidth

Kp=Ls/Ti; % Current cntroller Proportionla gain

Ki=Rs/Ti; % Current controller Integral gain

% Voltage controller parameters %

Tv=1e-2; % DC link voltgae controller bandwidth

Kpv=0.407*(2/3); % DC link voltage controller proportional gain

Kiv=23.5*(2/3); % D C link voltage controller Integral gain

The main aims of the proposed system is to make vdc constant and to make vg and ig in phase so as to maintain unity power factor by adjust iq reference . Here we have studied the performance of the system for unity, lagging and leading by providing iq reference signal as zero, positive and negative magnitude implemented with the help group signal block in matlab Simulink. The step signal shown below gives the idea of reference value Iq at each point of time. In this Simulink model we have kept run time of t=1.5sec

Fig 9 input reference iq signal

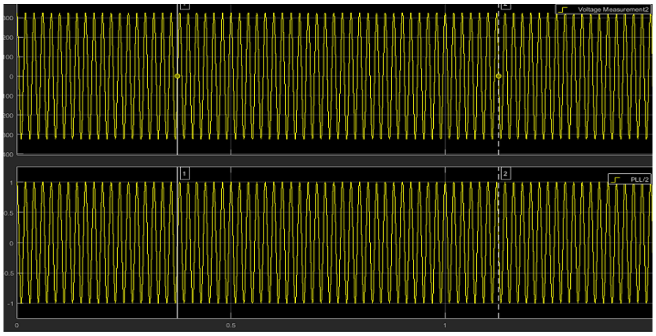

Fig 10 comparision of frequency of source voltage and output normalization of PLL

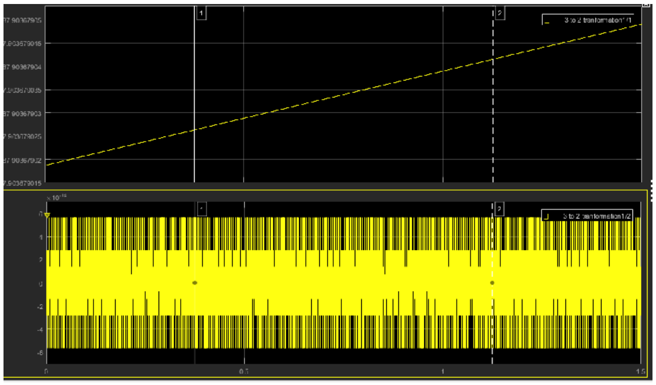

Fig 11 shows out of 3 to 2 phase transformation where vd reference settle at tits value where vq reference is zero

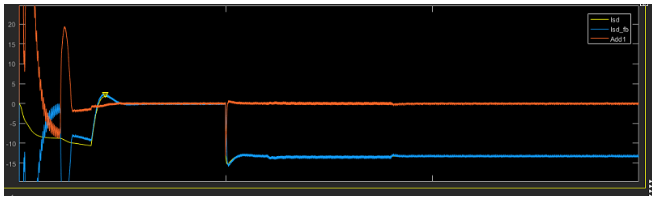

Fig 12 shows the oupput of id current controller following refrence

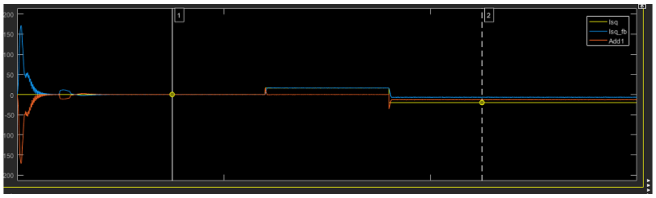

Fig 13 shows output of iq current controller following reference current iq

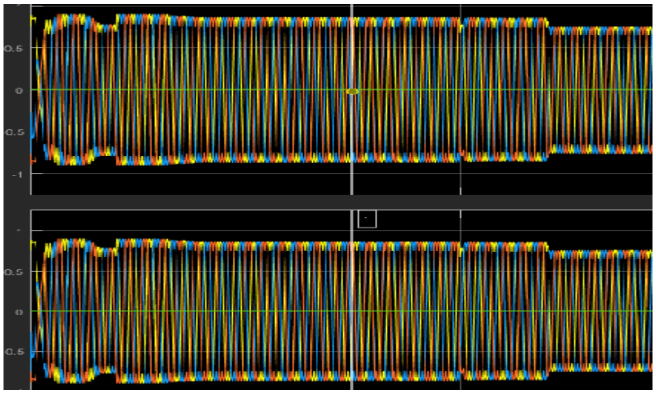

Fig 14 shows space vector pluse width modulation

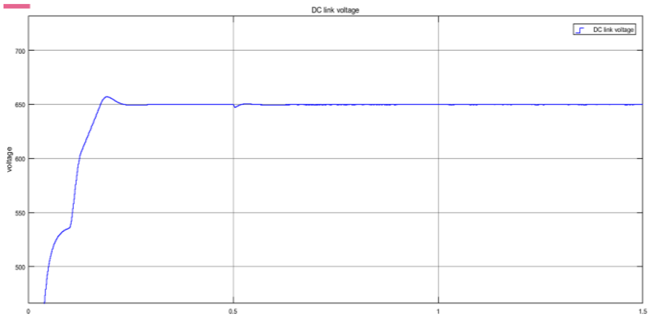

Fig 15 shows constant dc bus link voltage

The objectives of the vector control are given as Voltage regulation of the DC-bus, Independent active and reactive power control, Bidirectional power flow, Operation at any desired power factor and Low current harmonics.

Achievements with vector control in the project, Making vg and ig in phase so as to maintain unity power factor by adjust iq reference and DC bus voltage regulation

Suppose load increases our DC-bus voltage reduces. We will give this information to DC- bus voltage controller which increases the current reference so that active current drawn from the supply increases to maintain active power balance between DC-bus side and grid side. Similarly if load decreases our DC-bus voltage increases, we will give this information to DC-bus voltage controller which reduces the active current drawn from the supply to maintain active power flow balance between DC side and grid side and allow Unity power factor operation.

If we make reactive current reference equal to zero in inner reactive current loop then we get unity power factor operation

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