التحكم فى الجهد و التردد لمولد حثى ثلاثى الأوجه المدار بواسطة طاقة الرياح

أ.د. ياسر جابر دسوقى   م. ايمان حسن بشر

مقدمة:

هذا البحث يقدم دراسه نظرية مع التطبيق العملى لنظام التحكم فى جهد و تردد مولد الحث الذاتى الاثارة. المنظومة النظرية تم تصميمها و تمثيلها باستخدام برنامج الحاسب و تم تطبيق المنظومة عمليا باستخدام الكترونيات القوى. مقارنة النتائج العملية و النظرية بينت تقارب المنظومتين بشكل جيد.

VOLTAGE CONTROL OF SELF EXCITED INDUCTIONGENERATOR DRIVEN BY WIND SPEED

Asso.Prof. Yasser G. Dessouky   **Eng.Eman H. Beshr**

Dept. of Electrical and computer control Eng.
Arab Academy for Science and Technology
Mami,P.o. Box:1029, Alexandria,Egypt

Abstract

This paper presents a theoretical and experimental analysis of a stand alone wind energy system using three phase squirrel cage self excited induction machine. The system is designed, simulated using MATLAB-SIMULINK software package and implemented practically using power electronics devices involving full wave rectifier ,choppers and inverters.

مقدمة

هذا البحث يقدم دراسه نظرية مع التطبيق العملى لنظام التحكم فى جهد و تردد مولد الحث الذاتى الاثارة . المنظومة النظرية تم تصميمها و تمثيلها باستخدام برنامج الحاسب و تم تطبيق المنظومة عمليا باستخدام الكترونيات القوى. مقارنة النتائج العملية و النظرية بينت تقارب المنظومتين بشكل جيد.

Keywords: Induction generator   Wind energy   Voltage control   Frequency control.

List of symbols

R_s, X_s : stator resistance and leakage reactance per phase
R_r, X_r : rotor resistance and leakage per phase
X_m : magnetizing reactance
X_c : per phase capacitive reactance
R_L, X_L: load resistance and reactance
F : per unit frequency /base frequency 50Hz
nd speed /the synchronous machine speed (per unit speed)
operator $p = \frac{1}{\omega}\frac{d}{dt}$

I- Introduction

Self excitation of a 3-ph induction machine can occur using a suitable amount of terminal capacitor connected to motor terminals by versue of residual magnetism of the machine [1].

In the experimental laboratory proto-type ,the generated voltage of the machine is controlled by controlling the amount of capacitor banks connected to machine terminals corresponding to wind speed. Capacitor banks are connected or disconnected to the machine using relays whose control signals are produced by a multi stage comparator circuit that compares speed signal with set values.

Three phase uncontrolled bridge rectifier is used to convert power from AC to DC. Which ,in turns, is stored in a back up battery using a push pull dc-to-dc single quadrant chopper. The base signal of the two power transistors are controlled through a feed back signal from a battery using pulse width modulation controller[2].

Then the dc power is converted to ac power with 220V and 50Hz.This is done by using a single phase inverter which uses a pulse-width modulation controller with a feed back signal from load voltage.

The schematic diagram of this shown in figure (1) represents this system has no speed control .

II- Theory

Steady state analysis of the induction generator may be obtained from the equivalent circuit model shown in figure (2). In a capacitor self excited stand alone induction generator, the terminal voltage and frequency are computed for a given speed, capacitance and load impedance. Knowing the parameters of the machine, it is possible to determine the machine performance for given wind speed, capacitance and load condition. All equivalent circuit parameters are assumed to be constant except the magnetizing reactance which is affected by the magnetic saturation[3].

Standard tests have been carried out on the machine in order to determine the equivalent circuit parameters. The machine parameters are as follows:

Rs, Xs :1.9,2.45ohm per phase
Rr, Xr : 2 ,2.45 ohm per phase
Xm : 10 ohm unsaturated

Wind turbine

Fig. (1) Schematic diagram of wind energy system

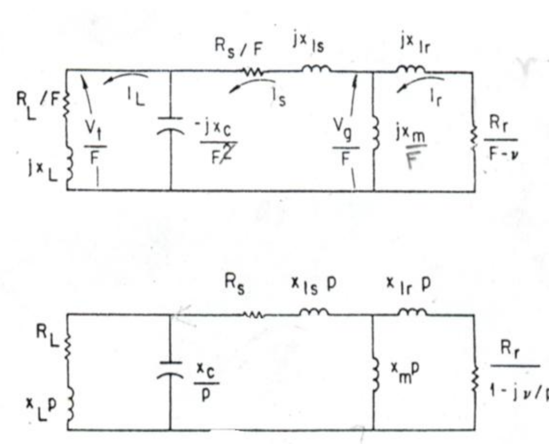

Fig. 2 Equivalent circuit of induction generator with load

Figure (2) shows the corresponding equivalent circuit of the induction generator, which is obtained by substituting F=-jp . It will be noted that the equivalent impedance of the circuit must equal to zero, expressed in terms of the circuit parameters and the per unit frequency 'F', then

$$Z_t = \frac{X_m p\left(X_r p + \frac{R_r}{1 - j\nu/p}\right)}{\frac{R_r}{1 - j\nu/p} + X_r p + X_m p} + R_s + X_s p + \frac{(R_l + X_l p)\, X_c/p}{R_l + X_l p + X_c/p}$$

This equation may be rearranged to get:

$$K_1 P^4 + K_2 p^3 + K_3 P^4 + K_4 P + K_5 = 0$$

where

$$K_1 = -jX_L X_r (X_m + X_r)$$

$$K_2 = -\nu X_L X_S (2 * X_m - X_s) - j[X_L (R_s + R_r)(X_m + X_r) + X_r R_L (2X_m + X_r)]$$

$$K_3 = -\nu X_L R_L (2X_m + X_r) - \nu R_s X_L X_S - j[X_r X_c (2X_m + X_r) + R_L X_s (R_S + R_r)]$$

$$K_4 = -\nu[X_c X_L X_S + R_S R_L X_S + XrX_C(2X_m + X_L)] - j[X_C X_S (R_L + R_S + R_r) + R_S R_r R_L + X_C X_L R_r]$$

$$K_5 = -\nu X_c X_S (R_S + R_L) - jX_C R_r (R_S + R_r)$$

where

$$X_S = X_m + X_r$$

For a given wind speed, load impedance and circuit parameters, the critical value capacitor (the minimum capacitance required for self excitation at certain wind speed) which results in a zero real part for the roots of equation (1) can be evaluated[4].

Now consider the case when the capacitor connected to the machine terminal is higher than the critical capacitor value and at unity power factor load, the roots of equation (2) will be two conjugates both have a large negative real part representing a current component which vanishes quickly. The real part of the other root is positive. This root causes the machine to be self excited. Due to self excitation, the terminal voltage and the air gap voltage continue to increase and the magnetic reactance will be decreased. The magnitude of the real part of this root will also decrease and the generator reaches steady state condition[5].

Best fitting curve is done to show the variation of the magnetization reactance versus the air gap voltage at synchronous speed (1500 rpm) as shown in figure (3).

$$V_g/F = -0.1926X_m^2 + 29.4775X_m - 912.3667 \quad (3)$$

Knowing magnetizing reactance Xm, the corresponding gap voltage is obtained from the relation between magnetizing reactance and air gap voltage at synchronous speed. The terminal voltage (V_t),stator current (I_S) , load current (I_L) and output power can be obtained using equivalent circuit is as follows:

$$I_s = \frac{V_g/F}{\frac{R_s}{F} + jX_s - \frac{X_c(X_L F + jR_L)}{F^2 R_L + jF(F^2 X_L - X_c)}}$$

$$I_L = \frac{-jX_C I_S}{FR_L + j(F^2 X_L - X_C)}$$

$$V_t = (R_L + jFX_L)I_L$$

$$P_{out} = 3|I_L|^2 R_L$$

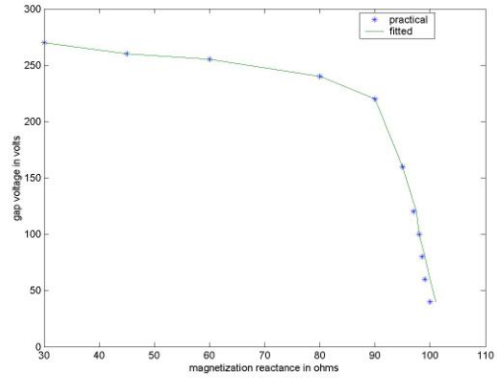

Fig. 3 Induction machine magnetization curve

In the self-excitation mode, the generator output frequency and voltage are affected by the speed, load and capacitance value[6].

Figure (4) shows the relation between the no load voltage and capacitor value connected across the induction generator terminals at 1000 rev/min. It can be noticed that the generated voltage increases with the increase of the amount of capacitance connected across machine terminals.

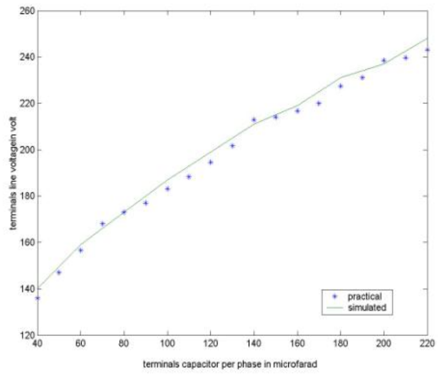

Fig. 4 The relation ship between no load voltage and capacitor per phase at 1000 rev/min

Therefore the generated voltage may be controlled by the controlling of the amount of capacitor connected across the machine terminals when the wind speed changes.

It can be noticed from figure (5) that terminal voltage is kept within acceptable range so as to protect generator from over voltage.

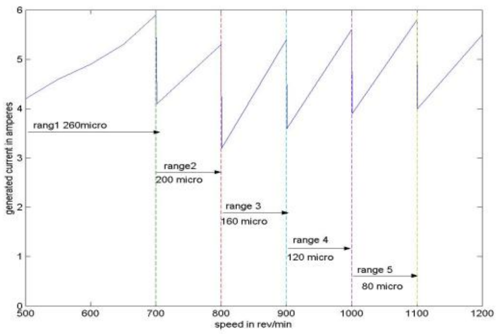

Fig.5 Computed voltage and wind speed after voltage control

III-Simulation

Figure (6) shows the relationship between the frequency of the output voltage from the generator and the load current at different speeds. It can be noticed that both load current and speed affect the frequency. To eliminate the effect of charging the frequency ,the ac voltage is converted to dc using an uncontrolled three phase rectifier whose input is the three phase voltage from the induction generator with almost constant magnitude and variable frequency. The rectified voltage is filtered using L-C filter type. The filter capacitor is selected to be as high as possible to make the capacitor impedance very low at certain harmonics . The filter inductance is selected to maintain filter ripple factor of 10%. The rectified voltage is shown in figure (7)[6].

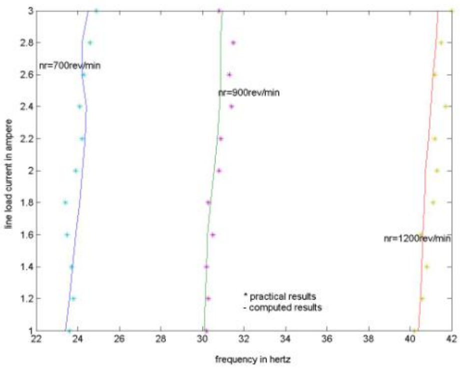

Fig. 6 Load current and frequency at different speeds

Fig. 7 Computed rectified voltage after filter

The dc voltage is used to charge a back up battery to its full voltage using dc-to-dc single quadrant chopper with a step down transformer (10:1).

The control scheme of the chopper is a pulse width modulation technique. Figure (8) shows the chopper output voltage from simulation program. The two base drive pulses of the two transistors are produced by comparing a feed back signal from the battery with a reference value. The error signal is then applied to a (PI) controller whose output is compared with a saw tooth pulse to generate square pulses.

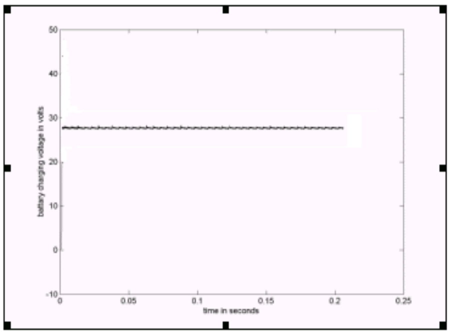

Fig. 8 Simulated battery voltage output from chopper circuit after being filter

Push pull single phase inverter is used to convert dc voltage to ac voltage. The dc voltage is converted to 220V ,50Hz ac voltage via an inverter which is controlled by a feed back pulse width modulation controller. Figure(9) shows simulation results from the inverter circuit[6].

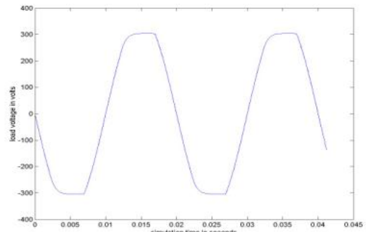

Fig. 9 Output line voltage of wind energy system

IV-Experimental implementation

It can be observed that the generated voltage from wind speed is converted to a smooth dc voltage.

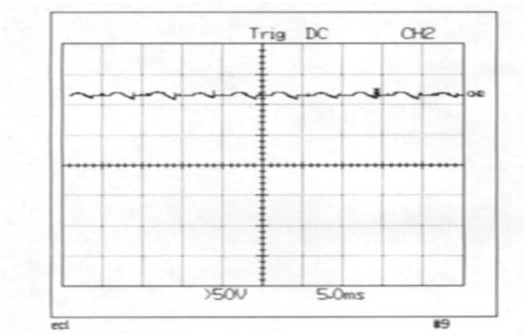

Fig.10 Experimental rectified voltage after filtration

Figure (10) shows the practical results from rectification stage .While figure (11) shows the practical output of the chopper circuit

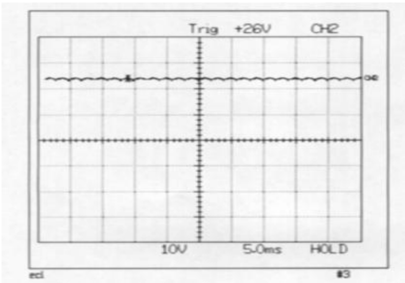

Fig. 11 Practical results from chopper circuit

The system input is a wind speed and system output is 220V and 50Hz single phase voltage . Figure (12) shows the load voltage of the over all practical system[7]. The details of the practical system is shown in figure (13).

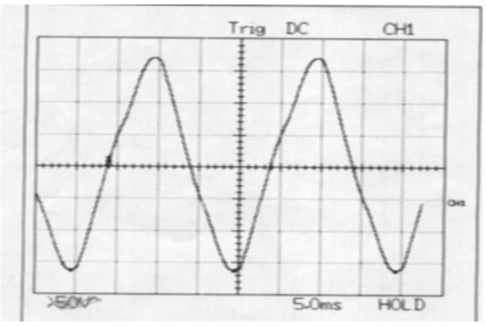

Fig.12 Experimental results of the load voltage

V-Conclusions

The use of induction machine as a self excited induction generator requires a sufficient amount of excitation capacitor and rotation by some external mechanical power and amount of residual magnetism placed on the machine core.

The results showed that the excitation capacitance required increases with decreasing speed to protect machine from over voltage. The range of speed between 500 rev/min and 1200 rev/min requires excitation capacitance of 40 F to 260 F.

The results showed that voltage is increased by 301% with the increase of excitation capacitor from 40 F to 260 F at constant speed of 800 rev/min. Also, voltage is increased by 748% with the increase of wind speed between 500rev/min to 1200 v/min at constant excitation capacitor of 130 F.

The results showed that the frequency is changed by 240% with speed variation between 500rev/min to 1200 v/min and frequency is changed by 2.5% with load current between 1 Ampere to 6 Ampere.

Excitation control has been obtained by employing a five steps capacitor banks connected to induction machine using relays to maintain the voltage not exceed than 1.05 from rated machine voltage with speed variation between 500rev/min to 1200 v/min.

The operating characteristics are governed by the magnetic saturation in the machine. Saturation has been incorporated by the use of experimental data which indicate the variation of the magnetizing reactance with the air gap voltage.

A computer simulation using MATLAB-SIMULINK software package has been developed to analyze the steady state performance of a capacitor self excited induction generator. The operational equivalent circuit of the machine has been used in the analysis to identify the steady state analysis. It was found that the condition of self excitation is one of the roots of the characteristic equation must be located on the imaginary axis(zero real part).

Battery is used as a back up source to wind energy and helps the improvement of voltage regulation due to its controlled constant voltage. The battery voltage is kept constant using single quadrant chopper that applies pulse width modulation control technique

VI -References

ol

conference Arab academy for science and technology,Vol.22, No. 9, September 2002.

analysis of capacitor self-excited induction

apparatus and systems,Vol.PAS-103, No. 3, 1984

Trans.on power engineering ,Vol.60, 1941.

[6] J.M.E

Proc.,Vol.130, No. 2, 1983.

design , book, John Wiley and Sons, 1993.