Medwell Online
International Journal of Electrical and Power Engineering 1 (1): 53-61, 2007

Implementation of Variable Speed Induction Generator System

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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 is done with resistive load, RL load and induction motor load. PWM rectifier has improved input Power factor and PWM inverter has reduced harmonics at the output. 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. The hardware was successfully implemented using microcontroller 89C2051. The experimental results agree with the simulation results.

Key words: Induction generator, wind power generation, wind energy, voltage control, closed loop system

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 Mahdi. This study 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 world wide 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 variable speed wind energy conversion system was given by V.T. Ranganathan[5]. The penetration of wind generation in existing distribution network was published by S.N. Lew[6]. A fuzzy logic based intelligent control of a variable speed cage machine wind generation system was proposed by B.K. Bose[7]. Power conditioning of variable speed wind turbine generator was given by I. Syed[8]. The circuit model for closed loop controlled variable speed induction machine is not available in the literature mentioned above. In the present research, an attempt is made to develop circuit model for closed loop system.

VSIG 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 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.

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RESULTS AND DISCUSSION

The simulation circuit model for VSIG system is shown in Fig. 1b. The MOSFETs in the semi converter 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. 1c and Fig. 1d. The PWM inverter output is shown in the Fig. 1e. The frequency spectrum for R-load is shown in Fig. 1f. The circuit model with RL load is shown in Fig. 2a. AC to AC PWM converter with RL load is shown in Fig. 2a. The inverter output is shown in Fig. 2b. The voltage across RL-load is shown in Fig. 2b. The frequency spectrum is shown in Fig. 2c. From this figure it can be seen that the output voltage is an improved PWM waveform. The above mentioned waveforms are obtained using transient analysis of PSPICE which calculates all the node voltages and branch currents over a time interval.

The Fourier components with R-load are given is given in Table 1. The Total Harmonic Distortion (THD)

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

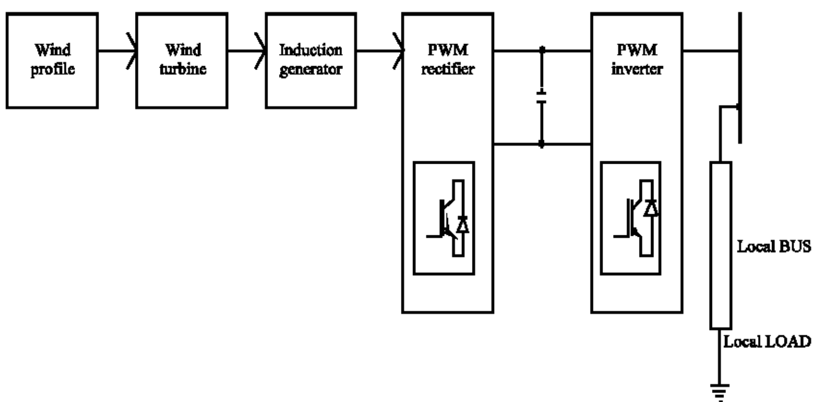

Fig. 1a: Block diagram of variable speed induction motor system

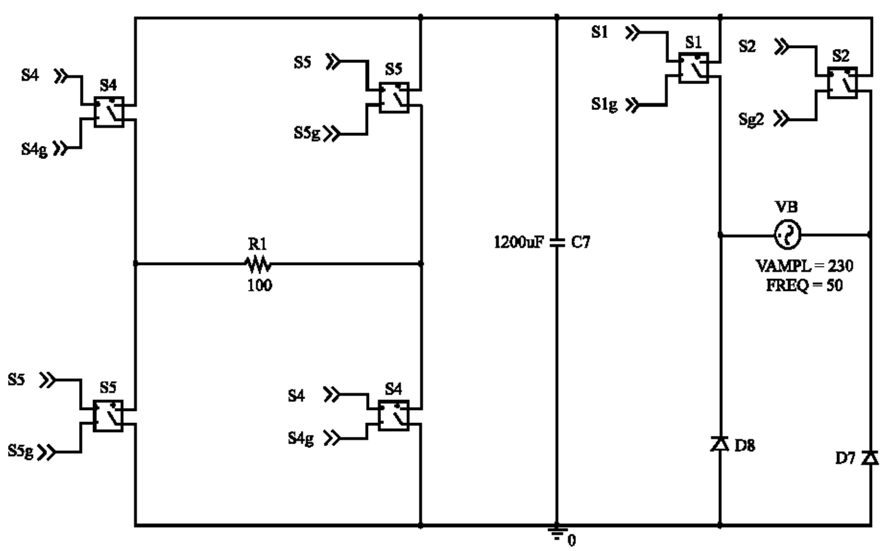

Fig. 1b: AC to AC PWM converter with R load

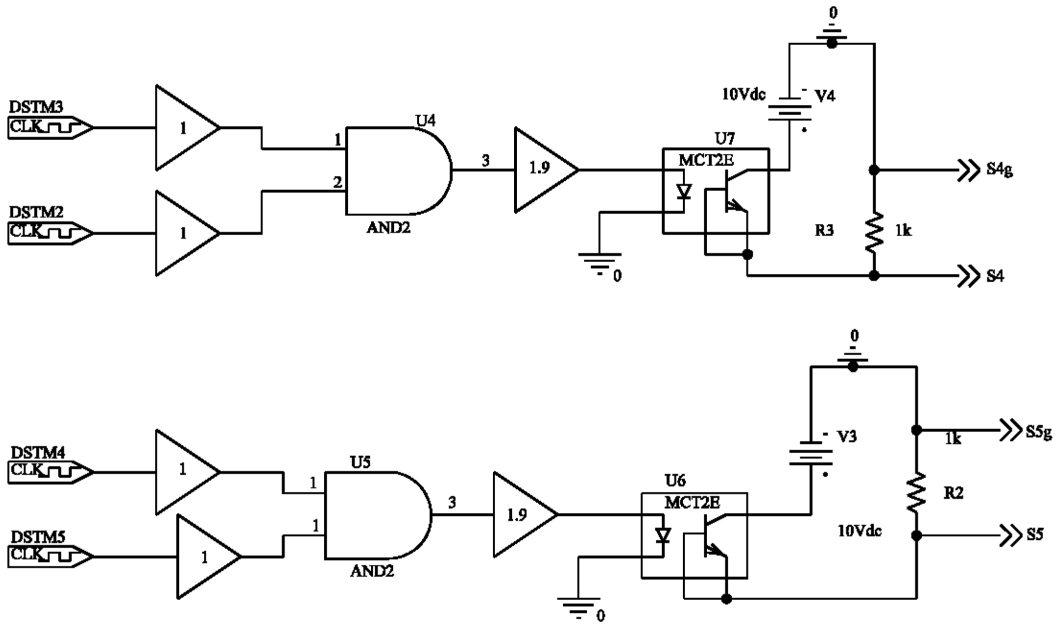

Fig. 1c: Inverter triggering circuit

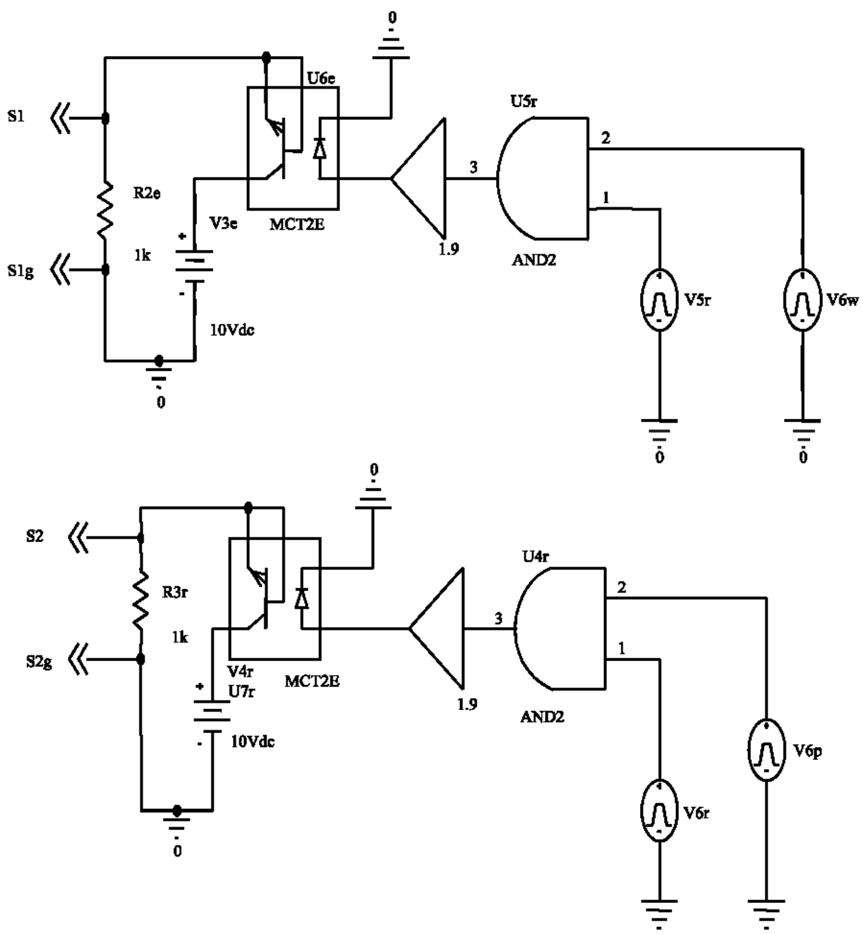

Fig. 1d: Rectifier triggering circuit

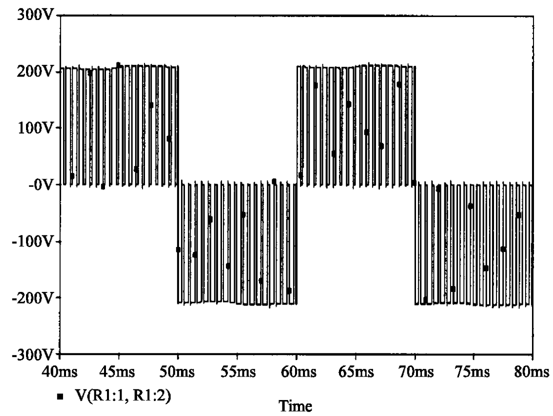

Fig. 1e: Inverter Output Voltage with R load

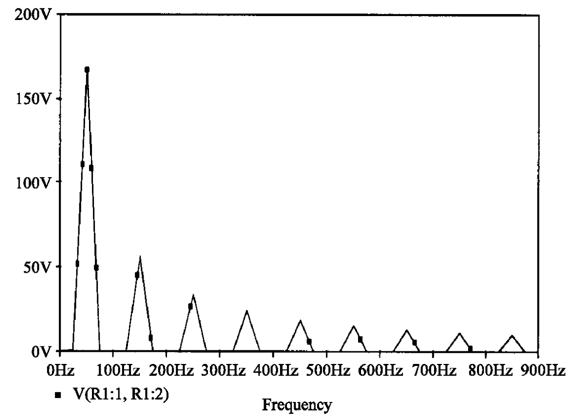

Fig. 1f: Frequency Spectrum with R load

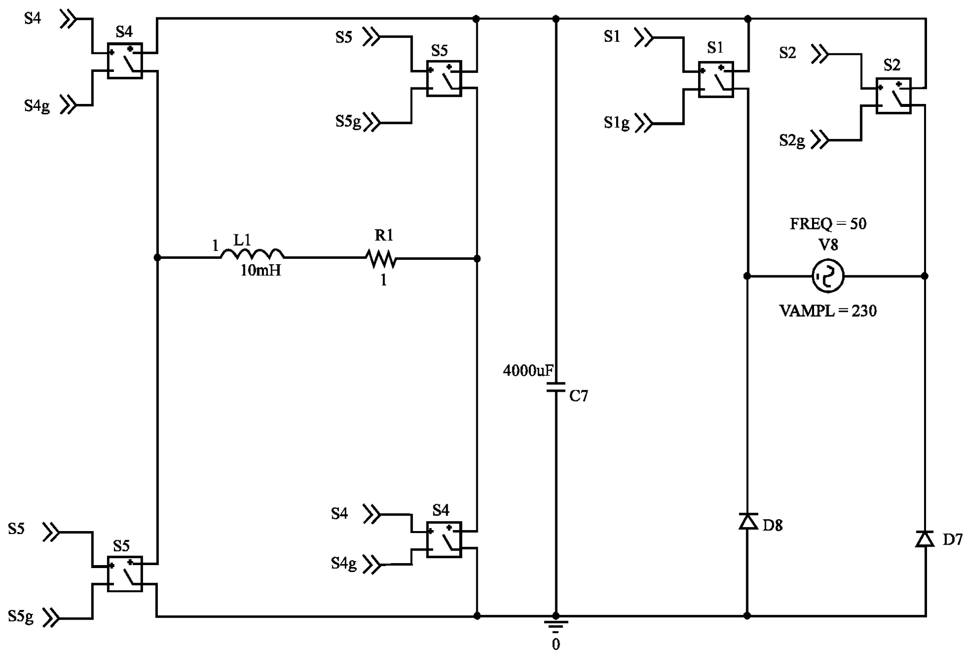

Fig. 2a: AC to AC PWM converter with RL load

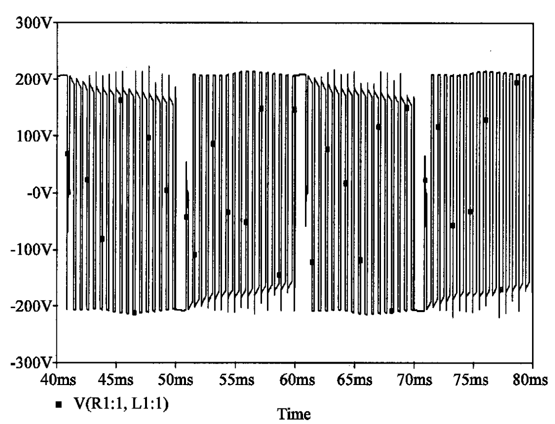

Fig. 2b: Inverter Output Voltage with RL load

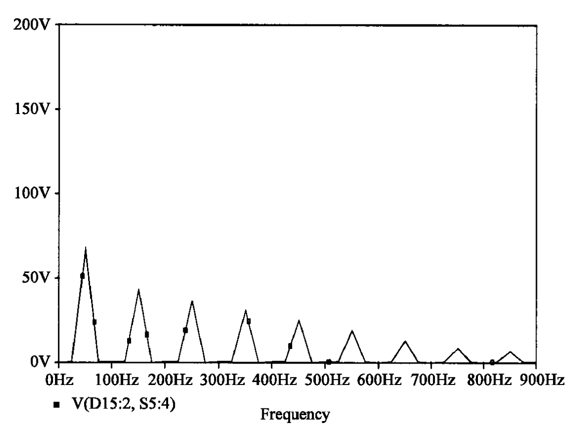

Fig. 2c: Frequency Spectrum with RL load

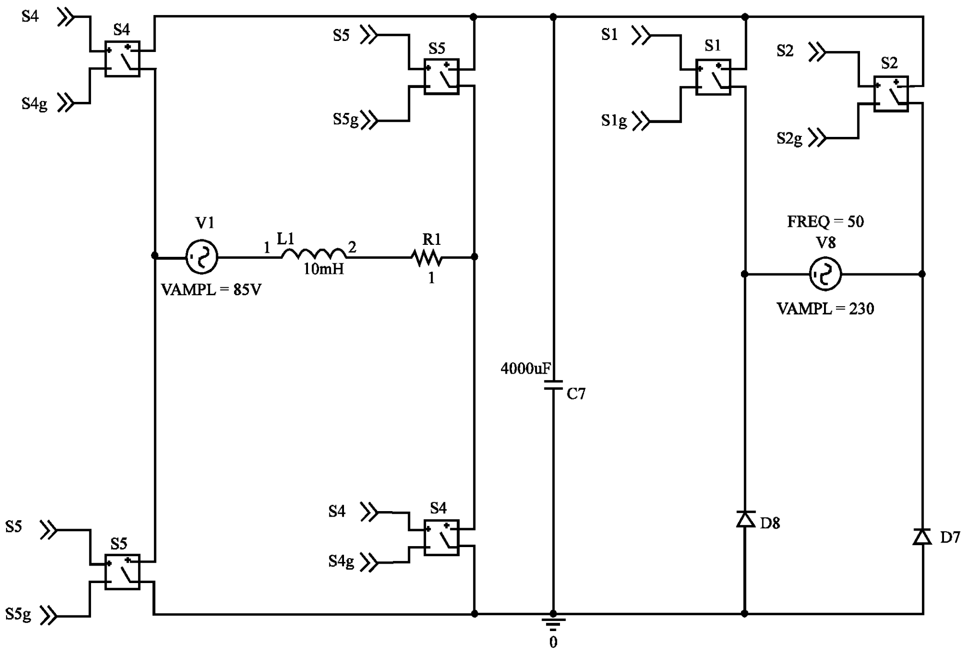

Fig. 3a: AC to AC PWM converter with RLE load

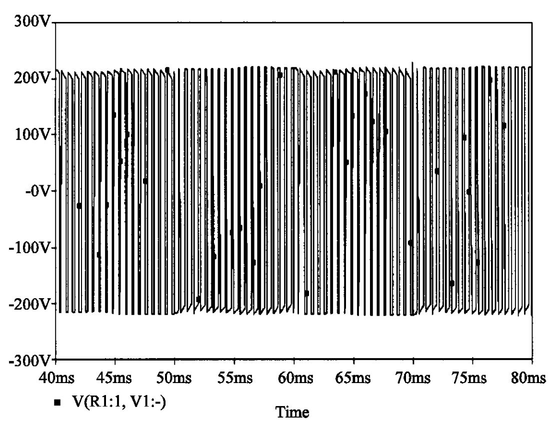

Fig. 3b: Inverter Output with RLE Voltage

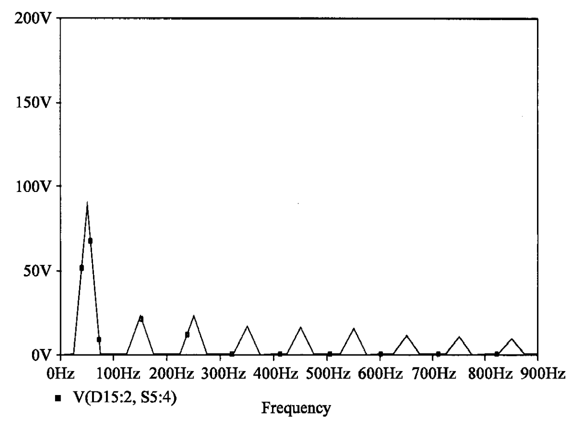

Fig. 3c: Frequency Spectrum with RLE load

was found to be 41.22%. The higher order harmonics were found to increase with R-load. AC to AC PWMC with RLE load is shown in Fig. 3a. 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. 3b. The corresponding frequency spectrum is shown in Fig. 3c. The Fourier components for the output voltage are given in Table 3.The circuit model for closed loop system is shown in Fig. 4a. The disturbance in the load was given using a parallel load resistance R4. The output voltage of inverter is sensed using E2. It is rectified and filtered. The actual

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

voltage is compared with reference voltage V4. The error signal adjusts pulse width to be given to the MOSFETs. It was observed that the pulse width increases automatically when the load is increased. When additional load is connected, the output decreases in

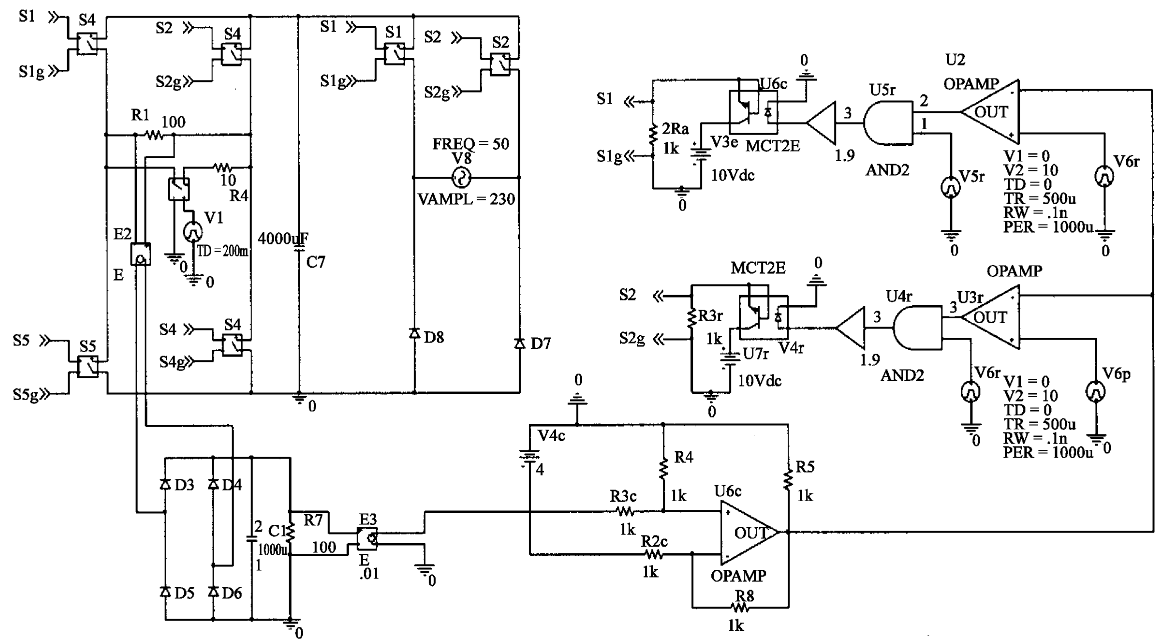

Fig. 4a: Circuit model for closed loop system using P spice

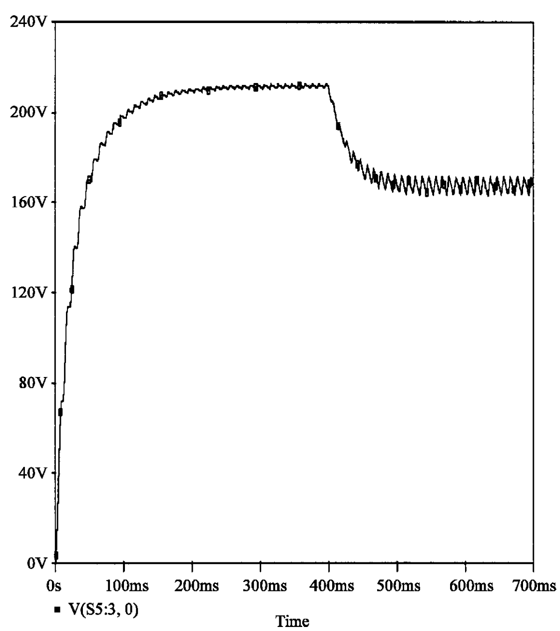

Fig. 4b: Output voltage under open loop condition

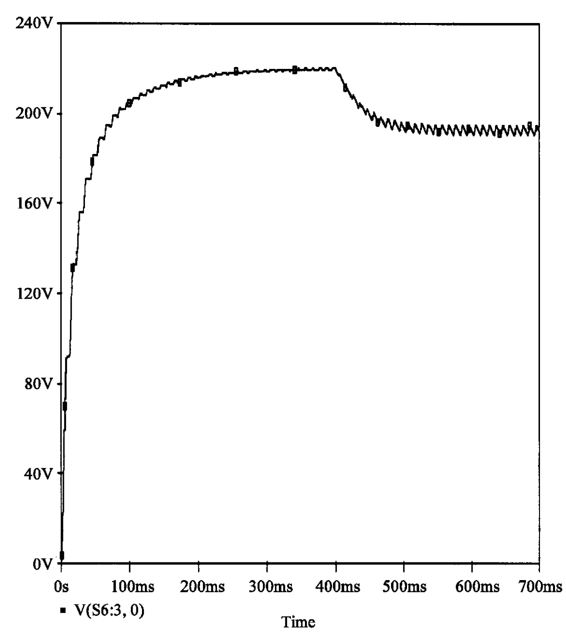

Fig. 4c: Output voltage under closed loop system

open loop as shown in Fig. 4b. The output voltage comes back to the normal value as shown in Fig. 4c. The closed loop model using matlab is shown in Fig. 4d. Rectifier output voltage in open loop under load disturbance is shown in Fig. 4e. The output voltage increase. The rectifier output voltage with closed loop is shown in Fig. 4f. From this figure it can be seen that the output voltage is constant.

Table 3: Fourier components with RLE load

Harmonic number	Frequency (HZ)	Fourier component	Normalized component
1	5.000E+01	3.568E+00	1.000E+00
2	1.000E+02	1.583E-02	4.435E-03
3	1.500E+02	2.559E+00	7.171E-01
4	2.000E+02	1.483E-02	4.156E-03
5	2.500E+02	1.513E+00	4.241E-01
6	3.000E+02	3.152E-03	8.832E-04
7	3.500E+02	8.401E-01	2.354E-01

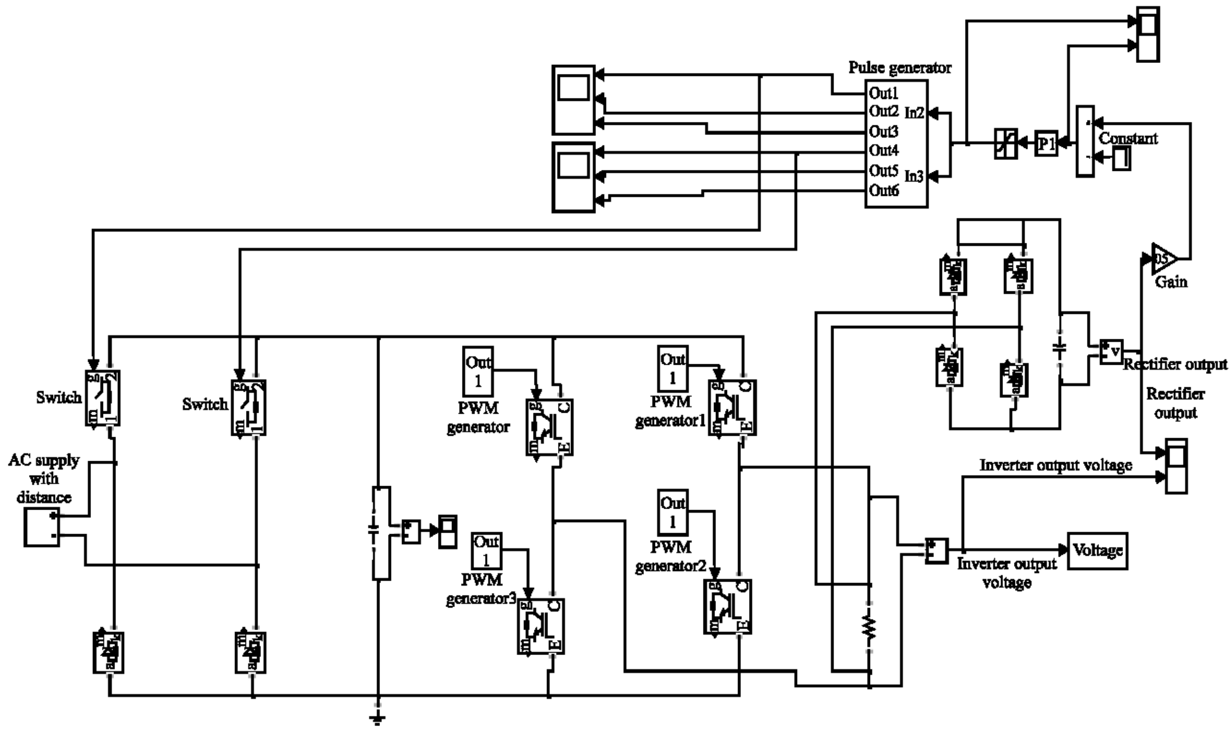

Fig. 4d: Closed loop system using matlab

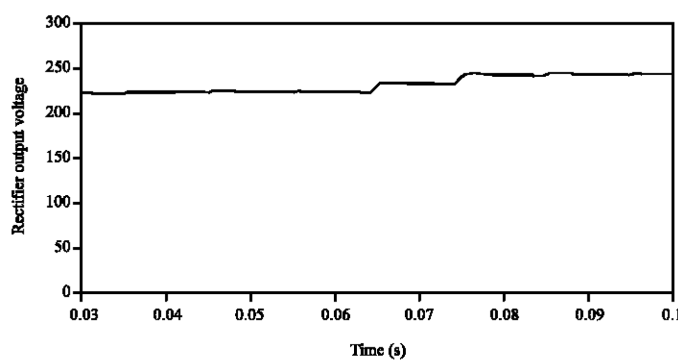

Fig. 4e: Output voltage with open loop under load disturbance

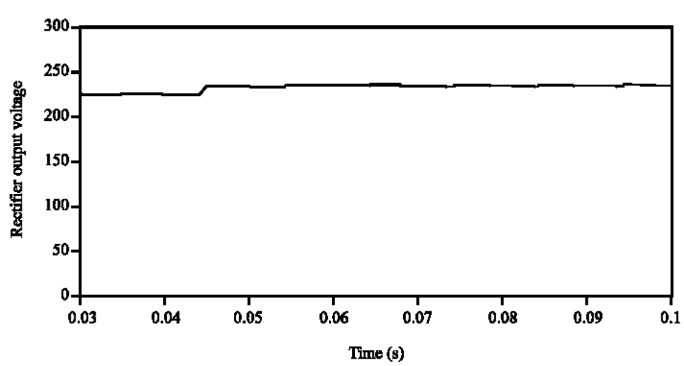

Fig. 4f: Output voltage with closed loop system

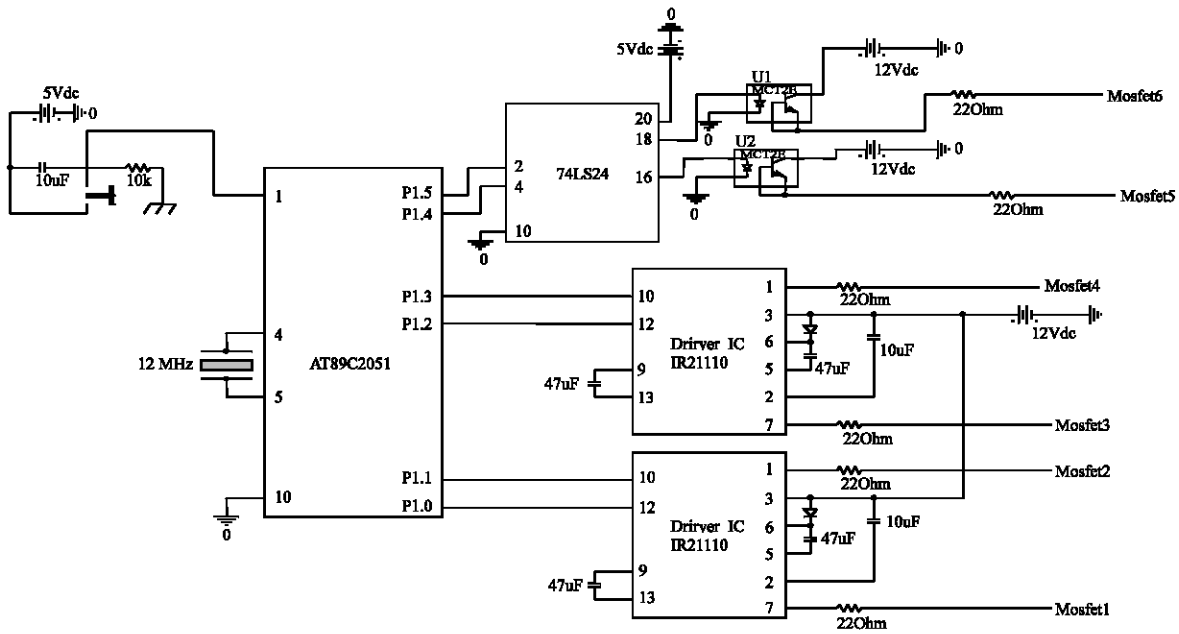

Fig. 5: Block diagram of control circuit

Fig. 6a: The pulses from the micro controller

Fig. 6c: The output voltage of inverter with inductive load

Fig. 6b: The output voltage of inverter with R-load

Fig. 6d: The top view of hardware

Hardware implementation: The pulses required for the MOSFETs are generated using microcontroller 89C2051. The block diagram of control circuit is shown in Fig. 5. The pulses are generated from the port1 of the microcontroller. They are given to the driver circuit through the buffer 74LS244. The 5 V pulses from the buffer are amplified to 10 V 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. 6a. The output voltage of the inverter with R load is shown in the Fig. 6b and that of inductive load is shown in the Fig. 6c. The top view of the hardware is shown in the Fig. 6d.

SYMBOLS

PWM	Pulse width modulation
VSIG	Variable speed induction generator
PSPICE	Pc based simulation package for IC's emphasize
THD	Total harmonic distortion
PWMC	Pulse width modulation converter

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. Harmonic analysis for the output was done and the results are compared. From the simulation studies it is observed that the output voltage remains constant even as the wind speed changes. This study has presented a comprehensive control strategy that addresses the requirement in a wind generation system. The response is faster since the power circuit uses MOSFET based PWM inverter. The PSPICE circuit model was developed for open loop and closed loop systems. Closed loop system is simulated using the proposed circuit model. The output voltage was sensed and it is compared with a reference voltage. The control circuit adjusts the pulse width such that the output is maintained constant. The output voltage was maintained constant using closed loop system. The hardware was successfully implemented using the microcontroller 89C2051. The experimental results coincide with the simulation results.

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