THE INDUCTION GENERATOR FOR CONTINUOUS OPERATION WITH WIND TURBINES

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ABSTRACT :

This paper presents an operation of wound rotor induction machine as a generator more suitable for wind or hydro turbines. The Load is supplied through the generator when the turbine speed is varried from zero to higher than double synchronous speed. AC supply of 50 Hz is connected to the rotor. The rotor is rotating in opposite direction to the rotor rotating field. A transformer power from the AC supply through the generator is to feed the load at zero speed rotor rotation. By increasing rotor speed, a mechanical power from the prime mover will be converted to the load. The output voltage at zero speed will be of 50 Hz. The speed increasing leads to outpu. voltage can be kept constant by reducing the input voltage with speed increasing.

Experimental investigation and theoritical analysis of the generator are obtained.

KEYWORDS :

AC generator; variable speed variable frequency, hydro generators, wind energy generator, electrical machines.

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1- INTRODUCTION :

There are many various schemes for w nd energy conversion systems for generating electricity. Which can be classified according to the type of the output as [1] AC constant frequency, AC variable frequency or DC also They are classified according to the speed as [1,2,3]; constant speed or variable speed.

The proposed generator is AC variable speed shown in Fig. 1.

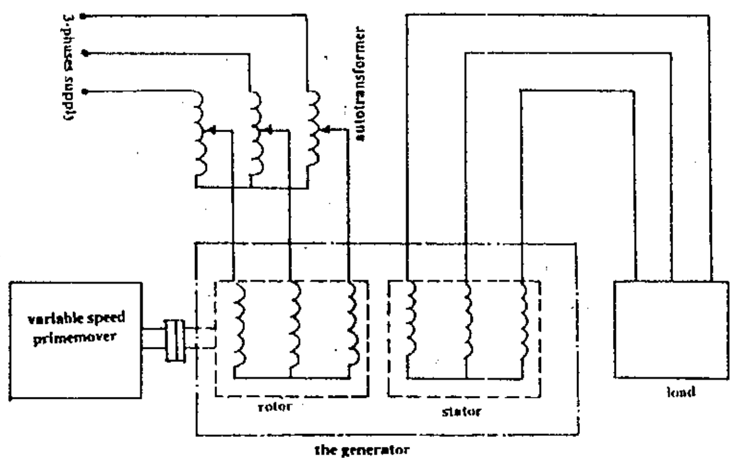

Fig. 1. Generator winding arrangrement

The generator is a wound rotor induction machine. The rotor is connected to the grid or constant frequency supply. The stator terminals are connected to the load. The generator should be rotating in opposite direction to the rotor rotating field. When the rotor at stand still, the load is supplied from the grid. Then the generator working as a transformer to feed the load. By increasing the speed a converted power from the primemover, through the generator will be transferred to the load. The load voltage and frequency will be increased by speed increasing. For constant output voltage, the input voltage is reduced by speed increasing. The output is converted to DC by bridge rectifier to avoid the effect of variable frequency. An inverter can be used after the bridge for constant output frequency.

The generator is investigated in two modes of operation; a-constant input voltage and freqency-variable output voltage and frequency, b-variable input voltage at constant frequency-constant DC output voltage. In mode (a), no input voltage regulator or output bridge is used. This can be used with wind or hydro systems to feed heating and battery storage loads. The input voltage regulator and ouptut bridge rectifier are used in mode (b), which can be used with constant DC voltage loads or constant voltage-constant frequency loads.

2- GENERATOR PERFORMANCE ANALYSIS:

The equivalent circuit of the generator per phase reffered to the rotor is shown in Fig. 2. The generator parameters are reffered to the rotor because it is the input member and the stator is the output member.

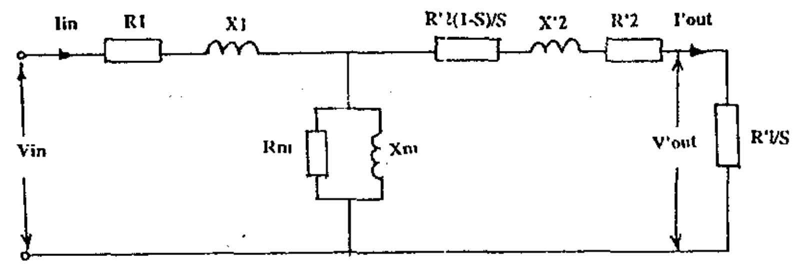

Fig. 2. Generator equivalent circuit referred to the rotor

Where;

R1 = rotor phase winding resistance.

X1 = rotor phase winding leakage reactance.

$R'2$ = stator phase winding resistance referred to the rotor.

$X'2$ = stator phase winding leakage reactance referred to the rotor.

$R'2 \, \dfrac{(1-S)}{S}$ = equivalent resistance of the mechanical power converted from the prime mover through the generator referred to the rotor.

Rm = equivalent iron loss resistance per phase.

Xm = magnetising reactance per phase.

$R'L$ = load resistance per phase referred to the rotor.

Vin = input voltage to the rotor per phase.

$V'out$ = output voltage to the load per phase referred to the rotor.

Iin = input current to the rotor per phase.

$I'out$ = output current to the load per phase referred to the rotor.

From the equivalent circuit of Fig. 2, the rotor input phase current (Iin) is calculated by,

$$Iin = Vin/(R_t + jX_t). \qquad (1)$$

Where;

$Rt = R21 + R1,$

$Xt = X21 + X1.$

$R21 = (Rmm * R2m + Xmm * X2m)/Az2,$

$X21 = (Xmm * R2m - Rmm * X2m)/Az2,$

$Xmm = (X'2 + Rzm) + (R2s * Xzm),$

$Rmm\ (R2s * Rzm) - (X'2 * Xzm),$

$R2m = R2s + Rzm,$

$X2m = X'2 + Xzm,$

$Az2 = (R2m)^2 + (X2m)^2,$

$$R2s = \left(\frac{R'2}{s} + \frac{R'L}{s} \right),$$

$Rzm = Rm * Xm^2/Azm,$

$Xzm = Rm^2 * Xm/Azm,$

$Azm = R^2m + Xm^2$

S = generator slip

$S = (ns + n) / ns$

ns = synchronous speed.

n = prime mover speed.

The output current referred to the rotor (I out) is

$$I\acute{o}ut = Iin * Z21/(R2s + J\acute{X2}) \quad (2)$$

The actual output phase current (Iout) is

$$Iout = I\acute{o}ut \;/\; a \quad (3)$$

Where, a = stator to rotor effective turns ra.io.

The input power factor (pf) is

$$Pf = Rt/ (Rt + J\,Xt) \quad (4)$$

The generator iron losses (pi) ar

$$Pi = 3\,(Iin\,Z21)^2/ Rm \quad (5)$$

The generator copper losses (Pc) are

$$Pc = 3\,(I^2in\,R1 + I^2out\,R2) \quad (6)$$

The input power to the rotor (P_{in}) is

$$Pin = 3\,Vin * Iin * Pf \quad (7)$$

The output power (pout) is

$$Pout = 3\,I^2out\,Rl/S \quad (8)$$

The mechanical power output from the prime mover (Pm) is calculated by

$$Pm = (Pout + Pi + Pc) - Pin \quad (9)$$

The generator efficiency eff. is

$$eff. = Pout/ (Pin + Pm) \quad (10)$$

According to equations (1-10), the generator performance characteristics are computed and given in Figs (3-15).

3- EXPERIMENTAL SYSTEM OPERATION:

The experimental system shown in Fig. 1, consists of variable speed prime mover (DC motor), variable voltage supply (Auto-transformer), the generator (wound rotor induction machine) and a resistive load. The connection diagram shown in Fig. 1. According to a rotating field from the generator rotor, the generator rotates in the direction gives the slip of generator to be positive. Generator output voltage will be increased by speed increasing when the rotor voltage is constant. But for constant output voltage, the rotor input voltage will be decreased by increasing the speed. As a result, decreases the rotor input power. While, the output power to the load is constant. The compensation of load power will be corverted from the prime mover.

Therefore, the proposed generator is used to work with wind or hydro turbines. When the turbine speed is zero or low, the load is fed from the main supply. Converted power from the main supply. For higher speed the converted power from the turbine to the load will be obtained. During a wide variation of turbine speed (from zero to more than double synchronous speed), the generator will be stable.

4- GENERATOR PERFORMANCE CHARACTERISTICS:

Performance characteristics are computed from the previous analysis for the two modes of constant and reduced input voltage. Experimental verification of these characteristics is obtained for the two modes of operation.

4.1. Generator characteristics in Mode (a):

In this mode variation of AC input power and output power with generator speed at constant voltage of 80, 100 and 120-V at 50 Hz are given in Fig. 3. At low speeds, the AC input power is higher than the output power at low speed to overcome the generator losses at small converted power. At high speed, the rate

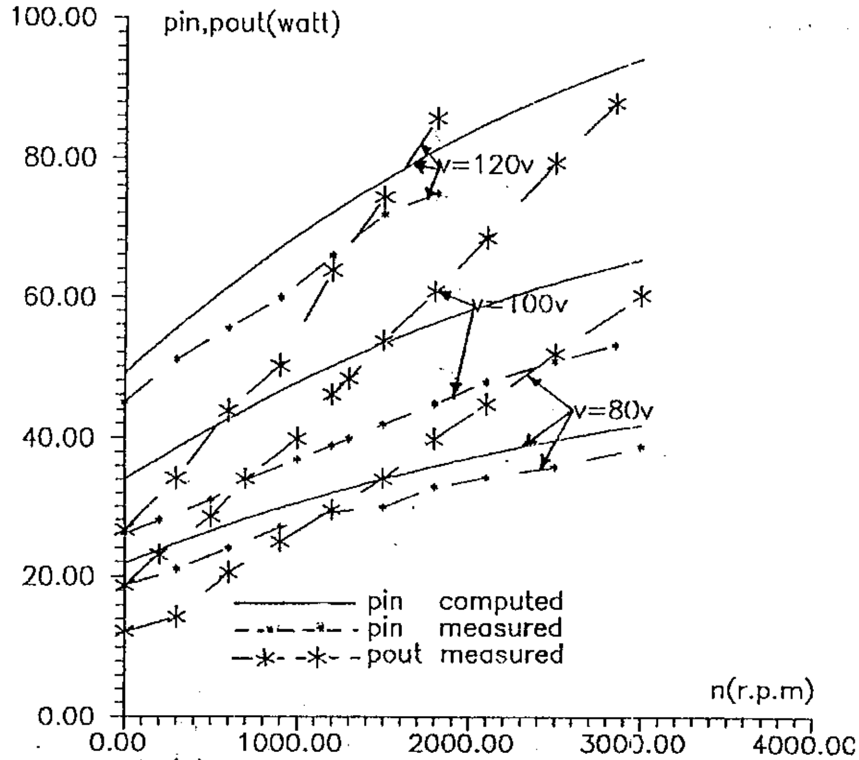

Fig.(3)The AC input&output powers against prime-mover speed for different constant applied volta

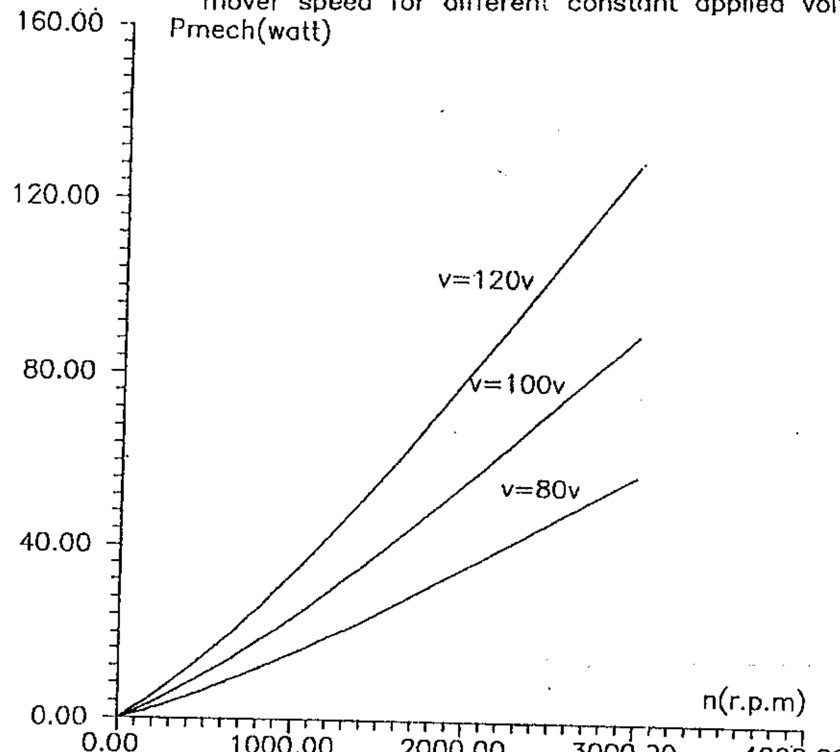

Fig.(4)The prime-mover output power against speed for different constant applied voltages

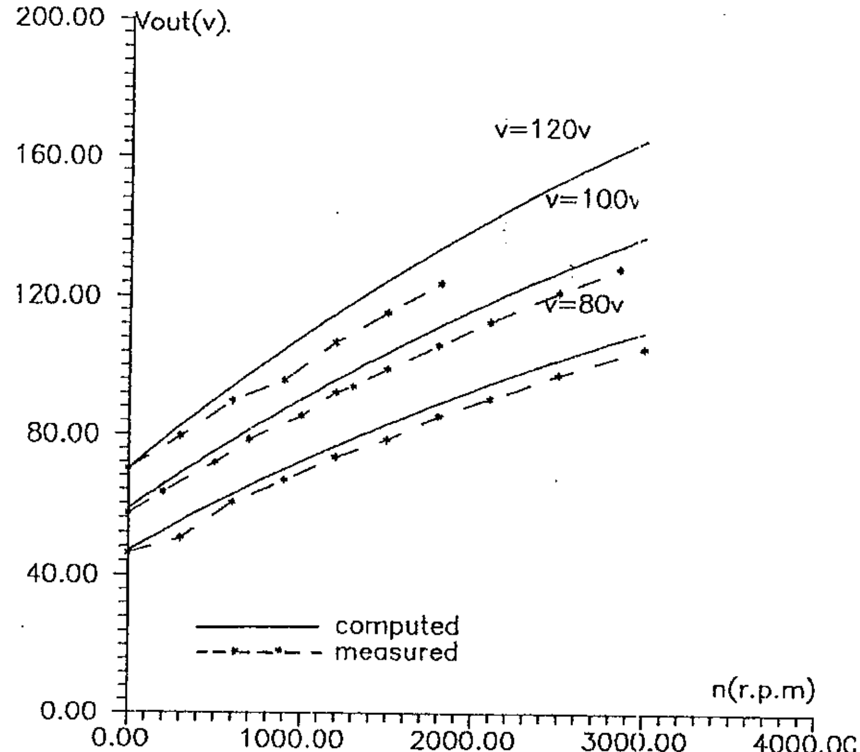

Fig.(5)The output voltage/phase againest prime-move speed for different constant applied voltages

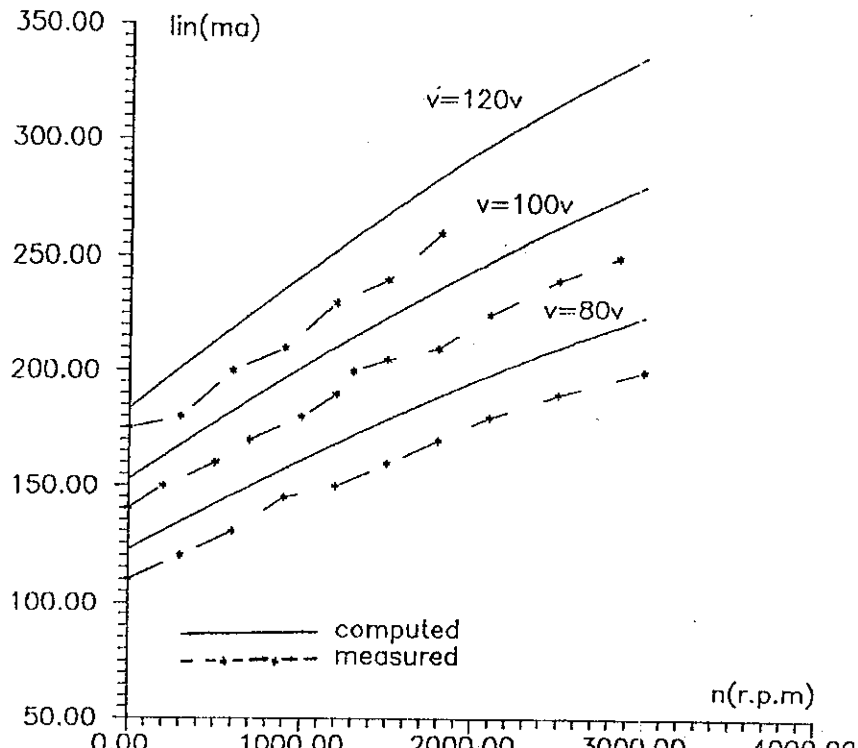

Fig.(6)The AC input current/phase againest prime-mover speed for different applied voltages

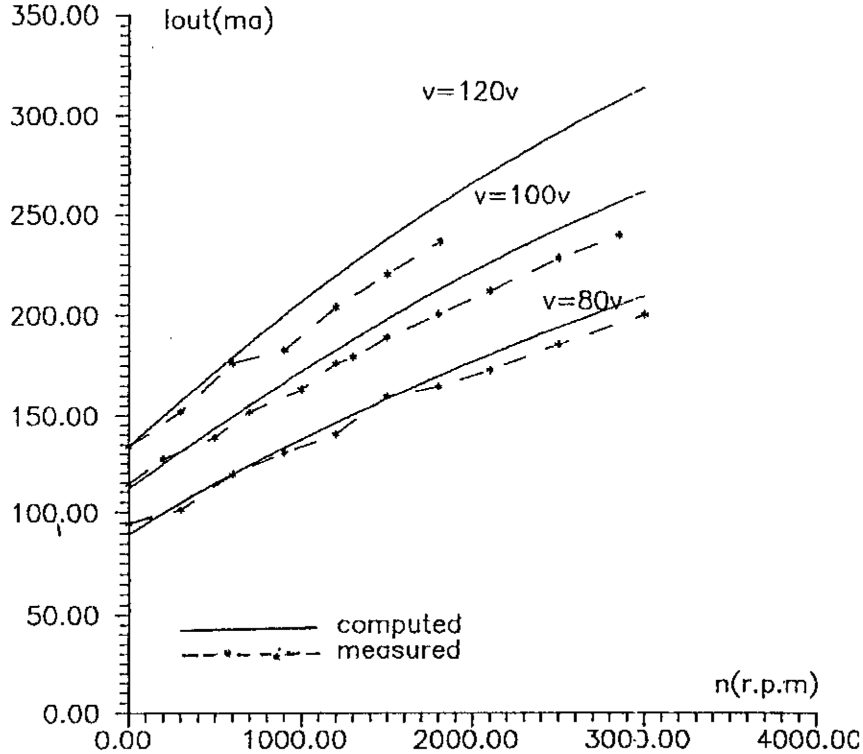

Fig.(7)The output current agiainest prime-mover speed for different conatant applied voltages

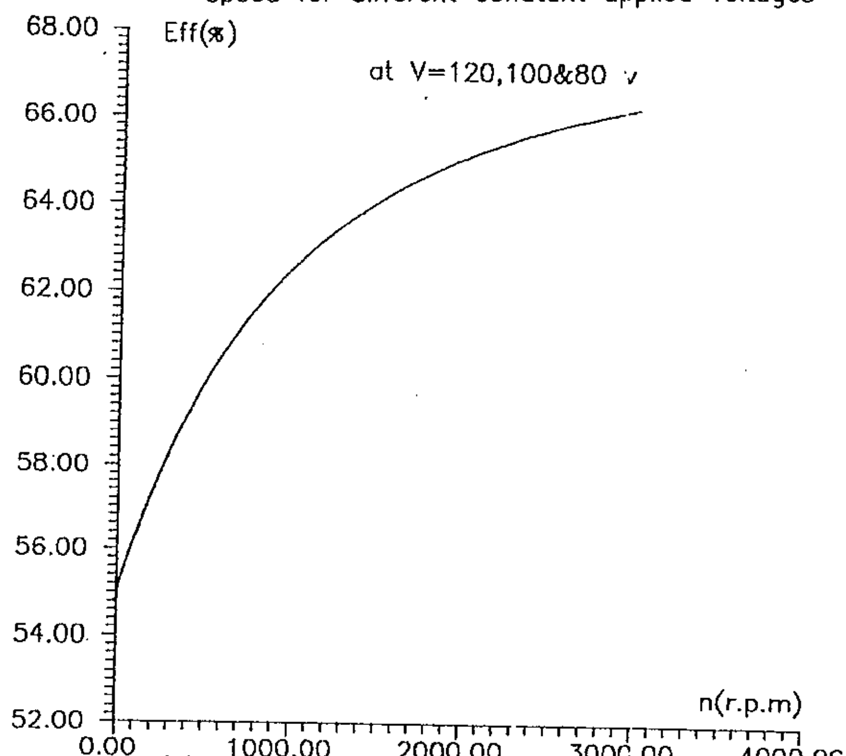

Fig.(8)The efficiency agiainest prime-mover speed for different constant applied voltages

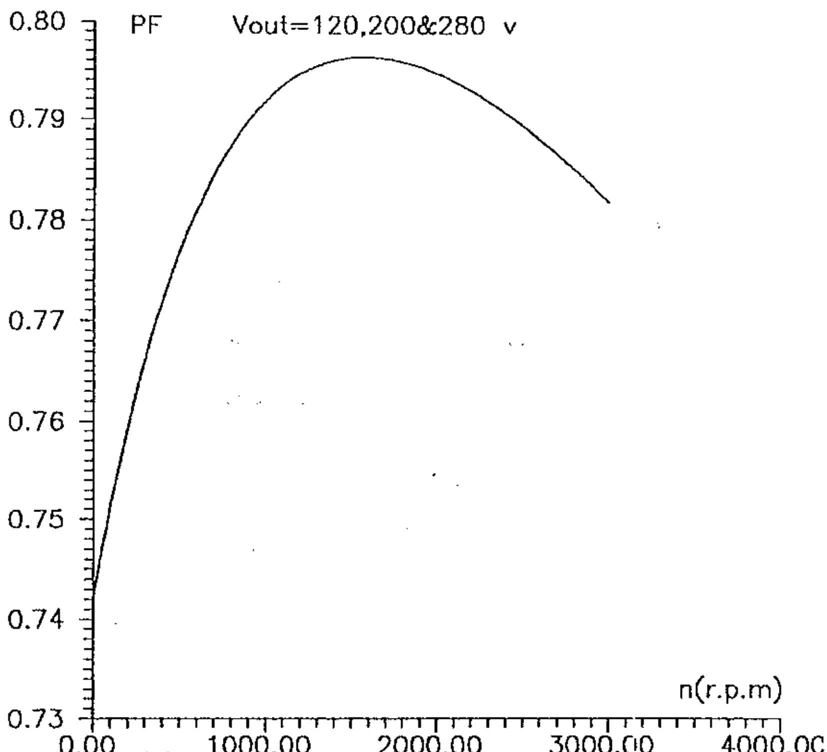

Fig.(9)The power factor againest prime-mover speed
for different constant applied voltages

of prime mover converted power is higher than the transformed power (from the AC supply), so that the output power is higher than the AC input power. Smaller input voltage leads to higher ratio of output power due to the reduction of input circuit losses Variation of the mechanical power converted to the output power with speed is shown in Fig. 4.

The output voltage is increased with speed at constant input voltages of 120, 100 and 80-V, as shown in Fig. 5. The rate of voltage increasing with speed is smaller than the linear relation due to the increased voltage drop on the generator winding. The corresponding variation of AC rotor input current are and AC stator ouput current is given in Figs. 6,7. The AC input current is increased due to the part of transformer effect corresponding to the increased output current.

Generator efficiency and input power factor variation with speed are shown in Figs. 8 and 9. The generator efficiency is not zero at zero speed because the generator will be working as a transformer. The efficiency is higher for this small laboratory generator during the variation of speed. The power factor and efficiency are similar for 120, 100 and 80-V.

4.2. Generator characteristics in Mode (b):

In this mode the constant output voltage (at 280,200 and 120-V), is obtained by speed variation. The load is a single resistance fed through a bridge rectifiers.

Fig 10. shows the variation of AC input power with speed to give constant output voltage and thus constant output power, for constant load resistance. The AC input power is higher than output power at low speeds due to the generator losses. The converted power from the prime mover is to overcome the generator losses and to fed the load, by speed increasing. The output power is higher than the AC input power when the speed is increased than above 1000-r.p.m. for the different values of load

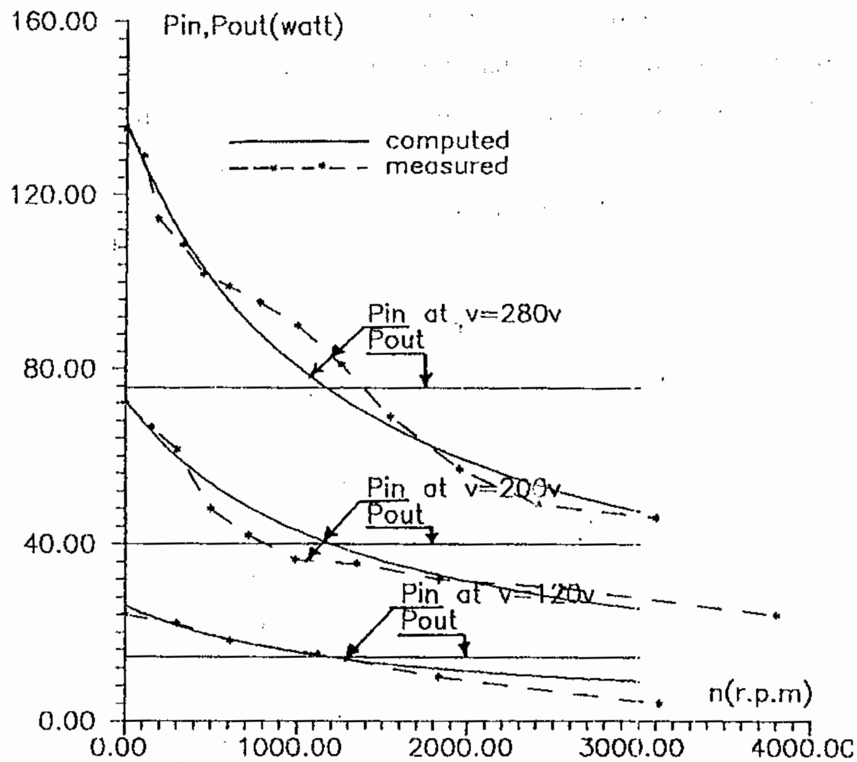

Fig.(10)The input&output powers agairst prime mover speed for different constant output voltages

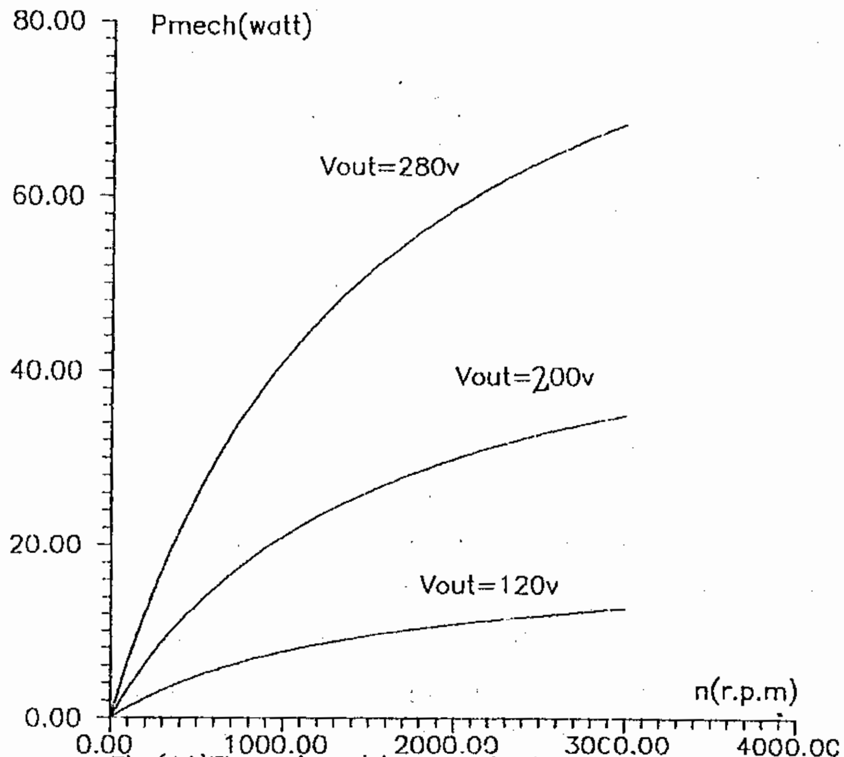

Fig.(11)The prime--mover output power againest speed for different constant output voltages

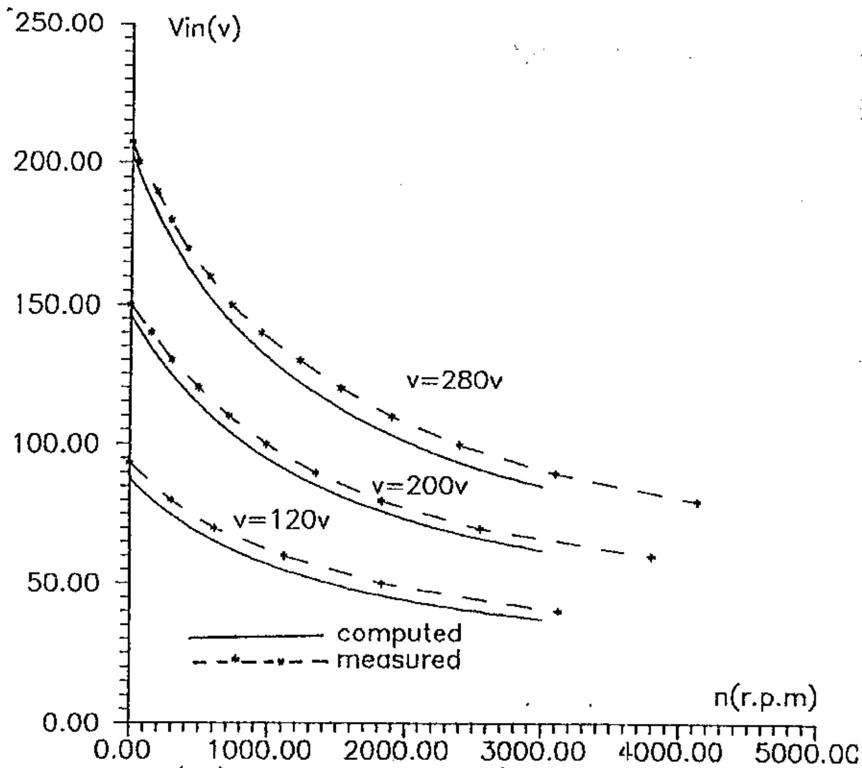

Fig.(12)The applied voltage/phase againest prime-mover speed for different costant output voltages

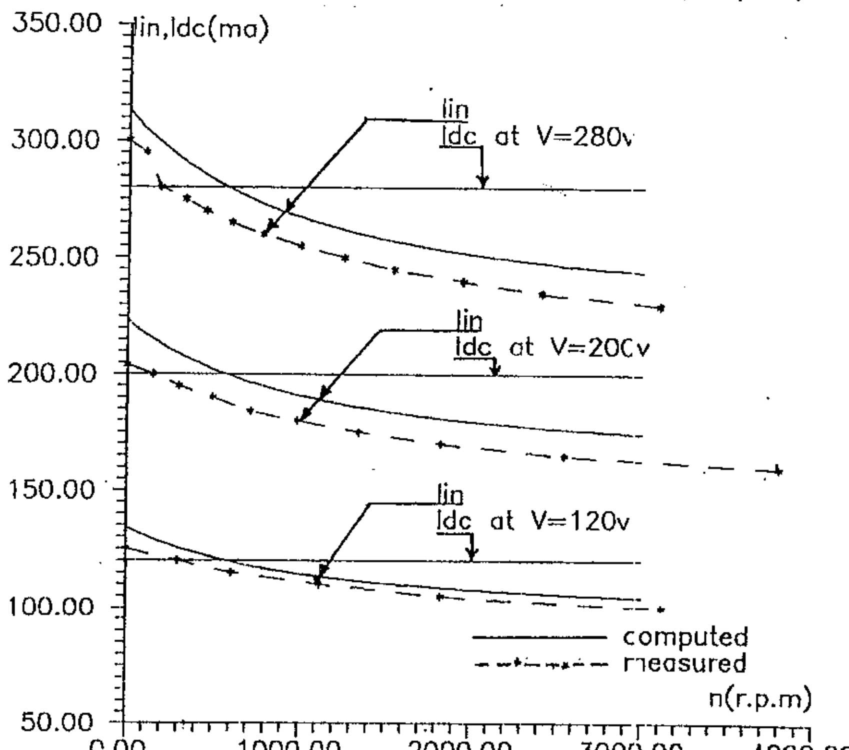

Fig.(13)The input/phase current&dc output load curre againest speed for different constant output voltag

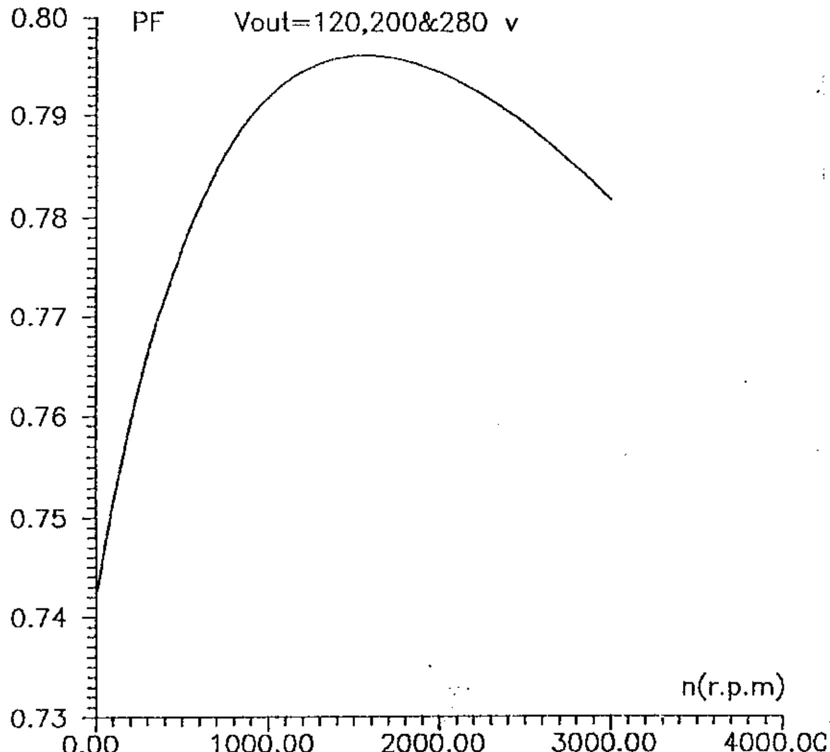

Fig.(14)The power factor againest prime–mover speec
for different constant output voltages

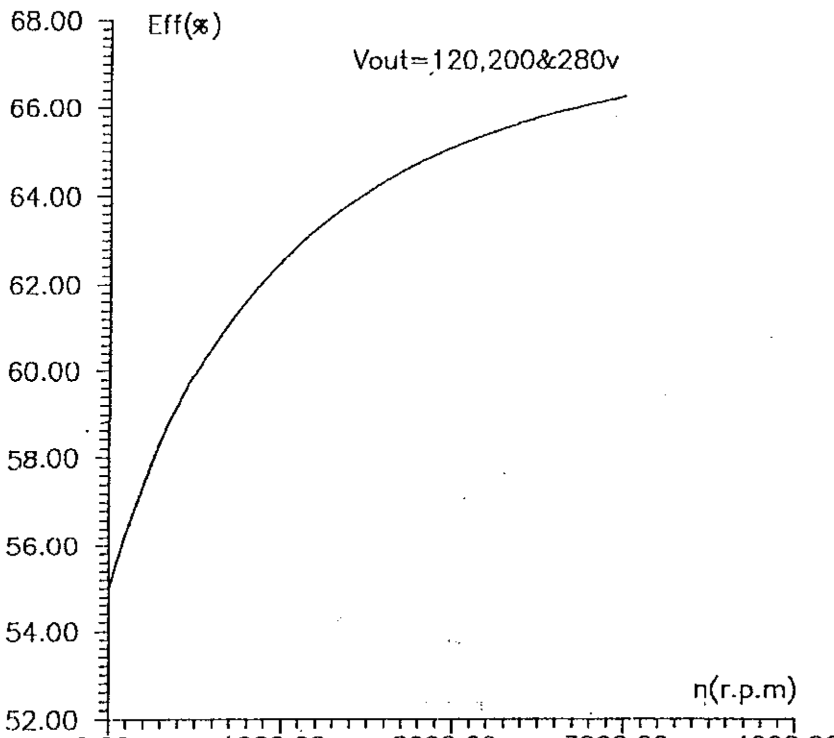

Fig.(15)The efficiency againest prime–mover speed
for different constant output voltages

voltages. Fig 11 shows the variation of prime mover output power, which is converted to the generator output power, with speed. To keep the ouput voltage constant (at 280, 200, 120 v) the variation of input voltage and corresponding input current are shown in figs 12, 13. Also, in Fig 13, the variation of the cuput DC current is polotted. As expected this variation is constant due to the constant ouput voltage.

The input power factor and generator efficiency variation with speed are shown in Fig. 14 and 15. Where the efficiency and power factor at any speed takes the same value for the different output voltages.

5. CONCLUSIONS :

The analysis and experimental investigation of this proposed generator gives the following features;

1- The generator can be used with wind or hydro turbines. This is due to the ability of it to work at very wide speed variation with constant output voltage from zero to more than twice synchronous speed.

2- The generator and load will be switched on at any speed. No need to switching off, the generator at zero or low speed in which the load will be supplied by transformer power from the AC supply.

3- The generator is capable to fed more electrical energy than of conventional induction generators due to the operation at high and very low speeds.

4- When the input voltage is constant, a very high energy can be converted from the turbine.

5- The mathematical analysis gives a compoted results in agreement with measured results.

REFERENCES

[1] ***Renzo, D.J. (1979);*** "Wind power development", Noyes data corporation, New Jersey, USA.

[2] ***Peltola, E. (1987);*** "A comparison of constant and variable-speed drives for wind turbines"l. Presented at the electromechanical research Symposium of the Helsimki University of Technology, Otaniemi, August 21 & 22.

[3] ***Solameh, Z.M. (1985);*** "Operating of the variable speed constant frequency double output induction generator (VSCF-DOIG) in a constant optimum power coefficient mode", Wind Engineering, Vol. 9, No 2, PP. 67-75.

APPENDIX :

3- Phase, Y-connected, 50 Hz wound rotor induction machine, number of poles = 4, stator voltage = 380 V, rotor current = 0.3 A, rotor terminal voltage at stand still = 342 V, rated power = 90 W.

مولد حثى دائم التشغيل بإستخدام التربينات الهوائية

د. سليمان التهامى عبد الله قنديل

ملخص:

هذا البحث يدرس إمكانية تشغيل وإستخدام الآله الحديثة ذات العضو الدائر الملفوف كمولد لتوليد الطاقة الكهربية بإستخدام طاقه الرياح أو المياه. حيث يعمل هذا المولد على تغذية الأحمال على الدوام بالطاقة الكهربية عندما تتغير سرعة التربينه من صفر حتى ضعف سرعه التزامن. ولتشغيل المولد يتم توصيل العضو الدائر إلى منبع ثلاثى الأوجه يتردد ٥٠ ذبذبه/ثانية ويوصل الحمل على أطراف العضو الثابت. يتم تدوير العضو الدائر فى الأتجاه الذى يعاكس أتجاه دوران المجال المغناطيسى الخاص به. وعندما تكون سرعة الدوران صفر فإن المولد يعمل كمحول فيغذى الحمل بالطاقة الكهربية بتردد ٥٠ ذبذبه/ثانية- عندما تزداد سرعه العضو الدائر فإن الطاقة الميكانيكية الخاصة بالآله التى تدير العضو الدائر سوف تتحول إلى طاقة كهربية وتغذى إلى الحمل ونتيجة ازياده السرعة فإن القوةالدافعة الكهربية المغذاة إلى الحمل وترددها سوف يزدادوا. ويمكن الحفاظ على ثبات مقدار القوة الدافعة الكهربية خلال تغير السرعة من صفر حتى ضعف سرعة التزامن بالتحكم فى الجهد المغذى إلى العضو الدائر. ولقد تم دراسة هذا البحث عملياً ونظرياً.