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Stator Flux Oriented Vector Control of Wind Driven Self Excited Induction Generator Connected to Grid through Cycloconverter

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Abstract

This paper deals with the stator flux oriented vector control of wind driven self excited induction generator through the cycloconverter at the point of common coupling. The control strategy of supplying the firing pulses is based on the stator flux oriented vector control of Self excited induction generator. The proposed cycloconverter is able to eliminate up to 21st harmonics in the supply current. The effect of load variation on Vector Controlled Self Excited Induction Generator (VCSEIG) through the cycloconverter is also studied to demonstrate the effectiveness of the proposed method. The complete electromechanical system is modeled and simulated in MATLAB using Simulink and simpower system block set. The simulated results are presented for regulating voltage and frequency of SEIG driven by wind turbine. The present study includes circulating current and semi-circulating current modes of operation with study of measuring and correction of output power factor of the cycloconverter and output voltage waveform harmonics.

Keywords: Cycloconverter,VCSEIG,step up transformer

1. Introduction

A wind power generation system generates electricity from wind energy and typically comprises an induction generator coupled to a wind turbine. In a wind power generation system, the mechanical energy of the wind turbine is converted into electrical energy by the induction generator. A **S**quirrel Cage Induction Generator (SCIG) is highly suitable to be driven by wind turbine because of its small size and weight, robust construction and reduced maintenance cost [1]. In order to initiate voltage generation by the induction generator (self-excitation), a leading reactive power is provided to the stator windings of the generator by connecting a capacitor bank to the stator windings. The induced e.m.f. and current in the stator winding starts rising and attains its steady-state value with frequency dependent on rotor speed and machine parameters. The generated voltage is sustained at this operating point till reactive power balance is maintained [2]. This, in turn, changes the generated torque and the rotor speed varies causing further changes in the generated voltage. This leads either to a collapse of the terminal voltage or building up to an excessively high value depending upon the values of the magnetizing inductance and the terminal (excitation) capacitance [3].

A cycloconverter is a type of power controlled in which an alternating voltage at supply frequency is converted directly to an alternating voltage at load frequency without any intermediate d.c stage. A cycloconverter is to controlled through the timing of its firing pulses, so that it produces an alternating output voltage. By controlling the frequency and depth of phase modulation of the firing angles of the converters, it is possible to control the frequency and amplitude of the output voltage. Thus, a cycloconverter has the facility for continuous and independent control over both its output frequency and voltage. This frequency is normally less than 1/3 of the input frequency. The quality of output voltage wave and its harmonic distortion also impose the restriction on this frequency. The distortion is very low at low output frequency.

Cycloconverters are suitable for large a-c machines because it has advantages:it has high efficiency owing to the simple construction of the main circuit, which consists, in its basic form, simply of an array of thyristor switches [5], and it is also naturally commutative, and no forced commutation circuits are necessary. As the same time it suffers from some disadvantages. It has a low maximum output frequency compared to the input frequency, and it suffers from voltage distortion. The application of a cycloconverter is rather limited, because the control circuit is often very complex, and therefore expensive[2].

1.1. System Configuration

The proposed system is as shown in Fig.1

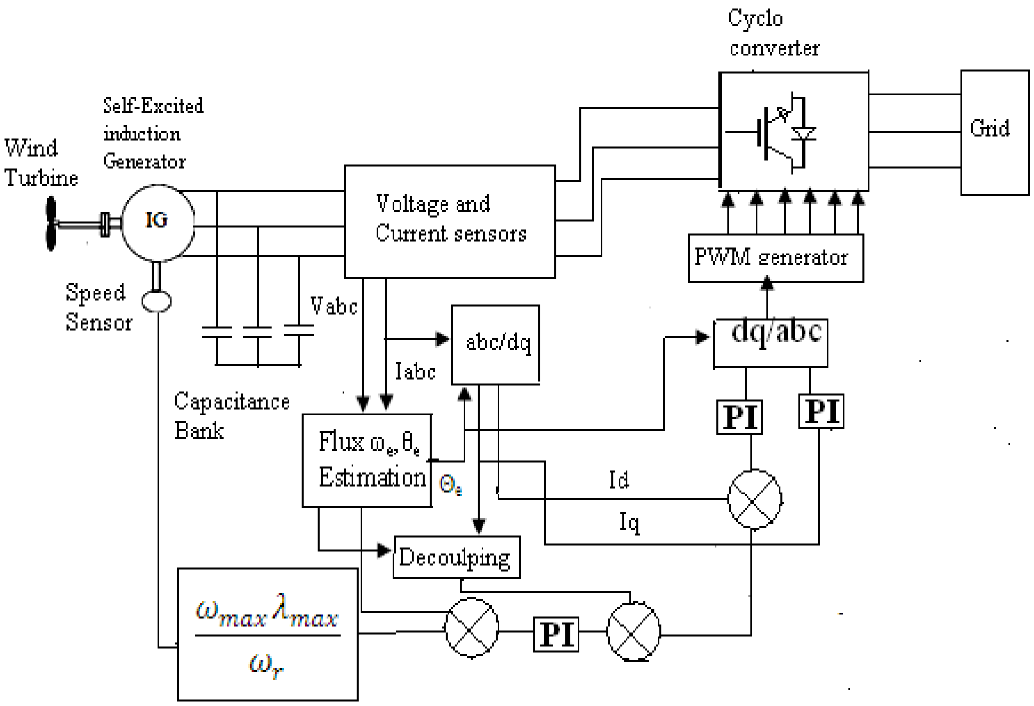


Fig.1.Overall system description

1.2 System Description

Fig. 1 shows the wind driven self excited induction generator with excitation capacitor, consumer loads, and conventional three phase cyclo converter. In order to control the output voltage of the phase-controlled converter or cycloconverter, it is necessary to control the phase of the thyristor firing pulses. Many alternatives exist for achieving this end. The task of a firing controller is to generate time-varying sequences of pulses for triggering the thyristor devices. In this work the control strategy is based on vector control technique.The output of the cycloconverter is connected to the grid through the step-up transformer.

1.3. Design Of The cycloconverter

As in case of the rectifier or phase-controlled converter circuit, from the view point of reducing the external harmonic voltages and currents to a minimum, the pulse number of the cycloconverter circuit should be as high as possible. Fig2 represents the diagram of three-phase to three-phase six-pulse bridge cycloconverter. A number of pure sinusoidal single phase supply are formed to represent a double secondary output of three-phase transformer

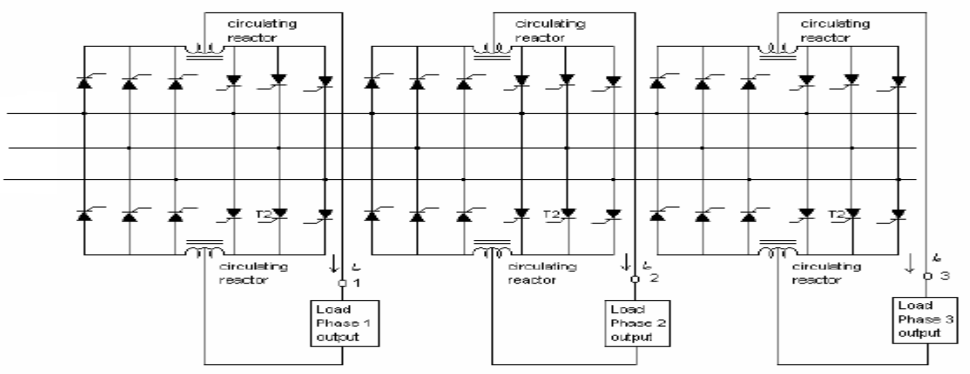


Fig.2. Six-pulse 3-phase to 3-phase bridge cycloconverter

Where first set represents the first secondary winding which shifted 30 degree to perform the zero crossing instant when using delta-star connection of three-phase transformer, and the second set represents the second windings, and it gives an inherently 180 degree phase shift between the input voltage waves for each converter. This makes the instants of starting new timing waves, i.e. the instants of zero firing angle for the positive converter coincide with those of the negative converter.,Which simplifies the control circuit model.

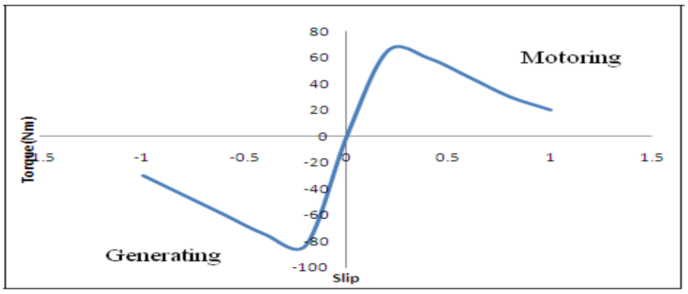
In the above fig.1 the constant prime mover shaft was connected to Induction generator shaft. In this paper uncontrolled wind turbine is used as a constant prime mover. These turbine characteristics and Induction generator parameters have given in APPENDIX. And the excitation capacitor bank value is depends on generator output parameters.

A.3.5KW, 440V, 50HZ Induction machine is used as SEIG and modeled using available power electronics block set like diode bridge rectifier and connected to a 440 V grid supplying to the college laboratories. Simulation is carried out in MATLAB version of 10 above at discrete step of 50E-6.Detailed simulation and analysis are given in the following section

2. Control Scheme

Stator flux oriented control is used in this paper. Its accuracy is dependent only on the stator resistance variation. In addition, it is insensitive to the variation in the leakage inductance of the machine. In induction motor the application of stator flux oriented control the parameter variation of resistance R_s tends to reduce the accuracy of the estimated signal at low voltage [1]. However, at higher voltage the effect of parameter variation in R_s can be neglected. Flux estimation accuracy in rotor flux oriented control is affected by rotor parameters. The rotor resistance variation becomes dominant by temperature and skin effect in squirrel cage induction machines [3].

Fig. 3 torque-slip



Induction machine characteristics

Compensation of this parameter is difficult because of inaccessibility, but it easier to compensate R_s [4].

As can be seen in Fig. 3, for the same magnitude of slip, the peak electromagnetic torque developed by the induction machine in the generating region is higher than that of the motoring region. Hence in the generating region the induction machine operates at a lower magnitude of slip than the corresponding motoring region for the same magnitude electromagnetic torque.

1.2. Induction Generator model and stator flux estimation

The induction generator shown in Fig. 1 can be described by the following equations in a reference frame with arbitrary angular speed ω_a.

$$V_s = i_s R_s + \frac{d\psi_s}{dt} + j\omega_a \psi_s \qquad (1)$$

$$0 = i_r R_r + \frac{d\psi_r}{dt} + j(\omega_a - \omega_r)\psi_r \qquad (2)$$

$$\psi_s = L_s i_s + L_m i_r$$

(3)

$$\psi_r = L_r i_r + L_m i_s$$

(4)

Equations (1) and (2) can be simplified by choosing the stationary reference frame (ω_r= 0). By eliminating the rotor currents and rotor flux linkages from (2), we obtain the following equations, which include the stator currents and the rotor flux linkages as state variables

$$\frac{d\psi_{s\alpha}}{dt} = V_{s\alpha} - R_s i_{s\alpha}$$

(5)

$$\frac{d\psi_{s\beta}}{dt} = V_{s\beta} - R_s i_s \qquad (6)$$

$$\frac{d\psi_{s\alpha}}{dt} = \frac{1}{L_m^2 - L_s L_r}(R_r L_s i_{s\alpha} - R_r \psi_{s\alpha} - (L_m^2 - L_s L_r)\omega_r i_{s\beta} - L_r \omega_r \psi_{s\beta}$$

(7)

$$\frac{d\psi_{s\beta}}{dt} = \frac{1}{L_m^2 - L_s L_r}(R_r L_s i_{s\beta} - R_r \psi_{s\beta} - (L_m^2 - L_s L_r)\omega_r i_{s\alpha} - L_r \omega_r \psi_{s\alpha} \qquad (8)$$

The magnetizing inductance as a function of the magnetizing current (($L_m = f(i_m)$) is required in Eqs. (7) and (8). This is known, as it is calculated from the magnetization curve obtained from the traditional no-load test .Estimation of the stator flux is based upon Eqs. (5) and (6), which are affected only by stator resistance variation.

1.3. Stator flux oriented control system

In order to model any field oriented control system, it is necessary to choose the synchronously rotating reference frame (d, q). This means that the arbitrary angular speed ω_a becomes ω_e . In the Statr flux oriented control system, the stator flux vector is aligned with the d-axis, which means

$$\psi_s = \psi_{sd} \; and \; \psi_{sq} = 0$$

(9)

Taking eq(4) into account eq(2) becomes

$$0 = \frac{1}{T_r}\psi_r - \frac{L_m}{T_r}\psi_r + s\psi_r + j(\omega - \omega_r)\psi_r$$

(10)

where s is the Laplace operator s=$\frac{d}{dt}$

Taking (3) and (4) into account, (10) can be modified as

$$(1 + sT_r)\psi_s - (1 - s\sigma T_r)L_s i_s - j\omega + sT_r(\psi_s - \sigma L_s i_s)$$

(11)

Rewriting (11) in the d, q reference frame and considering (9), (11) becomes

$$(1 + sT_r)\psi_r = (1 + s\sigma T_r)L_s i_{sd} - T_r \omega_s \sigma L_s i_{sq})$$

(12)

$$\omega_s T_r(\psi_s - \sigma L_s i_{sd}) = (1 + s\sigma T_r)L_s i_{sq}$$

(13)

Equations (12) and (13) indicate that the stator flux ψ_{sd} is a function of both the $i_{sd}$and i_{sq} currents. In other words, there is a coupling effect. Consider the decoupler shown in Fig. 1 where the decoupling signal i_{dec} is added to the stator flux control loop to generate the d-axis stator current reference i_{sd} . This decoupling signal can be calculated using the following equation [9]

$$i_{dec} = \frac{\sigma L_s i_{sq}^2}{\psi_s - \sigma i_{sd} L_s} \tag{14}$$

Hence, the stator flux in the Stator Flux Oriented control system is controlled by the d-axis stator current in the d, q reference frame.

1.4. Operation of Six-pulse 3-phase to 3-phase bridge cycloconverter

Commercial 3 phase cycloconverter machine drives, with their 36 thyristor, 6-pulse circuits with input isolation transformers, are too expensive except for specialized applications. The 3-pulse cycloconverter is low enough in cost for general purpose use, particularly where regeneration is required, as it has only 18 thyristors and does not require transformers, but the performance with conventional modulation techniques is inadequate. The use of double integral control corrects this problem and, as can be seen from the test data in this section, results in a performance which in some areas is comparable to that of the conventional 36 thyristor 6-pulse cycloconverter

Three identical three-phase input to single-phase output, 3-pulse (or 6-pulse in circulating current mode) cycloconverters connected together to supply a three-phase load. For a balanced three-phase output, theoretically, there is no need to connect the load neutral to the supply neutral and therefore it is not possible to have zero-sequence current components in the input lines. Another advantage of three-phase output circuits with a floating neutral point or even without a neutral point such as the delta connection is that it provides a better harmonic content in the output line-to-line voltage due to the cancellation of the common mode voltage harmonics between the outputs.

2. Results and Discussions

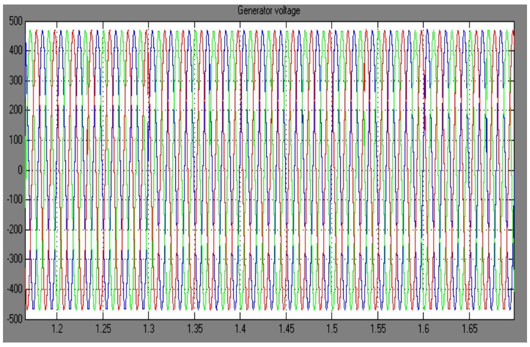
The simulation stator oriented vector control is implemented using MATLAB/SIMULINK. The features in the Power Systems Blockset are used to model an inverter, rectifier and all circuit components. The induction machine model in the Power Systems Blockset is modified to include speed as an input and to update the variation of magnetizing inductance as the voltage builds up during self-excitation. To get the right control parameters and performance it is simply a matter of tuning the PI controllers in the DC voltage controller and flux linkage controller given in Fig. 1.

If the excitation capacitance is too small there will not be enough exciting current and as a result there will not be voltage build up. Fig.4 shows the no load build up of generated line to line voltage at the terminals of the induction generator during the start of self excitation. The voltage build up process is under the no load condition. If there is load, with magnitude above a given minimum value, the voltage build up process will fail.

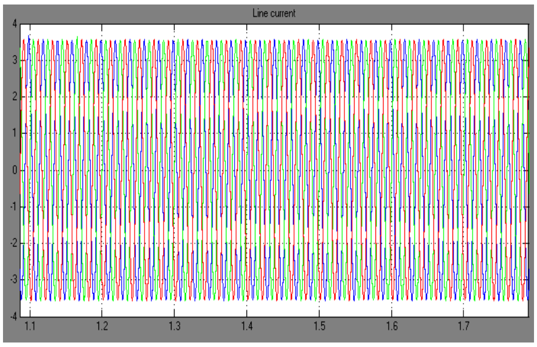
The frequency of the generated voltage is estimated as :

$$\omega_e = \frac{(V_{qs} - i_{qs} R_s)\lambda_{ds} - (V_{ds} - i_{ds} R_s)\lambda_{qs}}{\lambda_{qs}^2 + \lambda_{ds}^2} \tag{15}$$

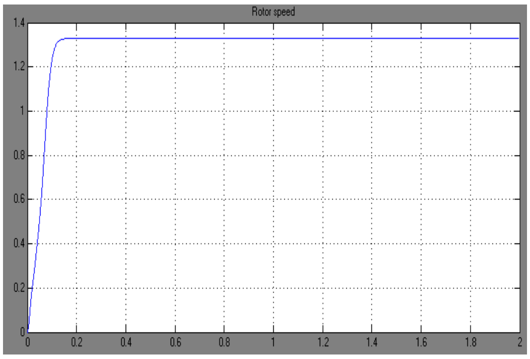
Here, transient waveforms of the generator voltage (Vabc), generator current (Igabc), Speed of the generator ,Electromagnetic torque, Voltage at the cycloconverter, Active and reactive power at the generator,Voltage at the step-up transformer, Load voltage, Load current and Active and reactive power at the load are given under the sudden application and short circuit at grid are as shown in Fig.4.respectively.


Generator voltage
500
400
300
200
100
0
-100
-200
-300
-400
-500
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65

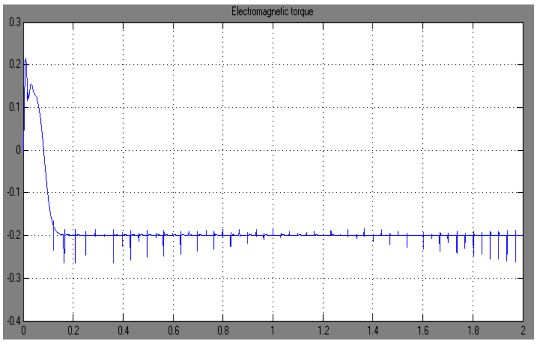
(a)


Line current
4
3
2
1
0
-1
-2
-3
-4
1.1
1.2
1.3
1.4
1.5
1.6
1.7

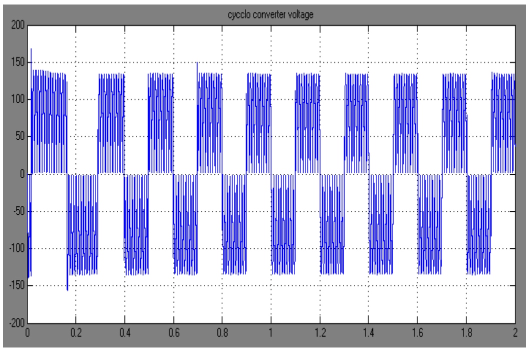
(b)

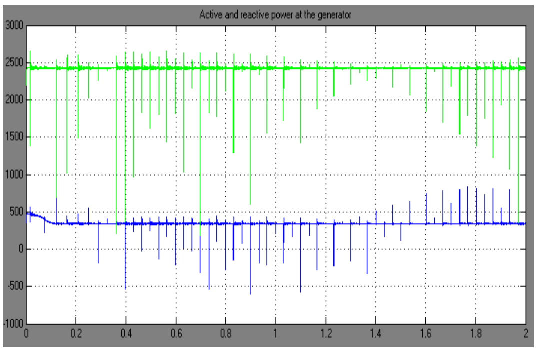

Rotor speed
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

(c)


Electromagnetic torque
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

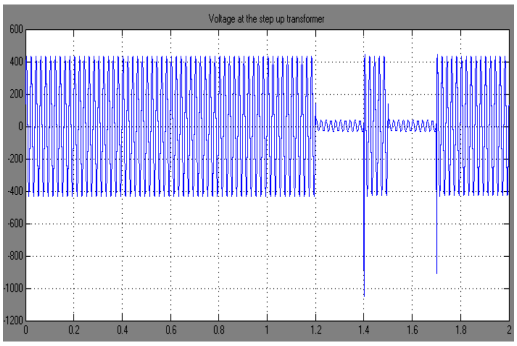
(d)

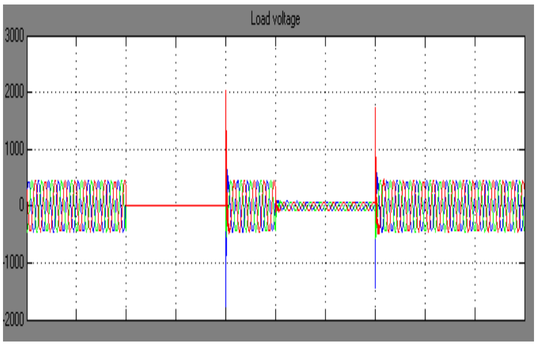

cycclo converter voltage
200
150
100
50
0
-50
-100
-150
-200
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


Active and reactive power at the generator
3000
2500
2000
1500
1000
500
0
-500
-1000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

(e)

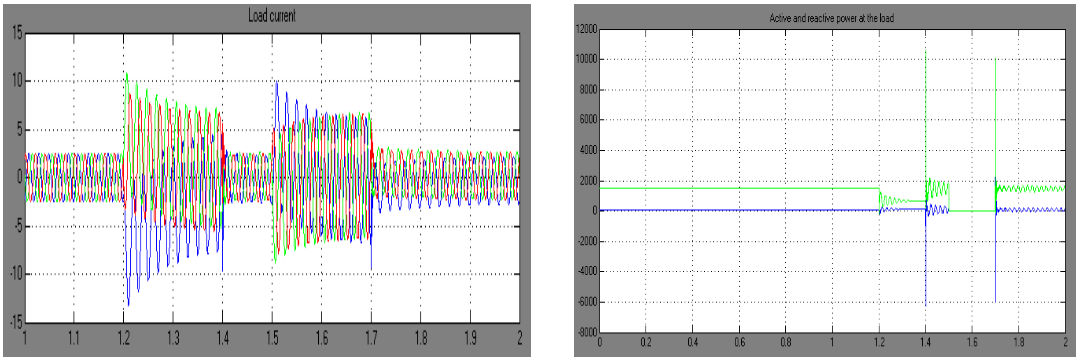
(f)


Voltage at the step up transformer
600
400
200
0
-200
-400
-600
-800
-1000
-1200
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


Load voltage
3000
2000
1000
0
-1000
-2000

(g)

(h)



(i) (j)

Fig.4.(a).Generated Voltage **(b).Line current** **(c).Rotorspeed**
(d).Electromagnetic torque **(e).Voltage at the cycloconverter**
(f).Active and reactive power at the generator **(g).Voltage at the step-up transformer**
(h)Load voltage **(i)Load current**
(j). Active and reactive power at the load

The MATLAB/Simulink model is as shown in Fig.5.This is designed using the Simulink block set
The load is applied at grid suddenly at t=1.0 sec to t=1.2 seconds. And short circuit is applied at load t=1.4sec to t=1.6 seconds. And the transient waveforms are observed as follows.

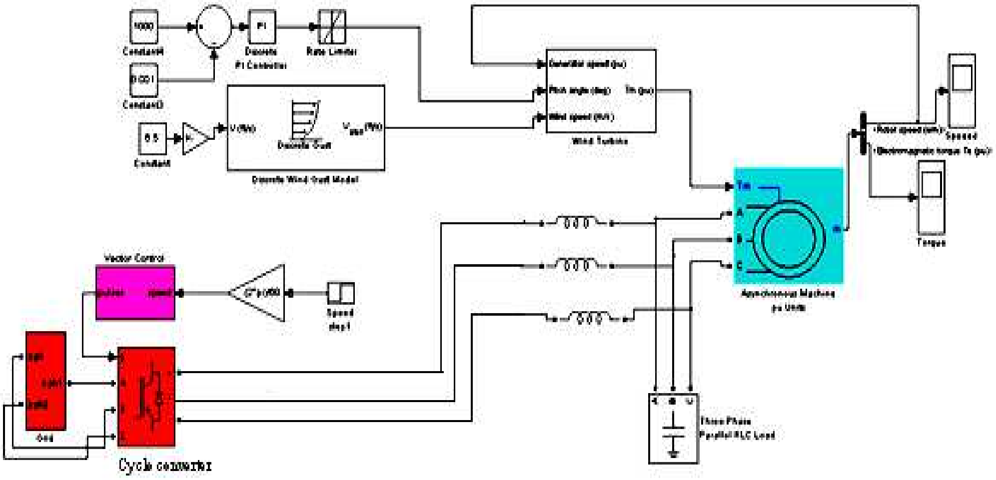


Fig.**5. Simulink/MATLAB model for vector control of SEIG through cycloconverter**

3. Conclusion

The voltage build up process of an induction generator with a cycloconverter using stator flux oriented vector control is discussed. Since due to the cycloconverter there is a decrease in the voltage, the voltage is increased using the step up transformer.

The total flux is aligned to the d-axis of the stator flux in the excitation reference frame. A decoupling signal is also generated the effect of q-axis current on the d-axis flux. The main advantage of stator flux oriented vector control is the magnitude of the estimated flux depends only on the stator resistance. Unlike the rotor resistance the variation of stator resistance depends manly on temperature. If the variation of stator resistance is causing a significant error then a compensation block can be added in the model.

The power quality has been improved using cycloconverter and the disadvantage with the cycloconverter is Harmonics are increased compared to the conventional vector control methods. This is demonstrated on the basis of simulation using standard software MATLAB. Hence the improved performance of voltage and frequency regulation of a wind turbine driven self excited induction generator.

Appendix

1. Machine Parameters

The parameters of the 3.5 kW,440V, 7.5A, 50 Hz,4-pole induction machine are given below.

$R_s = 0.69\ \Omega$, $R_r = 0.74\Omega$, $L_{ls} = L_{lr} = 1.1$ mH, J = 0.23kg/m2,

$L_{ss} = L_{ls} + L_m$ and $L_{rr} = L_{lr} + L_m$.

2. Excitation capacitor C = 15 µF/ phase and Capacitor at rectifier C=3200 µF

3. **Air gap voltage**:

The piecewise linearization of magnetization characteristic of machine is given by:

E_1=0	$X_m \geq 260$
E_1=1632.58-6.2X_m	$233.2 \leq X_m \leq 260$
E_1=1314.98-4.8X_m	$214.6 \leq X_m \leq 233.2$
E_1=1183.11-4.22X_m	$206 \leq X_m \leq 214.6$
E_1=1120.4-3.9.2X_m	$203.5 \leq X_m \leq 206$
E_1=557.65-1.144X_m	$197.3 \leq X_m \leq 203.5$
E_1=320.56-0.578X_m	$X_m \leq 197.3$

4. Magnetics Rating:

12-pulse-based converter: Autotransformer rating 12Kva,
Interphase transformers 2.7kVA, passive filter 3kVA.References

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