International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.3., Issue.1, 2015

RESEARCH ARTICLE

ISSN: 2321-7758

# Modeling and simulation of Concentrated Solar Thermal Plant (CSTP) turbine based DG system feeding Vector Controlled Motor

**RAVI KRISHNA SUNKARA[1], KRISHNA KUMBA[2]**

[1,2]Dept of Electrical & Electronics Engineering

Nalanda institute of Engineering & Technology, Andhra Pradesh, India

Article Received: 01/01/2015 | Article Revised on: 08/01/2015 | Article Accepted on:10/01/2015

**Ravi Krishna Sunkara**

**Krishna Kumba**

ABSTRACT

The stunning attributes of Concentrated solar thermal plant turbines is gaining the attention of Engineers today. Simultaneous generation of heat and electricity with the flexibility to run on different renewable fuels reduces the cost of energy production and difficulty to reduce waste disposal. In order to achieve this Distributed generation came in to the picture and works efficiently and eco friendly. CSTP turbine generator systems are considered as distributed energy resources which are interfaced with the electric power distribution system. This paper presents the implementation of the Distributed generation using CSTP turbine feeding to vector controlled induction motor drive and other static loads. In this modeling of Micro turbine, PMSM, VCIM, 2-level Inverter with SPWM is required. The PMSM, VCIM and Inverter models are built on dq reference frame and implemented in M TL B/SIMULINK using SIM POWER SYSTEMS Library. The performance of the proposed model studied/simulated and analyzed for different load variations.

**Keywords:** CSTP turbine, Distributed generation, PMSM, VCIM, filters, SPWM, converter controller.

**Nomenclature:**

F: Combined viscous friction of rotor and load J: Combined inertia of rotor and load

$L_q$, $L_d$: q and d axis inductances $p$ :Number of pole pairs

R: Resistance of the stator windings $T_e$: Electromagnetic torque

$T_M$: Shaft mechanical torque

$V_d$, $V_q$, $i_d$, $i_q$ = d-axis and q-axis voltages and Currents respectively

$\vartheta$ : Rotor angular position

λ : Flux induced by the permanent magnets in the stator windings

$\omega_r$ : Angular velocity of the rotor

$\Psi_d$ , $\Psi_q$ : d-axis and q-axis Flux linkages

**INTRODUCTION**

Based on user's demand of Quality, Reliability and Security of electric power, Distributed generation is the alternative method for providing electricity to consumers and retailers. Distributed power is a concept that covers a wide spectrum of schemes used for local electric power generation from renewable and non-renewable sources of energy in an environmentally responsible way. The other main disadvantage of transmission of electricity from power plant to typical user wastes roughly 4.2 to 8.9 percent of the electricity as a consequence of aging transmission equipment, inconsistent enforcement of reliability guidelines and growing congestion is overcome by DG system. Distributed generator is generally connected directly to grid (ANSI/IEEE C84.1-1995, IEEE 519-1992, I 929-2000, IEEE 1547-2003) or can operate independently. It has various applications such as peak shaving, co-generation, remote power and base load power which make its use worldwide. Main schemes are mainly based on Solar energy, Wind energy, Fuel cells and CSTP turbine energies.

In this paper CSTP turbine based Distributed generation system is implemented to feed to vector controlled induction motor drive and other static loads. The CSTP turbine provides input mechanical energy for the generator system, The generator nominal frequency is usually in the range of 1.4 - 4 KHz. This frequency stepped down to 60Hz (or) 50Hz frequency trough Inverter and Rectifiers. The electrical energy passing through the transformer is delivered to the Grid or used to run the local loads.

**II. CSTP TURBINE:**

CSTP turbine is one of DG sources system. These are small and simple-cycle gas turbines with outputs ranging from fraction of kilo watts to few hundreds of kilo watts. Micro turbine designs usually consist of a single stage radial compressor, a single stage radial turbine and a recuperator. Typical CSTP turbine efficiencies are 25 to 35%. When in a combined heat and power cogeneration, efficiencies of greater than 80% are commonly achieved. The typical model consists of speed governor, acceleration control blocks, fuel system control, temperature control and turbine dynamics. The simplified single shaft gas turbine including all its control systems is implemented in MATLAB / SIMULINK is shown in fig. 1 [5, 6].

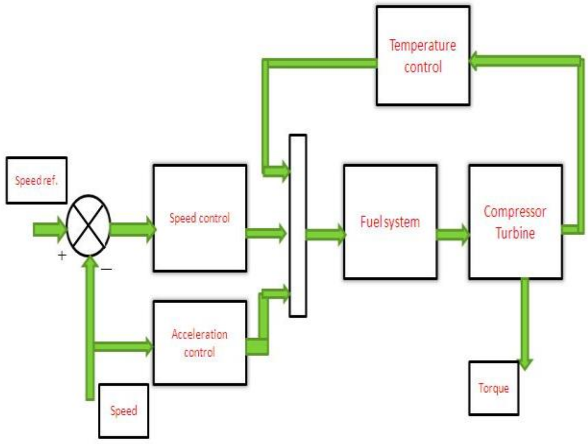



**Fig1: Control System of Microturbine**

**III.PMSM MODELING AND CONTROL**

High energy permanent magnets and high yield strength materials like neodymium-iron- boron (NdBFe) or Samarium-cobalt magnets are very suitable for high speed electrical machines [1],[5]. In a permanent magnet synchronous machine (PMSM), the dc field winding of the rotor is replaced by a permanent magnet. The advantages are elimination of filed copper loss, higher power density, lower rotor inertia, and more robust construction of the rotor. The drawbacks are loss of flexibility of field flux control and possible demagnetization. The machine has higher efficiency than an induction machine, but generally its cost is higher. The analysis of the PMSM is done in dqo axis theory. For a balanced system the 0-axis quantities are equal to zero, the dq axis equations can be written as follows:

Electrical equations:

$$T_e = 1.5\rho(\lambda i_q + (L_d - L_q)i_d i_q) \quad ...1$$

$$\frac{d}{dt} i_d = \frac{1}{L_d} V_d - \frac{R}{L_d} i_d + \frac{L_q}{L_d} \rho\omega_r i_q \quad ...2$$

$$\frac{d}{dt} i_q = \frac{1}{L_q} V_q - \frac{R}{L_q} i_q - \frac{L_d}{L_q} \rho\omega_r i_d - \frac{\lambda\rho\omega_r}{L_q} \quad ...3$$

Mechanical equations:

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - F\omega_r - T_M) \quad ...4$$

$$\frac{d}{dt}\theta = \omega_r \quad ...5$$

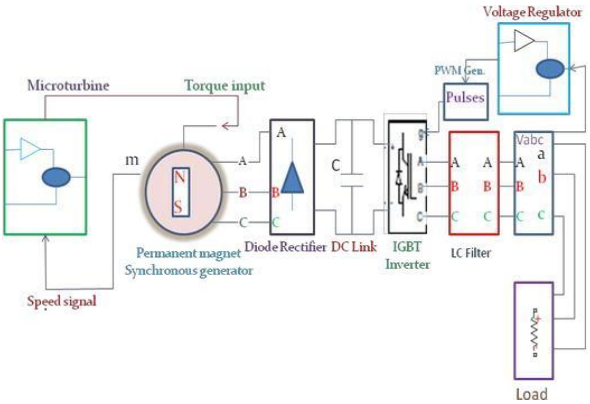



**Fig2: Operation of Distributed Generation System**

**INDUCTION MOTOR MODELING AND CONTROL**

The dynamic equations of the induction motor in any reference frame can be represented by using flux linkages as variables. This involves the reduction of a number of variables in the dynamic equations. Even when the voltages and currents are discontinuous the flux linkages are continuous. The stator and rotor flux linkages in the stator reference frame are defined as

$$\left.\begin{aligned} V_{ds} &= R_s\, i_{ds} + \rho\, \varphi_{ds} \\ V_{qs} &= R_s\, i_{qs} + \rho\, \varphi_{qs} \\ V_{dr} &= R_r\, i_{dr} + \rho\, \varphi_{qs} + \omega_r \varphi_{qr} \\ V_{qr} &= R_r\, i_{qr} + \rho\, \varphi_{qr} - \omega_r \varphi_{dr} \end{aligned}\right\} \quad \text{...6}$$

$$\left.\begin{aligned} \varphi_{qs} &= L_s\, i_{qs} + L_m\, i_{qr} \\ \varphi_{ds} &= L_s\, i_{ds} + L_m\, i_{dr} \\ \varphi_{qr} &= L_r\, i_{qr} + L_m\, i_{qs} \\ \varphi_{dr} &= L_r\, i_{dr} + L_m\, i_{ds} \\ \varphi_{qm} &= L_m\, (i_{qr} + i_{qs}) \\ \varphi_{dm} &= L_m\, (i_{dr} + i_{ds}) \end{aligned}\right\} \quad \text{....7}$$

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(i_{qs}\varphi_{dr} - i_{ds}\lambda_{qr}\right) \quad \text{...8}$$

$$T_e - T_L = \frac{2}{P} J \frac{d\omega_r}{dt} \quad \text{...9}$$

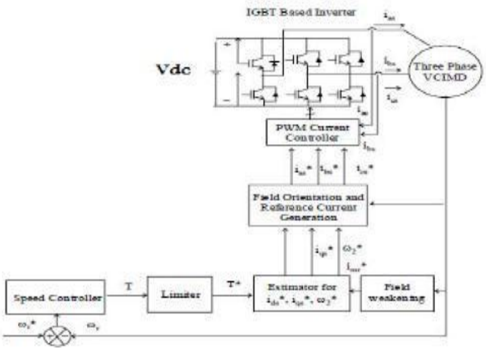



Fig3: Induction Motor controlled by indirect vector control method

**V. Modeling of 2-level Inverter with SPWM:**

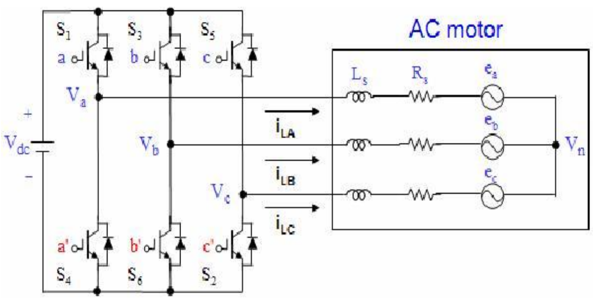



**Fig4: Power Circuit for Two-Level Inverter**

Three phase inverters are widely used for AC motor drives and general purpose AC supplies. t consists of three half-bridges, which are mutually phase shifted by 2∏/3 angle to generate the three phase voltage waves. Here the input DC supply obtained from out put of the generator through a three phase diode-bridge rectifier and a LC filter is connected at the output in order to reduce the harmonics in output voltage wave form. The required output voltage is obtained by the switching of the power devices. The operation of the inverter can be explained by following theoretical analysis.

The relationship between the switching variable vector [a, b, c]t and the line-to-line voltage vector $[V_{ab}\ V_{bc}\ V_{ca}]^t$ is given by the matrix: where the elements of the switching variable vector matrix of can be either 0 or 1. 0 corresponds to the switch on of upper leg device and 1 corresponds to the switch on for a lower leg device.

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{dc} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}.$$

Also the relationship between the $[a, b, c]^t$ and the phase voltage vector $[V_a\ V_b\ V_c]^t$ is given by the following matrix as shown in Table 1:

Each state corresponds a level of voltage that is each state can represent either a 0,-$V_{dc}$/2, +$V_{dc}$/2. The transformation from one level to the other state will involve only change in the status of one device at a time.

**VII. SIMULATION RESULTS AND DISCUSSIONS**

Various simulation tools available for simulation of power electronics and drive system. MATLAB has been chosen in this work due to its versatility. To verify the above design, the proposed DG system is simulated in MATLAB/SIMULINK. The simulations are carried out on Micro turbine based DG systems with the various load conditions and are presented here for different operating conditions.

| Voltage vectors | witching vectors | | | Phase –neutral voltage | | | Line-line voltage | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | Va | Vb | Vc | Vab | Vbc | Vc |
| V0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| V1 | 1 | 0 | 0 | 2/3 | -1/3 | -1/3 | 1 | 0 | -1 |
| V2 | 1 | 1 | 0 | 1/3 | 1/3 | -2/3 | 0 | 1 | -1 |
| V3 | 0 | 1 | 0 | -1/3 | 2/3 | -1/3 | -1 | 1 | 0 |
| V4 | 0 | 1 | 1 | -2/3 | 1/3 | 1/3 | -1 | 0 | 1 |
| V5 | 0 | 0 | 1 | -1/3 | -1/3 | 2/3 | 0 | -1 | 1 |
| V6 | 1 | 0 | 1 | 1/3 | -2/3 | 1/3 | 1 | -1 | 0 |
| V7 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

**TABLE 1: Switching States of Two-Level Inverter**

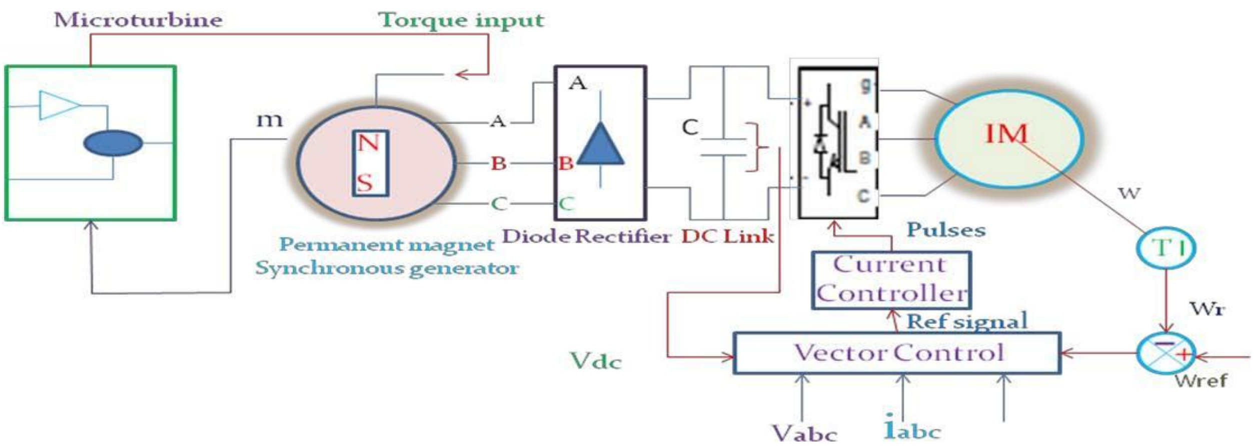



Fig.5. CSTP turbine based DG system feeding to Vector controlled induction motor (VCIM) drive

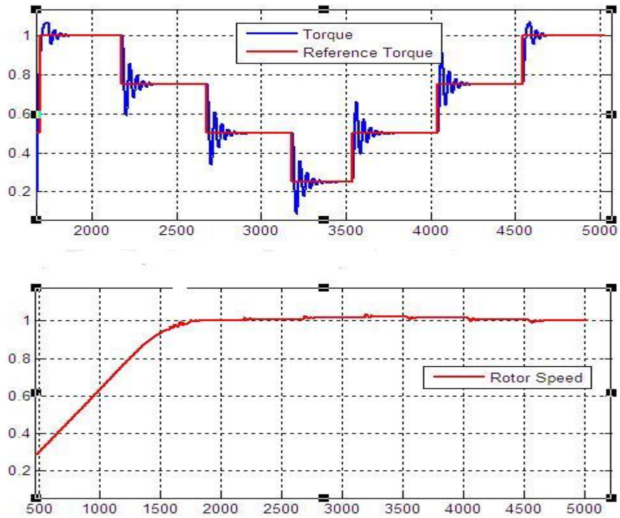
## VII. SIMULATION RESULTS AND DISCUSSIONS

Various simulation tools available for simulation of power electronics and drive system. MATLAB has been chosen in this work due to its versatility. To verify the above design, the proposed DG system is simulated in MATLAB/SIMULINK. The simulations are carried out on Microturbine based DG systems with the various load conditions and are presented here for different operating conditions.

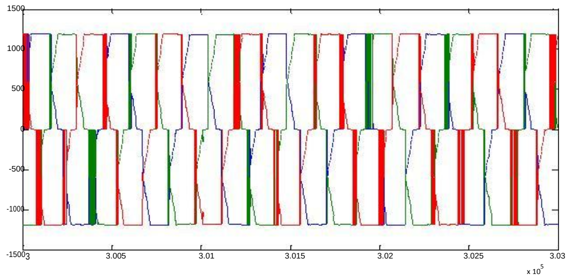
The Load Torque demanded by the drive system is supplied by CSTP turbine by taking proper fuel input from fuel system .The Torque which is generated by the CSTP turbine is meeting load demand throuh out as shown in fig(10) and corresponding variations in turbine speed, Temparature and fuel demand from fuel system is also captured through simulations as shown in the fig(10).

The dynamics of source current, generated torque and rotor speed of the Indirect vector controlled Induction motor drive with CSTP turbine DG System against step speed changes (w=2500 rpm→1500 rpm) and load torque(TL=0 N-m→2 N-m & 2 N-m →8 N-m) changes are shown in the fig. at t=11s, The reference speed of the drive is changed from 2500 rpm→1500 rpm,at this instant the generated torque of the VCIM undergoes a bit dynamics and immediately after 1ms the generated torque is tracking its reference value(0 N-m).The Load torque (TL) is changed from 0 N-m→2 N-m & 2 N-m →8 N-m at t=12.5s & t=14s respectively, the moment when the load torque changes, there is no dynamics in the rotor speed of VCIM i.e the generated torque and speed are decoupled.

The dynamics of source current, generated torque and rotor speed of the Indirect vector controlled Induction motor drive with CSTP turbine DG System against step speed changes (w=2500 rpm→1500 rpm) and load torque(TL=0 N-m→2 N-m & 2 N-m →8 N-m) changes are shown in the fig. at t=11s, The reference speed of the drive is changed from 2500 rpm→1500 rpm,at this instant the generated torque of the VCIM undergoes a bit dynamics and immediately after 1ms the generated torque is tracking its reference value(0 N-m).The Load torque (TL) is changed from 0 N-m→2 N-m & 2 N-m →8 N-m at t=12.5s & t=14s respectively, the moment when the load torque changes, there is no dynamics in the rotor speed of VCIM i.e the generated torque and speed are decoupled.




Fig(6).Generated Torque,Load Torque and pu Speed of CSTP turbine under Dynamic Conditions



Fig(7) Voltage generated by PMSG

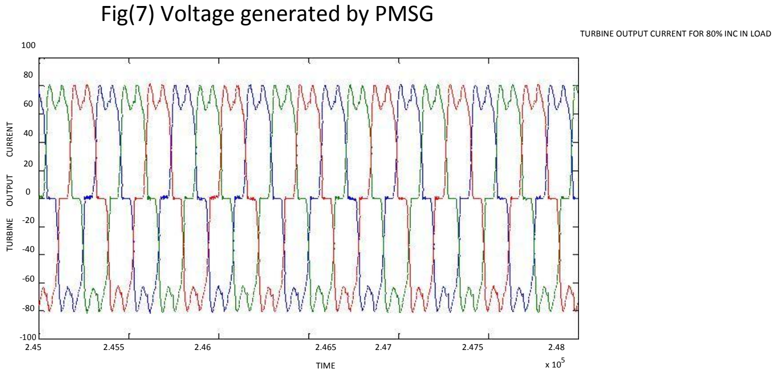



Fig.(8). Current Supplied by PMSG

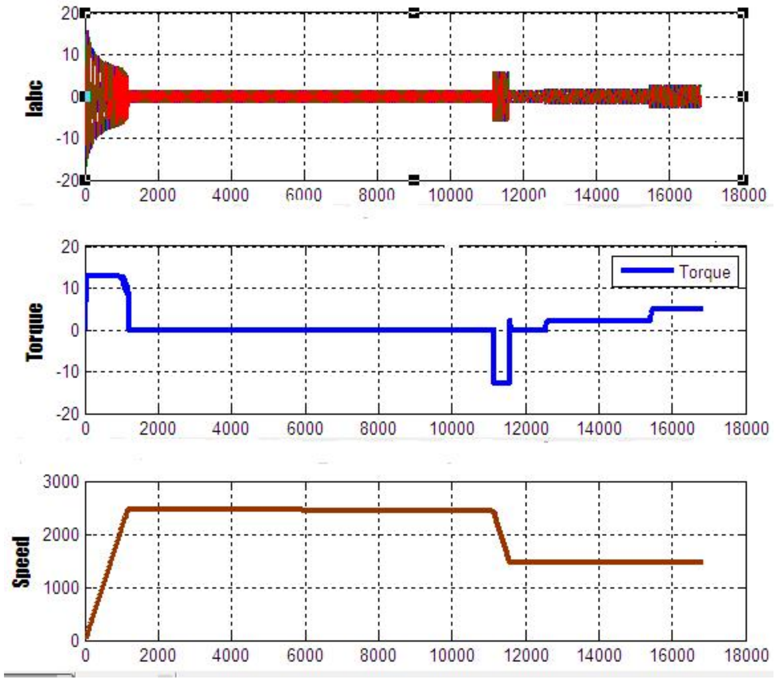



Fig.(9).Input current, Generated Torque and Rotor Speed waveforms of VCIM with CSTP turbine DG System

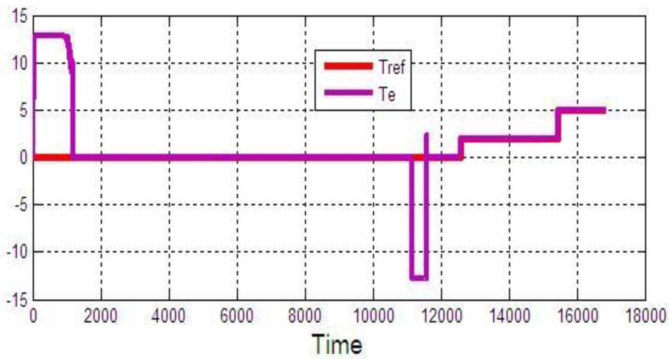



Fig.(10).Reference Load Torque and Generated Torque waveforms of VCIM with CSTP turbine DG System

The load torque and the generated torque of the VCIM drive; the generated torque of the motor tracks the reference value as shown.

**CONCLUSIONS**

The modeling of a single- shaft CSTP turbine DG system suitable for isolated Drive (an indirect vector controlled Induction Motor Drive (VCIM) and Three phase static load applications are presented in this paper. First, mathematical modeling of the CSTP turbine DG system is given and followed by detailed simulation model of the CSTP turbine based Distributed Generation (DG) systems feeding an indirect vector controlled Induction Motor Drive (VCIM) and Static load system is developed using MATLAB's SimPowerSystems library. Evaluations of this stand-alone model show that it is reasonable and suitable for slow dynamic simulation studies. Also in the CSTP turbine model, for combined heat and power applications, recuperator model could be added to increase the overall efficiency. The drive system is operating satisfactorily with CSTP turbine DG system.

**REFERENCES**

[1]. Thomas Ackermann, Goran Andersson and Lennart oder, 'Distributed Generation: a definition,' *Electric Power Systems Research,* vol. 57, 2001, pp. 195 -204.

[2]. Al-Hinai and A. Feliachi, 'Dynamic model of microturbine used as a distributed generator,' in *Proc. 34th South Eastern Symposium on system Theory,* Huntsville, Alabama, 2002, pp. 209-213.

[3]. M. Liserre, F, Blaabjerg and S. Hansen, 'Design and control of an LCL filter-based

three-phase active rectifier,' *IEEE Trans. On Industry pplications,* vol. 4, no. 5, pp.1281-1291, September /October 2005.

[4]. S. Morimoto, M. Sanada and Y. Takeda, 'Wide speed operation of interior permanent magnet synchronous motors with high performance current regulator,' *IEEE Trans. Industrial Application*s, vol. 30, pp. 920-926, July / Aug. 1994.

[5]. O. Fethi, L. A. Dessaint, and K. Al-Haddad, 'Modeling and simulation of the electric Part of a grid connected micro turbine,' in *Proc. IEEE PES general meeting,* 2004, pp. 2212

[6]. Ned Mohan, *Advanced electric drives analysis, control and modeling using Simulink*. MNPERE Minneapolis, USA.