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Electrical Power
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ELECTRICAL POWER ENGINEERING

Design and Construction of Wind Power Generation Control System

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Abstract— **The primary application envisaged for wind is in the generation of electrical energy. Wind-electric systems convert energy in moving air to constant voltage and frequency AC form to be fed into existing utility lines to augment the total energy generated and save fuel. Wind electric systems generate power only when the wind blows. The problem for wind power system is the velocity of the wind is variable unsteady and irregular. Also wind turbine speed is not constant and also the wind-generator output frequency and voltage are fluctuated. So wind power generation control system is required to control this output frequency and voltage. This paper emphasizes permanent magnet three-phase generator control system used in small scale wind turbine to control variable voltage and frequency. In voltage control system composes three-phase uncontrolled rectifier, charging controller, electrically breaking system and in frequency control system uncontrolled rectifier, controlled frequency converter. They have been constructed and tested.**

Keywords— **voltage controller, frequency controller, rectifier, electrical breaking for wind turbine**

I. Introduction

Wind power can be an essential part of renewable energy input, but requires much more time and energy in designing and implementation. The mounting of wind system is vital for safety and efficiency. Wind energy has a limitation, although in no way negligible, environmental impact. The primary application envisaged for wind is in the generation of electrical energy. The ease with which aero turbines transform energy in moving air to rotary mechanical energy suggests the use of electrical devices to convert wind energy to electrical form for variety of end users.

Wind electric system generally comprises into a rotor blade, a generator or alternator mounted on a frame, a tail, a tower, wiring and balance of system components, inverters and batteries.

Wind electric systems generate power only when the wind blows. The problem for wind power system is the velocity of the wind, is variable unsteady and irregular. Also wind turbine speed is not constant and therefore the wind-generator output frequency and voltage are fluctuated. Therefore wind mill generation control system is required for this output frequency and voltage. Frequency and voltage controllers have been designed and constructed.

II. Frequency Control System

Wind turns the blades of the turbine which spins a shaft within the turbine structure. The shaft drives a generator to produce electricity. The electricity is either used or stored in batteries. Battery less system 300 watts, 6 poles, 24 V permanent magnet three-phase wind generator control system is provided. In this control system composes rectifier, filter and inverter. Driver circuit is used for switching transistors of inverter. They are as shown in Fig. 1 and Fig. 2.

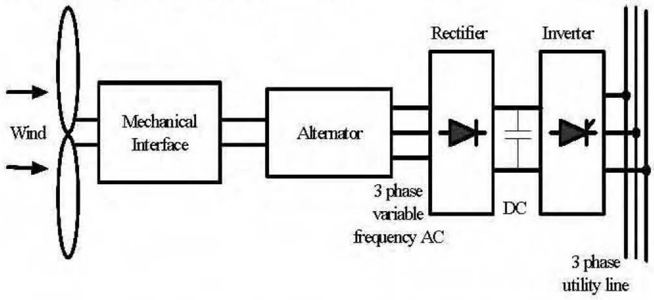

Fig. 1 Schematic of wind-electric system employing AC-DC-AC link

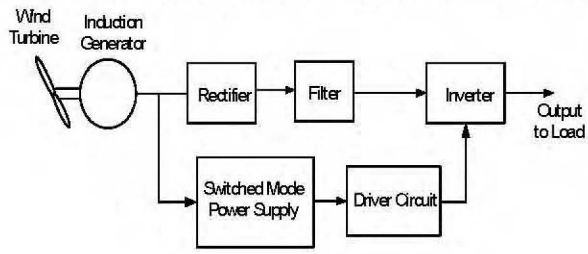

Fig. 2 Wind Electric System

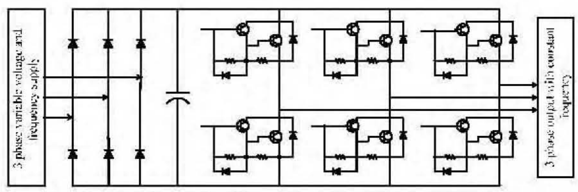

Fig. 3 Schematic of Generator Control System

Standard AC supply is converted to DC voltage by using a three-phase diode bridge rectifier. A capacitor filters the ripple in the DC bus. This DC bus is used to generate available voltage and variable frequency supply. A voltage source inverter is used to convert the DC bus to the required AC voltage and frequency.

The inverter has six switches that are controlled in order to generate from the DC input. Switching signals generated from the digital controller board control these MP 6501 six switch transistors as shown in Fig. 3. In time a maximum of three switches will be on either one upper and two lower switches, or two upper and one lower switch. When the switches are on, current will flow from the DC bus to the output terminal. That must be known upper and lower switches of the same limb should not be switch on at the same time. This will prevent the DC supply from being short.

The AC source frequency is obtained from the rated speed of the alternator can be calculated by Equation 1 and also obtained required capacitor as filter.

$$f = \frac{pn}{120} \quad (1)$$

where;

f = frequency

p = number of poles

n = speed

Variable speed applied therefore variable frequency obtained according to equation 5.1.

$n_1 = 1000\,\text{rpm}$, $f_1 = 50\,\text{Hz}$

$n_2 = 1100\,\text{rpm}$, $f_2 = 55\,\text{Hz}$

$n_3 = 1200\,\text{rpm}$, $f_3 = 60\,\text{Hz}$

$n_4 = 1300\,\text{rpm}$, $f_4 = 65\,\text{Hz}$

$n_5 = 1400\,\text{rpm}$, $f_5 = 70\,\text{Hz}$

$n_6 = 1500\,\text{rpm}$, $f_6 = 75\,\text{Hz}$

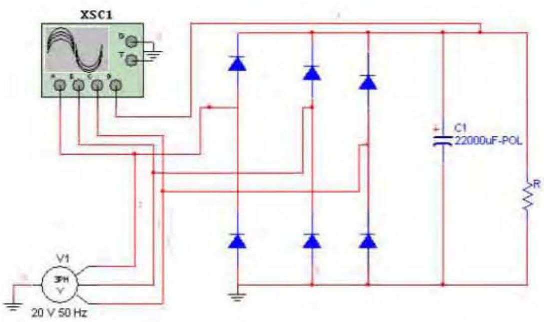

Fig. 4 Full Bridge Uncontrolled Rectifier

AC wind mill generator usually uses a pair of diodes for each stator winding, for a total of six diodes. By using a pair of diodes that are reverse bias to each other, full wave rectification of the AC sine wave is achieved as shown in Fig. 4.

With each stator winding connected to a pair of diode. With six peaks per revolution, the voltage will vary slightly during each cycle. This condition produces the steady-state response shown in Fig. 5 with no filter capacitor and after filtered in Fig. 6 are presented.

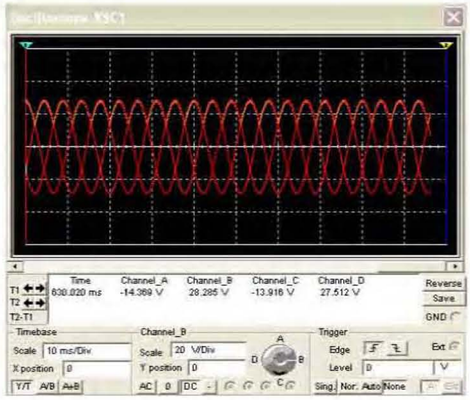

Fig.5. Voltage Response for Uncontrolled Rectifier

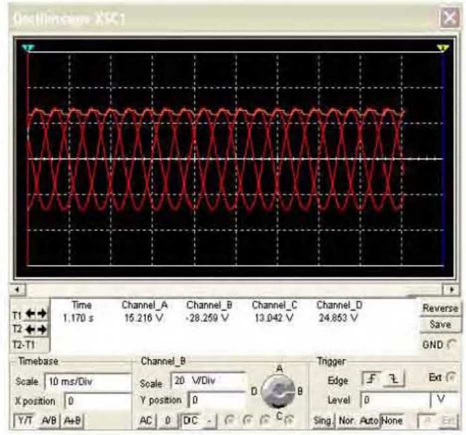

Fig. 6 Voltage Response for Uncontrolled Rectifier after Filtered

The rated voltage of the alternator is 24 V. Assume $V_{r.m.s} = 20$ V.

So, the average load voltage, $V_{O(avg)} = 0.955\, V_{L(m)}$ (2)

where; $V_{O(avg)}$ = average load voltage

$V_{L(m)}$ = maximum line voltage

But the maximum value of line voltage is

$$V_{L(m)} = \sqrt{2} \times V_{r.m.s} \quad (3)$$

$$= \sqrt{2} \times 20$$

$$= 28.28\ \text{V}$$

where; V_{rms} = line voltage

Therefore, the DC voltage across the load is

$$V_{O(avg)} = 0.955\, V_{L(m)}$$

$$= 0.955 \times 28.28$$

$$= 27\ \text{V}$$

The DC load current is

$$I_O = \frac{V_{O(avg)}}{R_L} \quad (4)$$

where; I_O = load current

R_L = load resistance

Assume R = 3 Ω,

$$I_O = \frac{27}{3} = 9 \text{ Amp}$$

For a six-pulse uncontrolled rectifier average current in one of the diodes ($I_{D(avg)}$) is

$$I_{D(avg)} = \frac{I_{O(avg)}}{3} = \frac{9}{3} = 3 \text{ Amp}$$

The RMS value of the diode current is

$$I_{D(RMS)} = \frac{1}{\sqrt{3}} I_{O(avg)} = \frac{1}{\sqrt{3}} \times 9 = 5 \text{ Amp}$$

The maximum blocking voltage for diode

$$PIV \geq V_{L(m)}$$

$$PIV \geq 30 \text{ V}$$

The ripple factor is

$$RF = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1} \quad (5)$$

Where; RF= ripple factor

V_{DC}=DC voltage

$$RF = \sqrt{\left(\frac{28.28}{27}\right)^2 - 1}$$

$$= 0.3115$$

Smoothing capacitor for 10% ripple is

$$C = \frac{5 \times I_O}{V_S \times f} = \frac{5 \times 9}{27 \times f} \quad (6)$$

From equation 5.6 capacitance values are

C_1= 33333 μF

C_2= 30303 μF

C_3= 27777 μF

C_4= 25641 μF

C_5= 23809 μF

C_6= 22222 μF

Therefore 22000 μF capacitor is used as filter.

The peak to peak ripple voltage is

$$V_r = \left(\frac{1}{fR_L C}\right) V_{P(in)} \quad (7)$$

V_r=ripple voltage

$$V_r = \left(\frac{1}{75 \times 3 \times 22000 \times 10^{-6}}\right) \times 27$$

$$V_r = 5.45 \text{ V}$$

The DC value of the filter's output voltage is

$$V_{DC} = \left(1 - \frac{1}{2fR_L C}\right) V_{P(in)} \quad (8)$$

$$V_{DC} = \left(1 - \frac{1}{2 \times 75 \times 3 \times 22000 \times 10^{-6}}\right) \times 27$$

$$V_{DC} = 24.27 \text{ V}$$

III. SWITCHED MODE POWER SUPPLY

Switching power supplies offer many advantages over linear regulators. Switching power supplies are more efficient and are smaller in size than linear regulators of similar ratings. Unlike linear regulators which operate the power transistor in the linear mode, the PWM switching power supply operates the power transistors in both the saturated and cut-off states. In these states, the volt-ampere product across the power transistor is always kept low (saturated, low-V/high-I; and cut-off, high-V/low-I). This more efficient operation of the PWM switching power supply is done by chopping the DC input voltage into pulses whose amplitude is the magnitude of the input voltage and whose duty cycle is controlled by a switching regulator controller.

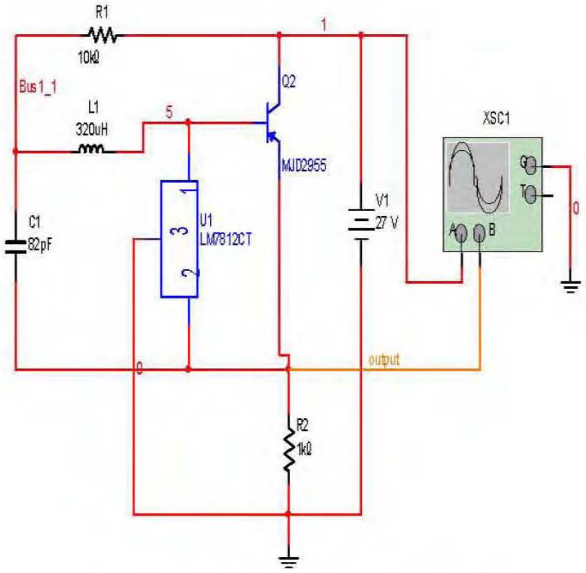

Fig. 7 12 V DC Supply Circuit for SG3525 IC

In this switching mode system consists PWM IC SG3525 is used as a switching regulator controller. And then two MOSFETs are used as pulse switches. For this PWM IC 12 V DC supply is achieved by this circuit as shown in Fig 7. The variable DC input is obtained from uncontrolled rectifier that may be greater than 12 V but output voltage is 12 V as shown in Fig 8.

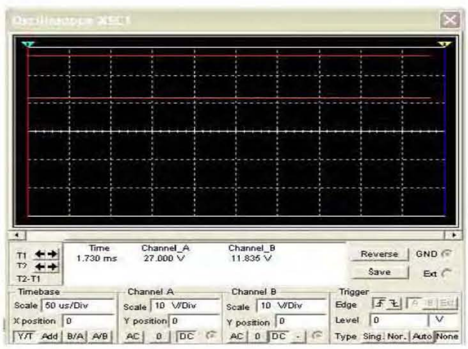

Fig. 8 Resultant Waveform for 12 V DC Supply Circuit for SG3525 IC

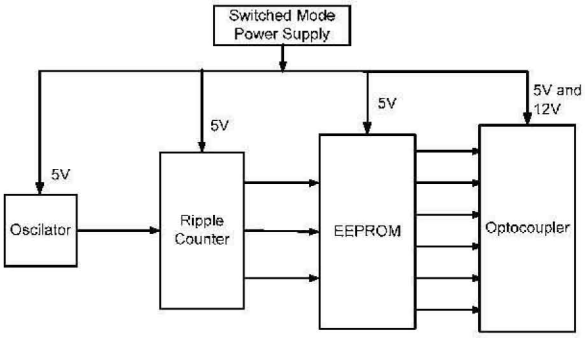

Fig. 9 Block Diagram of Power Supply for Switching Inverter

Block diagram for power supply is shown in Fig. 9 and circuit diagram in Fig. 10.

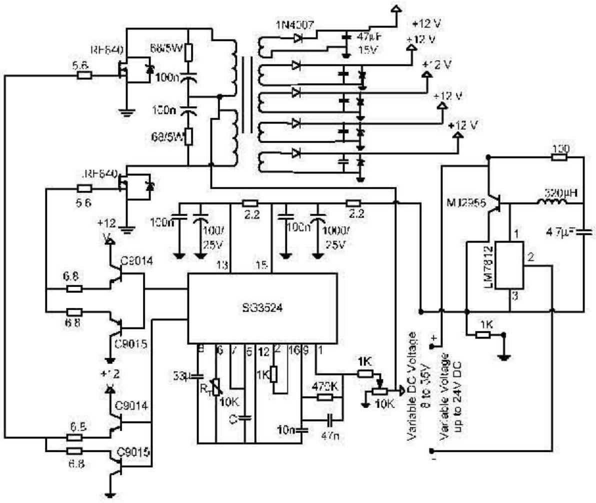

Fig. 10 Circuit Diagram of Switched Mode Power Supply

The capacitor charge current at oscillator's terminal of SG 3525A,

$$I = C\frac{dv}{dt}$$

$$T = 0.7R_T C_T$$

$$V_{th} = \frac{V}{R_D} e^{-(T/R_D C)}$$

$$T = 3R_D C_T$$

$$T = 0.7R_T + 3R_D C_T$$

(9)

$$F_{osc} = \frac{1}{T} = \frac{1}{(0.7R_T + 3R_D)C_T}$$

(10)

In this SMPS circuit R_D is neglected because of using low voltage high frequency that is between 13 kHz and 18 kHz.

$$F_{osc} = \frac{1}{0.7R_T C_T} \qquad (11)$$

Therefore variable resistor (R_T=10 kΩ) and capacitor (C_T=1 nF) are used in this SG 3525A PWM IC.

IV. SWITCHING INVERTER

An inverter converts from a DC input into an AC output statically. The inverter also has a switching control circuit that provides the necessary pulses to turn ON and turn OFF each static switching element with the correct timing and sequence. These switches are repetitively operated in such a way that the DC source at the input terminals of the converter appears as AC at its output terminals. The AC frequency is precisely adjustment of the switching frequency of the power switching elements. This is usually determined by the frequency of a clock oscillator. Block diagram of the switching converter circuit is shown in Fig. 11. This switching converter has four portions.

(1) Power supply
(2) Oscillator
(3) Sequence decoder (ripple counter and EEPROM)

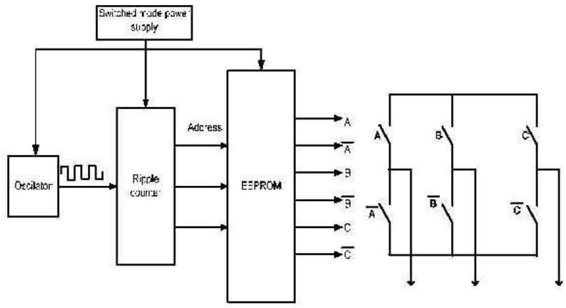

Fig. 11 Block Diagram of Switching Inverter

Power supply is used for the switching converter control circuit 12 V and 5 V DC supply voltage. Oscillator is circuit that generates an output signal without an input signal. It is used as signal sources in all sorts of applications. Different types of oscillators produce various types of outputs including sine waves, square waves, triangular waves and saw-tooth waves. Square waves are used for this thesis.

Whenever the number of process actions or events are of significance and need to be stored, counters are used. These programmable counter circuits are available on all programmable logic controllers. In this converter circuit, counter counts the signal to memory storage (EEPROM).

EEPROM is programmed to get required output signals for switching devices. CMOS 4047 may be used both as a greate, or free-running, astable circuit and as a monostable multivibrator. The CMOS 'on' resistance is normally several hundred ohms. If 10 kΩ resistor and 0.47 μF capacitor are used, 50 Hz frequency will be achieved.

The operation of the circuit as shown in Fig. 12 is described as below. The circuit includes power amplifier circuit, driver for switching transistor circuit, control circuit, ripple counter, and oscillator.

The oscillator stage is using CMOS 4047 multivibrator to produce oscillator frequency to control the ripple counter circuit. The ripple counter is used as a 74LS261 asynchronous binary ripple counter to count and give address bits for 28C64 EEPROM.

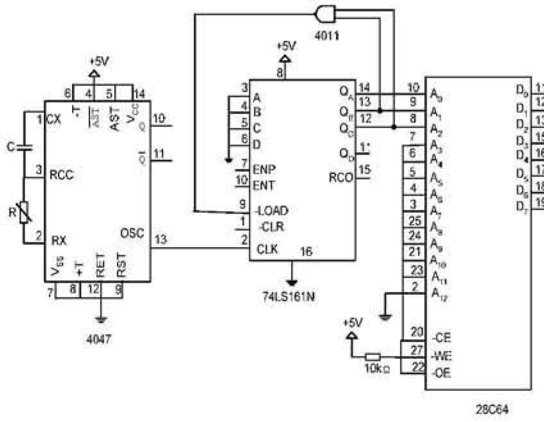

Fig. 12 Driver Circuit for Switching Inverter

The sine wave code is programmed in the ROM to produce the control signal for the driver circuit. The output voltage signal of the ROM is connected to the PC922. This PC922 opto couple totem pole transistor array is subdivided in high voltage driver parts and low voltage control parts. That is switching for transistor as shown in Fig. 13.

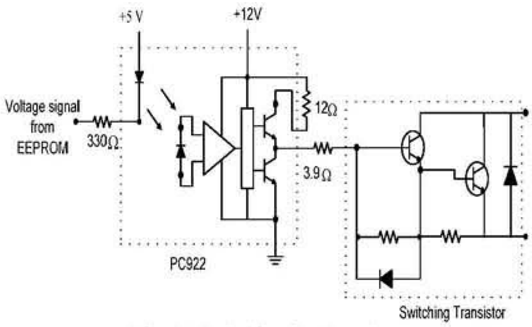

Fig. 13 Switching for Transistor

V. CONCLUSION

Thus this thesis provides knowledge of the variable frequency drive system for variable speed wind power system. The conventional wind power system consist AC/DC generator, rectifier, battery and charger, and also include inverter.

In frequency control system switching inverter portion is important. In this portion regulated voltage must be obtained from variable input supply. Therefore switched mode power supply has been used with PWM IC. By using this SMPS regulated and efficient DC supply voltages are obtained, stabling the control circuit.

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