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Simulation and Hardware model of Induction Generator using PWM

S.Saravanakumar , S.Sankar,D.Jayalakshmi, M.Padmarasan

Abstract-- A variable speed cage type Induction Generator system is simulated and implemented. The complete model consists of Induction Generator, PWM converter, PWM inverter and local load. The system studied maintains constant voltage when the speed is fluctuating. The advantages of PWM rectifier and PWM inverter are utilized. Circuit model for variable speed induction generator is developed and the simulation studies performed on the circuit model for variable speed cage machine wind generation unit show that the output voltage is constant even as the load changes.

Index Terms-- Induction generator, wind power generation, wind energy, Voltage control, micro controller.

1. INTRODUCTION

In recent years wind power generation has experienced a very fast development in the entire world. Wind power provides an additional source of energy for power corporations and state electricity boards. With the advent of large scale wind farms, utilities are finding it attractive and cost effective to purchase wind power. Wind power is environmentally friendly and enjoys positive public acceptance. It provides a hedge against spiraling increase in fuel price. Variable speed operation is introduced to gain high efficiency in the generating system. Otherwise the generating system cannot capture the largest possible energy available in the wind comprehensive control strategy for variable speed cage machine wind generator unit is given in this analysis. This paper has discussed the control of local bus voltage to avoid voltage rise.

The simulation was done using nonlinear model for variable speed induction machine. Growth of worldwide wind generation capacity as compared with nuclear capacity was dealt by C.R.De Azua [1].The variable speed wind power generation using doubly fed wound rotor induction machine was dealt by R.Datta [2].The use of load controlled regulated voltage on distribution networks with embedded generation was dealt by N.C. Scott [3]. The voltage input of distributed wind generation on rural distribution feeder was presented by Smith [4]. A method of tracking the peak power point for the variable speed wind energy conversion system was given by V.T.Ranganathan [5].

Dr.S.Sankar is a Professor of of EEE, Panimalar Institute of Technology, Chennai, TamilNadu, India,ssankarphd@yahoo.com
Dr.S.Saravanakumar is a Prof. of IT, Panimalar Institute of Technology, Chennai, TamilNadu, India,saravanakumars81@gmail.com
Mrs.D.Jayalakshmi is an Assistant Professor of of EEE,SRMeswari Engineering,College Chennai, TamilNadu, India,
Mr.M.Padmarasan is an Assistant Professor of of EEE, Panimalar Institute of Technology, Chennai, TamilNadu, India,padmaras_mathi@yahoo.com

2. THE WIND TURBINE SYSTEM

The block diagram of variable speed Induction Generator system is shown in Fig.1. The system has Induction Generator (IG), PWM rectifier, PWM inverter and the local load. The modeling of each block is discussed and the overall model is used for simulation. IG is represented as variable frequency source in the simulation. PWM. Rectifier converts ac into dc. The dc output is filtered using the capacitor filter. The rectifier and the capacitor filter acts as voltage source at the input of PWM inverter .The PWM inverter converts dc into constant frequency of ac. The output frequency is constant since the MOSFETs are triggered at constant power frequency. The PWM output has very low harmonics since sinusoidal pulse width modulation is employed.

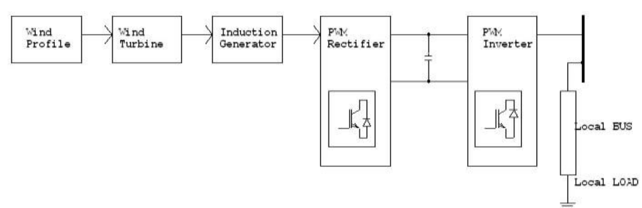


Fig . 1. Block diagram of variable speed induction generator system

3. ANALYSIS OF HYBRID SYSTEM

The objective of the optimization model is to optimize the availability of energy to the loads according to their levels of priority. It is also proposed to maintain a fair level of energy storage to meet peak load demand, demands during low or no radiation periods, or wind speed is very less. The loads are classified as primary and deferrable loads.

Machines used to produce power from the wind are usually classified into two different groups: horizontal-axis and vertical-axis machines [1]. In order to develop a model to any one of the machine groups, Betz theory [1] is usually used. Betz assumes that the wind rotor is ideal and that is to say; it has no hub and an infinite number of blades offering no resistance drag to the passage of air. Moreover, the conditions over the whole area swept by the wind rotor are supposed to be uniform and the speed of the air through and beyond the rotor is assumed to be axial. The power of the moving air through the wind rotor can be expressed as [2]:

$$P_o = \frac{1}{2} A_r \rho V_w^3 \quad (1)$$

A_r represents the swept area by the motor rotor and it will be set in this investigation to

$A_r = \pi r^2$. r represents the radius of the rotor.

ρ: density of the air which may be taken at normal temperature and pressure as equals to 1.25 kg/m^3

V_w: is the wind speed in meter/second (m/s).

The moving air power (P_o) can be converted partially to a mechanical power. The mechanical power that can be extracted from such moving air power can be expresse :

$$P_w = P_o C_p$$
$$P_w = \frac{1}{2} A_r \rho V_w^3 C_p \quad (2)$$

Where C_p is a dimensionless performance power coefficient and its value is naturally always < 1. There is no radical theoretical basis that can lead to the development of a well defined analytical expression for the power coefficient C_p.

$$C_p = C_1(C_2 - C_3 p - C_4 p^x - C_5)e^{-C_6} \quad (3)$$

Investigators [2] dealing extensively with the subject of wind energy have proposed a handy formula or expression of the form:

Where C_1= 0.5 , C_2= 116/λ_i, C_3=0.4, C_4=0.,C_5=5, C_6=21/λ_i,

$$\lambda = \frac{r\omega_w}{V_w}$$

x= 1.5.

$$1/\lambda_i = \frac{1}{\lambda + 0.08p} - \frac{0.035}{p^3 + 1} \quad (4)$$

ω_w: angular velocity of the wind motor (rad/sec)

V_w: wind speed (m/s)

r: radius of the rotor of the wind motor (m)

p: pitch angle between the blade element with respect to the plane of rotation. Such an angle is fixed in this investigation and is set to be equal to π/180 radian.

λ: is known as the tip speed ratio.

Examining equation 2, one can deduce that for each possible wind speed, the extracted wind power (P_w) can be maximized when the power coefficient C_p is maximized. The power coefficient C_p attains its maximum when the condition $dC_p/d\lambda = 0$ is satisfied. Such condition is reached and can be checked when the tip speed ratio λ is equal to 7.975340822. The corresponding value of the coefficient C_p at such tip speed ratio is $C_{p,max}$ = 0.413814988.

Thus, for the sake of extracting maximum wind power ($P_{w,max}$) at a certain wind speed (V_w), the wind motor speed has to be controlled and made rotating at the following angular velocity:

The maximum extracted wind power is of the form:

$$P_{w,max} = \frac{1}{2} A_r \rho V_w^3 C_{p,max} = \frac{0.413814988}{2} A_r \rho V_w^3 \quad (6)$$

It is desired to minimize, dumped energy, $Q_{dump}(t)$. The dumped energy is the excess energy, or energy which cannot be utilized by the loads.

$$\omega_w = \frac{7.975340822 * V_w}{r}$$

The objective function is to Maximize

$$\sum_{t=1}^{24} \left\{ \sum_i P_i . I_i(t) - Q_{dump}(t) \right\} \quad (7)$$

with $I_i(t) \geq 0$

where

t is hour of a particular day t = 1,2, …24

i is load type primary and deferrable loads

P_i is Demand of load *i* at time t in KW

$I_i(t)$ is the fraction of time t that the load *i* is supplied energy.

A. Load constraints

The energy distribution from the energy devices at period *t*to each load *i* is given as follows:

$$Q_{P,i}(t) + Q_{W,i}(t) + Q_{G,i}(t) + Q_{B,i}(t) = I_i(t).P_i \quad (8)$$

Where Q_P, Q_w, Q_G, Q_B are the energy supplied by the Hybrid energy system (PV, Wind, Gasifier and Battery respectively)

B.PV Array constraints

Ep(t) is the sum of the energy supplied by the PV array to the loads and to the battery bank, hour t,

$$Q_{P,B}(t) + \left(\sum_i Q_{p,i}(t) \right) + Q_{P,R}(t) = E_P(t) \quad (9)$$

where $Q_{P,R}(t)$ is the energy dumped by the PV array

$Q_{P,B}(t)$ is the energy supplied by the PV array to the battery bank

Since energy generated by the system varies with insolation, therefore the available array energy *Ep(t)* at any particular time is given by

$$E_a = K_a \phi \omega_w$$

$$E_P(t) = VS(t) \quad (10)$$

Where V is the capacity of PV array

S(t) is the insolation index

C. Wind energy system constraints

$E_W(t)$ is the sum of the energy supplied by the wind energy system to the loads and battery bank at hour t,

$$Q_{W,B}(t)+\left(\sum_i Q_{p,i}(t)\right)+Q_{W,R}(t)=E_W(t) \tag{11}$$

(5)

$$P_{elec}=E_aI_a=\frac{\left(K_a\phi\omega_w\right)^2}{R_a+R_L} \tag{12}$$

where $Q_{w,R}(t)$ as the dumped energy by the wind energy system

D. Gasifier constraints

The energy produced by the Gasifier Q_G is distributed to the loads and battery Bank respectively, with a possibility of excesses. It desire to run the generator at its Optimum capacity to ensure longevity and efficiency

$$Q_{G,B}(t)+\left(\sum_i Q_{G,i}(t)\right)+Q_{G,R}(t)=Q_G \tag{13}$$

where
$Q_{G,I}(t)$- is the energy supplied by the gasifier to the loads
$Q_{G,B}(t)$ – is the energy supplied by the gasifier to the battery bank
$Q_{G,R}(t)$- k the dumped energy from the gasifier
Q_G- is the maximum capacity of the generator

$$Q_{G,i}(t), Q_{G,B}(t), Q_{G,R}\geq 0$$

E. Battery bank constraints

The battery serves as an energy source entity when discharging and a load when charging. The net energy balance to the battery determines its state-of-charge, (SOC) the state of charge is expressed as follows

$$Q_B SOC(t)=Q_B SOC(t-1)+(Q_P(t)+Q_G(t)+Q_W(t))-\sum_i Q_{B,i}(t) \tag{14}$$

where Q_B is the capacity of the battery bank

The battery has to be protected against overcharging; therefore, the charge level at *(t-1)* plus *the* influx of energy from the PV, wind and gasifier at period *(t-l), (t)* should not exceed the capacity of the battery.
Mathematically,

$$Q_B\geq Q_B SOC(t-1)+Q_P(t)+Q_G(t)+Q_W(t) \tag{15}$$

It is also necessary to guard the battery against excessive discharge. Therefore the SOC at any period *t* should be greater than a specified minimum *SOC*, SOC_{min}

$$1\geq SOC(t)\geq SOC_{\min} \tag{16}$$

F. Dumped energy

From the above equations the total dumped energy in each hour t as follows

$$Q_{p,R}(t)+Q_{G,R}(t)+Q_{W,R}(t)=Q_{dump}(t) \tag{17}$$

3. SIMULATION RESULTS

The simulation circuit model for VSIG system is shown in Fig.2. The MOSFETs in the semi rectifiers are represented as the switches S1 and S2. The switches S1 and S2 are voltage controlled switches. The output of the rectifier is filtered using the Capacitor C1. The MOSFETs of the inverter are represented using the voltage controlled switches. Two MOSFETs are adequate in rectifier since one MOSFET and diode come in series. The controlled circuit used for generating the pulses is shown in Fig. 2(a) and Fig. 2(b). The PWM inverter output is shown in the Fig. 2(c). The frequency spectrum for R- load is shown in Fig. 2(d). The circuit model with RL load is shown in Fig. 2(e). AC to AC PWM converter with RL load is shown in Fig. 2(f). The frequency spectrum is shown in Fig. 2(g). From this figure it can be seen that the output voltage is an improved PWM wave form. The above mentioned waveforms are obtained using transient analysis of PSPICE which calculates all the node voltages and branch currents over a time interval.

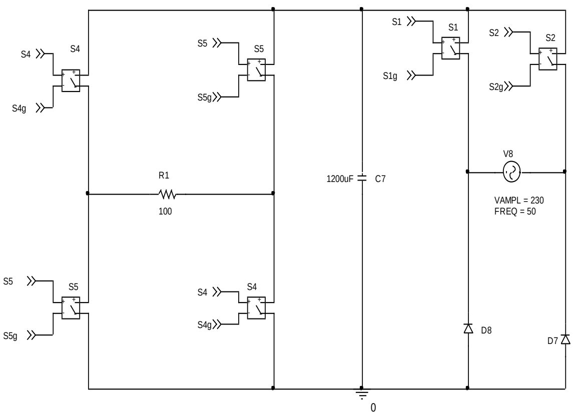


Fig. 2. AC to AC PWM converter with R load

The Fourier components with R-load is given is given in table1. The total harmonic distortion (THD) was found to be 41.22%. The higher order harmonics were found to increase with RL load. AC to AC PWMC with RLE load is shown in Fig. 3(a). The THD was found to be 9.82% with RLE load. The Fourier components with RL load are given in table.2. The THD was found to be 26.53%. The inverter output voltage with RLE load is shown in Fig. 3(b).

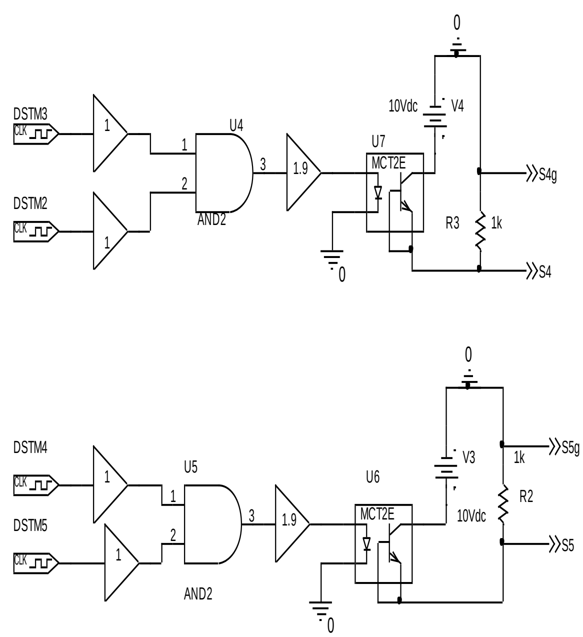
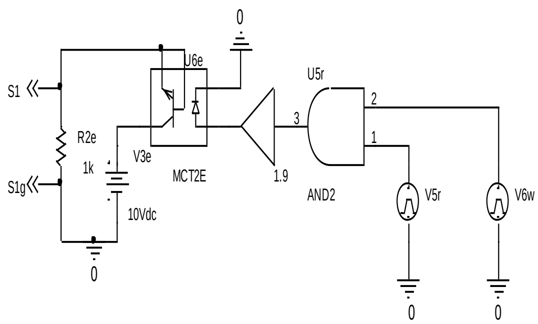


Fig. 2(a). Inverter triggering circuit



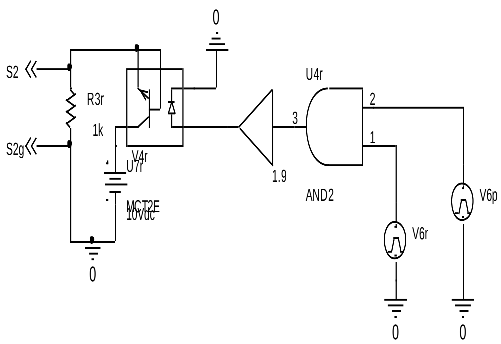


Fig. 2(b). Rectifier triggering circuit

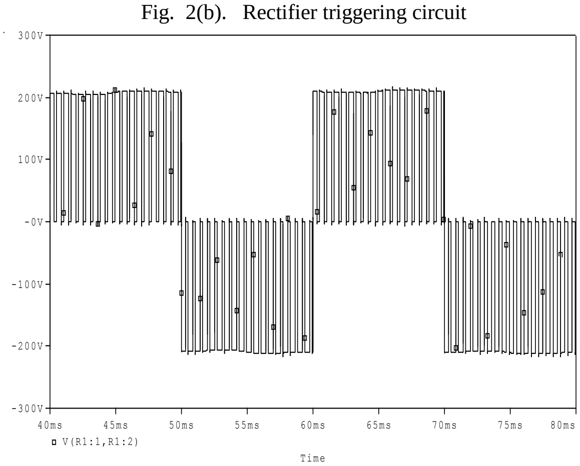


Fig. 2(c). Inverter Output Voltage for R load

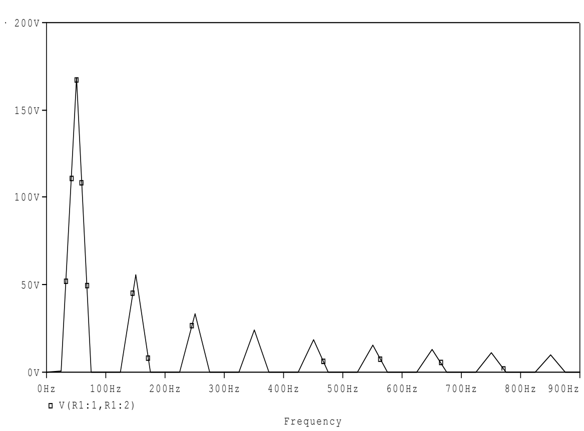


Fig. 2(d). Frequency Spectrum for R load

The moments constitute the basis for a non classical representation of linear systems. The characterization of an impulse response by its moments is equivalent to the moment characterization of a probability density function. Impulse response moments are system invariants. Like for a probability

Table.1. Fourier Components with R-Load

Harmonic number	Frequency (HZ)	Fourier component	Normalized component
1	5.000E+01	1.671E+02	1.000E+00
2	1.000E+02	4.236E+00	2.535E-02
3	1.500E+02	5.749E+01	3.441E-01
4	2.000E+02	4.542E+00	2.719E-02
5	2.500E+02	3.447E+01	2.063E-01
6	3.000E+02	4.195E+00	2.511E-02
7	3.500E+02	1.391E+01	8.327E-02

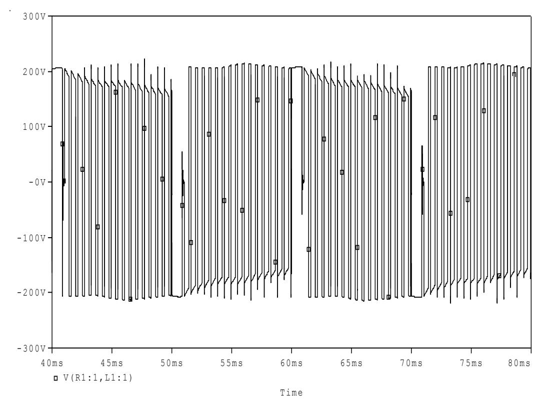


Fig . 2(e). AC to AC PWM converter with RL load

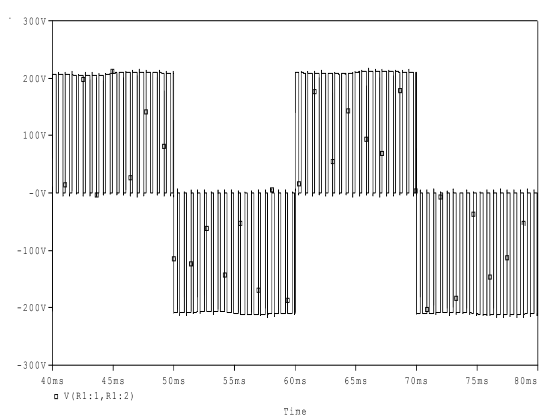


Fig. 2(f). Inverter Output Voltage for RL load

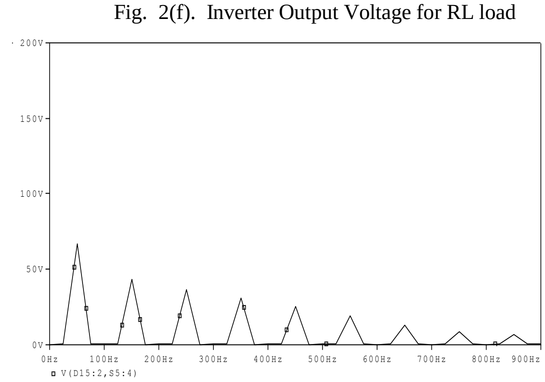


Fig. 2(g). Frequency Spectrum for RL load

Table. 2. Fourier components with RL load

Harmonic number	Frequency (HZ)	Fourier component	Normalized component
1	5.000E+01	2.037E+01	1.000E+00
2	1.000E+02	2.128E-02	1.045E-03
3	1.500E+02	4.645E+00	2.281E-01
4	2.000E+02	2.308E-02	1.133E-03
5	2.500E+02	2.368E+00	1.163E-01
6	3.000E+02	1.526E-02	7.494E-04
7	3.500E+02	1.423E+00	6.987E-02

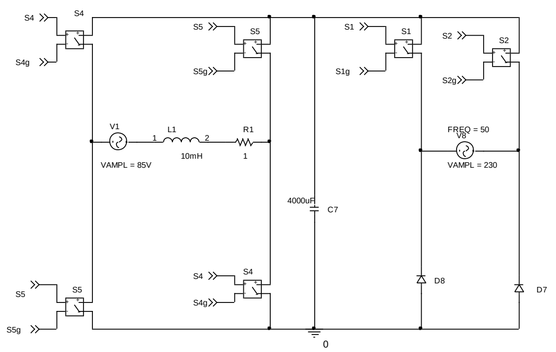


Fig. 3(a). AC to AC PWM converter with RLE load

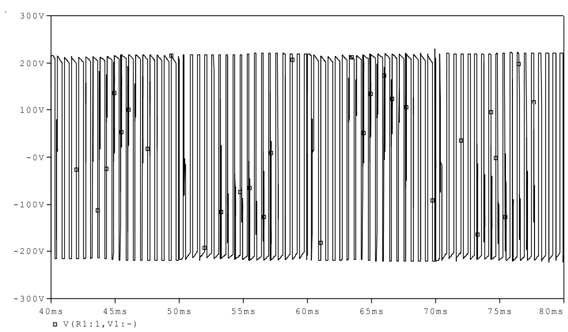


Fig. 3(b). Inverter Output for RLE Voltage

4. HARDWARE IMPLEMENTATION

The pulses required for the MOSFETs are generated using microcontroller 89C2051. The block diagram of control circuit is shown in Fig. 4. The pulses are generated from the port1 of the microcontroller. They are given to the driver circuit through the buffer 74LS244.

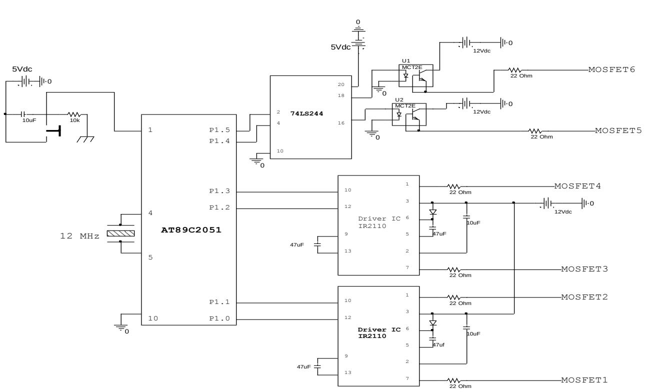


Fig. 4. Block Diagram of Control Circuit

The 5V pulses from the buffer are amplified to 10V using the driver IC IR2110. Two driver chips were used in the present work. Each driver IC can amplify two pulses. Therefore two driver ICs are required to control four MOSFETs. The other two MOSFETs are controlled using MCT2E chips. The pulses from the microcontroller are shown in Fig. 4(a). The output voltage of the inverter with R load is shown in the Fig. 4(b) and that of inductive load is shown in the Fig. 4(c). The top view of the hardware is shown in the Fig. 4(d).

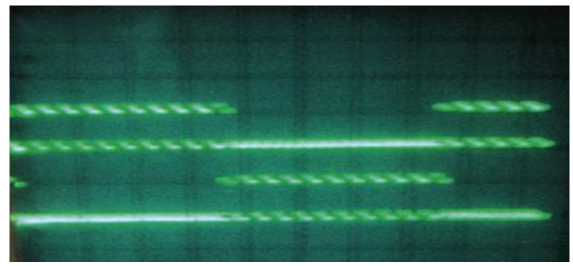


Fig. 4 (a). The pulses from the micro controller

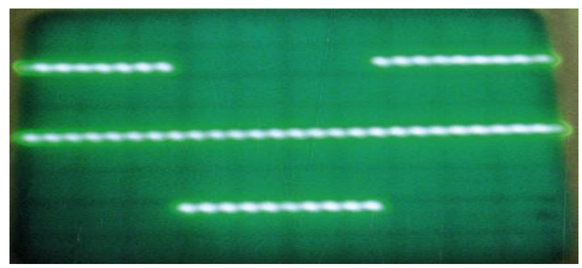


Fig. 4 (b). The output voltage of inverter with R-load

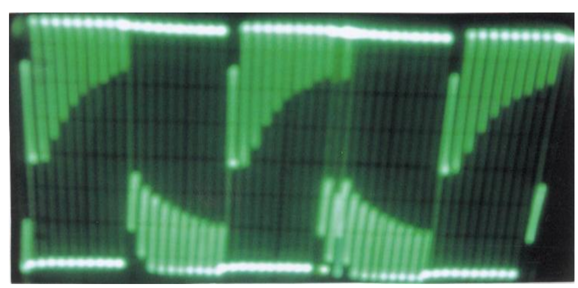


Fig. 4 (c). The output voltage of inverter with inductive load

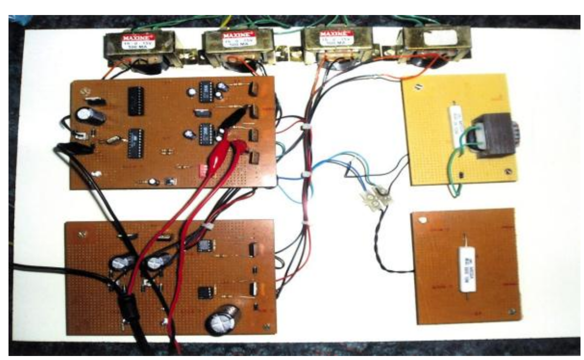


Fig. 4 (d). The top view of hardware

5. CONCLUSION

A complete circuit model for variable speed cage induction generator machine wind generator system has been developed using Pspice and matlab. In the circuit model, induction generator, rectifier, inverter and local load are considered. All the control aspects of double sided pulse width modulation were included. The variable speed wind generator system with R, RL and RLE loads were simulated. From the simulation studies it is observed that the output voltage remains constant even as the wind speed changes. The hardware was successfully implemented using the microcontroller 89C2051. The experimental results coincide with the simulation results

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BIOGRAPHY

Dr S.SARAVANAKUMAR has more than 11 years of teaching and research experience. He did his under graduate in B.Tech in Information Technology at Adhiparasakthi Engineering college, Madras university Chennai and Postgraduate in ME in Computer Science and Engineering at Bharath engineering college,anna university chennai, and Ph.D in Computer Science and Engineering at Bharath University, Chennai. He has guiding a number of research scholars in the area Adhoc Network, ANN, Security in Sensor Networks, Mobile Database and Data Mining .

Dr.S.Sankar obtained his B.E Degree in Electrical & Electronics Engineering at Sri Venkateswara College of Engineering, from Madras University and M.E (Power System) Degree from Annamalai University Chidambaram. He has done his Ph.D in the area of FACTS controllers in 2011. His research interests are in the area of FACTS, Electrical Machines, Voltage stability, power quality, Power system security and Power System Analysis.

D.Jayalakshmi obtained her B.E Degree in Electrical & Electronics Engineering at Jaya College of Engineering, from Madras University and M.E (Power System) Degree from AnnaUniversity Chennai.. Her area of interest is Power System Stability, Dynamics, Renewable Power Generation, Hybrid Power Generation & High Voltage Engineering. He published various papers in International Journals & Conferences.

Mr.M.PADMARASAN has completed his B.E. in Priyadharshini Engineering College, Vaniyambadi. He completed his M.E. (Power System Engineering) at Annamalai University, Chidambaram in the year of 2004. He is a Research Scholar in Sathyabama University. His area of interest is Power System Stability, Dynamics, Renewable Power Generation, Hybrid Power Generation & High Voltage Engineering. He published various papers in International Journals & Conferences.