VOLTAGE STABILIZATION OF A THREE-PHASE INDUCTION MACHINES CONNECTED AS A SINGLE-PHASE GENERATOR

M.EL-SHEBINY

Department of Electrical Engineering, Faculty of Engineering, Menoufiya University, Shebin El-Kom, EGYPT.

ABSTRACT

In remote areas and high zone situations it is necessary to use a single-phase generator to be employed as a standby unit, where a single wire earth return system is found to be economical to install.

In this paper, a three-phase induction machine is connected as an isolated self-excited single-phase generator. The possibility of operating this generator through the use of an excited capacitor is outlined. The effect of the excited capacitor is obtained for loaded and unloaded operations. The experimental system is used to study the effect of generator speed on its loading of the generator. Moreover the output voltage of the generator is stabilized using the designed parametes for a fixed capacitor thyristor controlled inductor scheme. This scheme is used to regulate the generator terminal voltage by controlling the thyristors firing angle. This is done by adjusting the self excitation to maintain the terminal votlage constant over a wide range of loading.

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LIS OF MAIN SYMBOLES:

C_1, C_2 : Excitation and balancer capacitance.
C_X : Compensator capacitance.
L_X : Controlled inductance.
I_A, I_B, I_C : Winding currents.
Z_L : Load impedance.
ϕ_L : Load phase angle.
ω : Angular frequency.

1. INTRODUCTION

The induction machines have many advantages such as low cost, robustness and the elimination of maintenance problem. To obtain reater output rating, the three-phase induction machine is used as an isolated self-excited single-phase induction genertor in which the output power rating is limited in single-phase induction machine.

The induction machines can be self-excited when a suitable capacitor is connected across its winding. This phenomenon is extensively exploited in power generation schemes which employ renewable energy resources such as hydro, wind, and biogas, where there are obvious advantages in using the squirrel-cage induction machine in preference to the conventional synchronous machines as the electromechanical energy converter.

Considerable attempts have been made to study the steady-state and transient performance of three-phase self excited induction generators [1-8]. However, some attempts [9-12] have been made on the analysis of capacitor exited single-phase induction generator, in spite of their various small scale applications, specially at remote places or above mountains in small towns. In Reference [10], a method for analyzing the steady-state performance of a single-phase self-excited induction generator which supplies an isolated resistive load is described. In reference [9], the performance of an isolated self-excited single-phase induction generator when the excitation capacitor is connected to one winding and the load is connected to the other. The simulation is depending upon the quivalent circuit to study the steady-state performance. The modelling and steady-state performance of a single-phase induction generator feeding an R-L load including saturation effect is reported in reference [11]. The performances of self-excited single-phase induction generators with shunt, short-shunt and long-shunt excitation connections are reported in reference [12].

The need for alternative and renewable energy sources for utility and autonomous applications especially in remote places has focused on the use of single-phase generators. In high zones which are in the top of mountains, a single-phase is used instead of three-phases. Therefore, the single phase genertors are used as a standby for generating the electric power when the main electric supply is off.

The rating of single-phase induction generators are limited for greater output rating induction generators. Thus, the three-phase induction machines are connected as an isolated self-excited single-phase generators to obtain high power ratings for these places which employs a single-phase supply.

In this paper, the steady-state performances of a three-phase induction machine connected as an isolated self-excited single-phase gnerator are obtained experimentally. The effect of excitation and balancer capacitor is obtained with unloaded and loaded generator with different drive speeds. The output votlage is stabilized using thyristor controlled inductor parallel with the capcitor as a type of votlage regulating system. The suitable parameters of the voltage regulating circuit are designed to obtain stabilized load voltage.

2. SYSTEM CONFIGURATION

Figure (1) shows the system configuration. It consists of a three-phase induction machines connected as a self excited single-phase generator supplying an isolated load. The generator is driven by a d.c motor as a prime-mover. A fixed capacitor-thyristor controlled inductor is used to stabilize the output voltage [13].

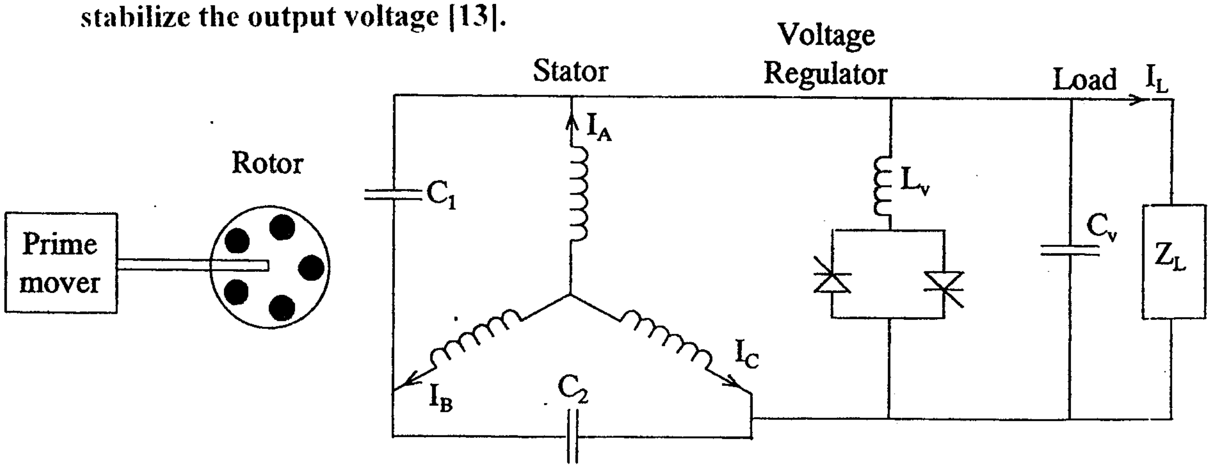

Figure (1): Three-phase induction machine connected as an isolated self excited single-phase induction generator coupled with the prime mover.

3. DESIGN OF VOLTAGE REGULATOR PARAMETERS

The value of inductor inductance (L_v) and capacitor capacitance (C_v) of the fixed capacitor thyristor controlled inductor are selected according to the following relationship [14]:

$$\omega C_v = 1 / \omega L_v = 1 / Z_L \sin \phi_L \qquad (1)$$

where, ω is the angular frequency,

Z_L is the load impedance and,

ϕ_L is the load phase angle.

The parameters value of the designed votlage regulator for the load are:

$C_v = 30\ \mu F$, $L_v = 0.006$ Henry.

The test machine used is a three-phase, 50 Hz, 1420 r.p.m, squirrel-cage, 2-HP, 4-pole, 380/220 volt, 3.6/6.2 ampere, star/delta connected induction motor. the measured parameters at 50 Hz are:

Stator phase resistance = 4.7 ohm.
Stator phase leakage reactance = 7.5 ohm.
Rotor phase resistance referred to stator side = 1.4 ohm.
Rotor phase leakage reactance referred to stator side = 7.5 ohm.
Magnetizing reactance = 100 ohm.

4. OPEN CIRCUIT CHARACTERISTICS

Figure (2) shows the variation of the open circuit terminal voltage with the excitation capacitance C_1 without voltage regulation ($C_v = 0$, $L_v = 0$). In (a) the rotor speed is 1100 rpm while in (b) it is 1000 rpm. The results reveals that the terminal voltages are increased with increasing rotor speed.

The variations of terminal voltages and winding currents versus rotor speed without voltage regulator ($C_v = 0\ \mu F$ and $L_v = 0$ H) are shown in Figures (3&4) respectively, when the machine is excited through the capacitance $C_1 = 44\ \mu F$, $C_2 = 0\ \mu F$.

Figure (5a,b,c) shows the effect of connecting the balancer capacitance C_2 on the open circuit charactersitics without voltage regulator (C_v=0 , L_v=0). It shows the variations of the terminal voltages versus rotor speed for two different combination values of excitation and balancer capacitances. ($C_1 = 44\ \mu F$, $C_2 = 20\ \mu F$) and ($C_1 = 39\ \mu F$, $C_2 = 25\ \mu F$). These selected values are chosen experimentally to give suitable values of terminal votlages and winding currents not to exceed the machine rated values.

It is noticed that the terminal voltages are higher than that obtained without balancer capacitance. This is due to the increased values of the excitation capacitances.

Figure (6) shows the variations of the winding currents versus motor speed with $C_1 = 44\ \mu F$, $C_2 = 20\ \mu F$, $C_v = 0\ \mu F$ and $L_v = 0$ H.

5. LOAD CHARACTERISTICS

Results of load tests on the machine for unity power factor and different values of rotor speed without voltage regulation with $C_v = 0\ \mu F$, $L_v = 0$ H, $C_1 = 10\ \mu F$ and $C_2 = 44\ \mu F$ are shown in Figure (7). The terminal votlage decreases with increased load current and more power can be extracted from the machine with increasing speed.

Figure (8) shows the load characteristics curves for unity power factor and rotor speed 1000 r.p.m. Curve (1) for $C_v = 0\ \mu F$, $L_v = 0$ H, $C_1 = 10\ \mu F$ and $C_2 = 44\ \mu F$. Curve (2) for $C_v = 0\ \mu F$, $L_v = 0$ H, $C_1 = 44\ \mu F$, and $C_2 = 0\ \mu F$. It is observed that there is a great reduction in the output voltage and current (power) when balancer capacitance is not used.

Figure (9) shows the load characteristics cuves for unity power factor and rotor speed of 900 r.p.m. for different values of excitation and balancer capacitances ($C_1 = 10\ \mu F$ and $C_2 = 42\ \mu F$) for curve 1 and ($C_1 = 15\ \mu F$ and $C_2 = 49\ \mu F$) for curve 2. Both curves are obtained without voltage regulation ($C_v = 0\ \mu F$ and $L_v = 0$ H)The curves are almost parallel, indicating a proportional increase in terminal votlage with excitation and balancer capacitances.

Figure (10) shows the load characteristics of the machine without voltage regulation ($C_v = 0\ \mu F$ and $L_v = 0$ H) for different values of power factor with rotor speed (1000 r.p.m.) and excitation, balancer capacitances of $C_1 = 10\ \mu F$, and $C_2 = 44\ \mu F$. It is noticed that very slight reduction in power factor causes high dropping effects on the load charcersitcis and great reductions in the output power.

6. IMPROVEMENT OF THE LOAD CHARACERISTICS

Thyristor controlled inductor voltage regulator system is used to improve the load charactersitics. The terminal voltage of the self excited machine, connected as single phase generator, can be maintained to a constant value if a fixed value of capacitor bank and thyristor controlled inductor are used in parallel while controlling the firing angle of thyristors as shown in Figure (1).

Figure (11) shows the load characteristic curves for 0.8 power factor lag., motor speed 1000 r.p.m. and excitation and balancer capacitance are $C_1 = 10\ \mu F$ and $C_2 = 44\ \mu F$ respectively. Curve (1) for the system without votlage regulator ($C_v = 0\ \mu F$, $L_v = 0$ H), curve (2) for the system with voltage regulator (C_v = 30 μF. L_v = 0.006 H). It is clear that the improvement of the output voltage is due to using of the voltages regulator.

Figure (12) shows the generator terminal voltage versus load current when voltage regulator is employed. It is clear that the terminal voltage is approximately constant and equal.

7. CONCLUSIONS

In this paper the proposed system consists of a three-phase induction machine connected as an isolated self-excited single-phase generator with and without phase balancer capacitor. This system can be used as a standby unit in remote areas, where a single wire earth return system is used to be economical to install.

From the results obtained at steady-state, the following conclusions are summarized:

- The terminal voltages are increased with increasing motor speed for no-load and load characteristics.
- The terminal voltages and power are increased with using balancer capacitance for no-load and load charaacteristics.

- The terminal voltage is decreased with increasing load current.
- Load power extracted is increased with increasing the speed.
- The reduction of load power factor causes high dropping effects on the load characteristics and great reduction in the output power.
- The generator terminal votlage can be maintained at constant value for a load variations using fixed capacitor-thyristor controlled inductor as a voltage regualtor.
- The generator terminal voltage is approximately constant using voltage regulator.

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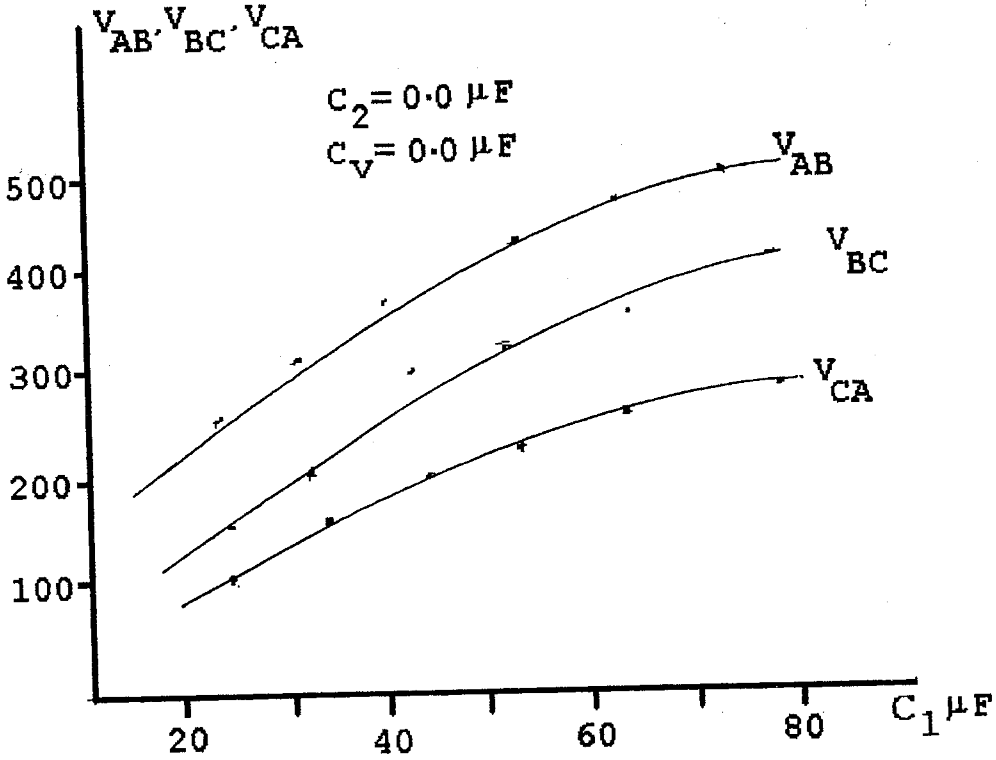
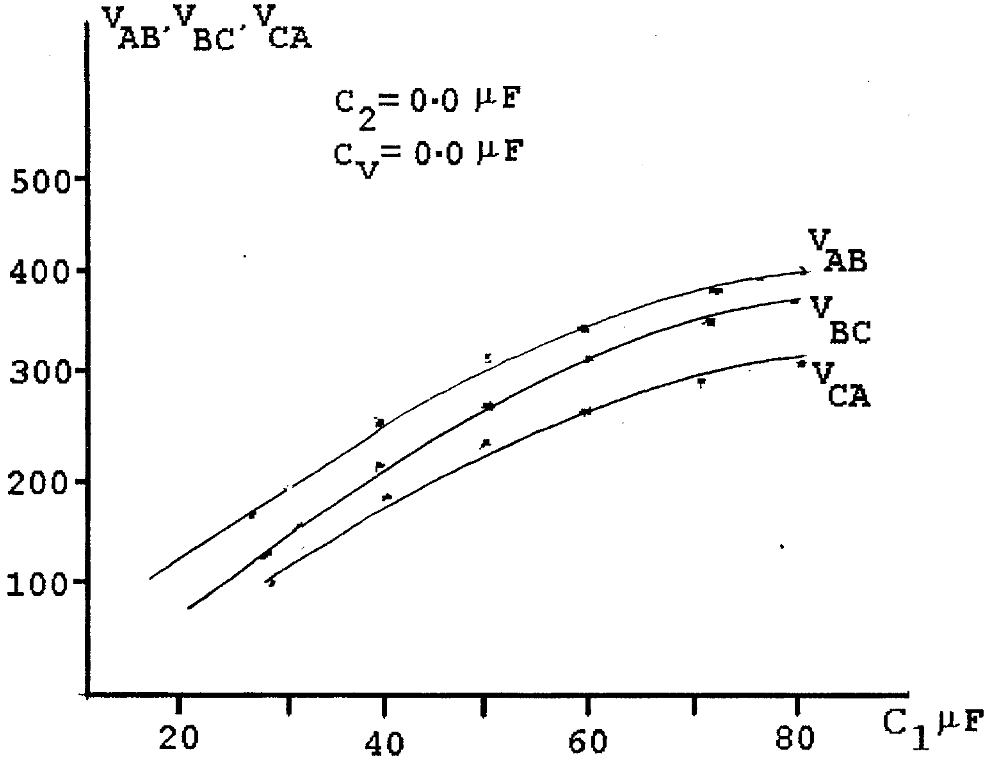


(a) n = 1100 r.p.m.



(b) n = 1000 r.p.m.

Figure (2) Variation of terminal voltages versus C_1 for rotor speed at no load without voltage regulators ($C_V = 0\ \mu F$, $L_V = 0$ H)

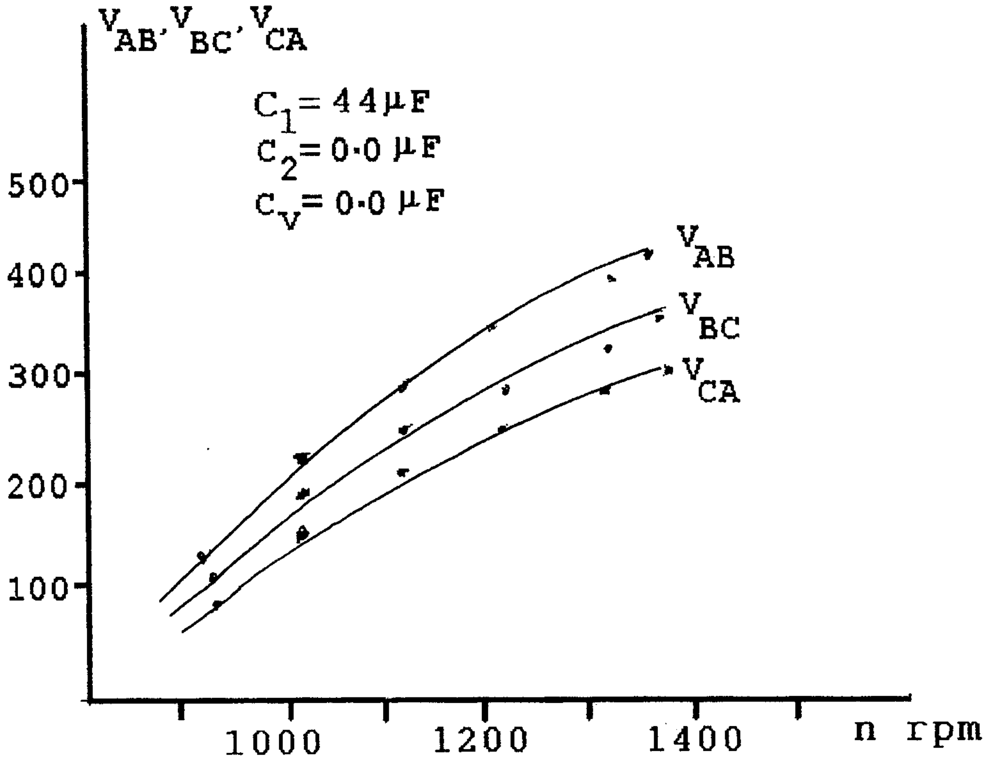


Figure (3) Variation of terminal voltages versus rotor speed at no load with $C_1 = 44\ \mu F$, $C_2 = 0\ \mu F$, $C_V = 0\ \mu F$)

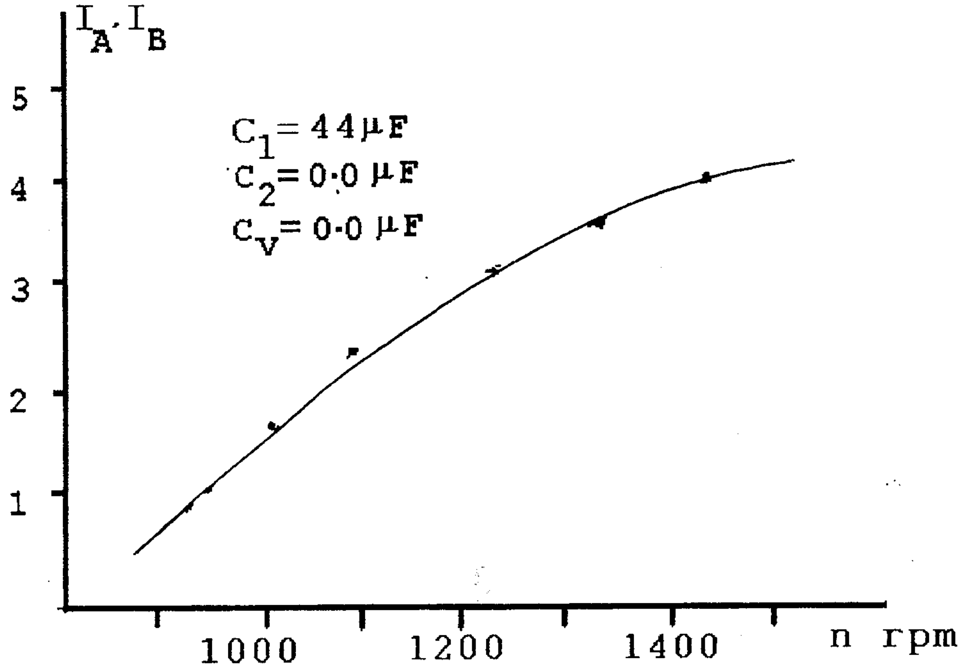
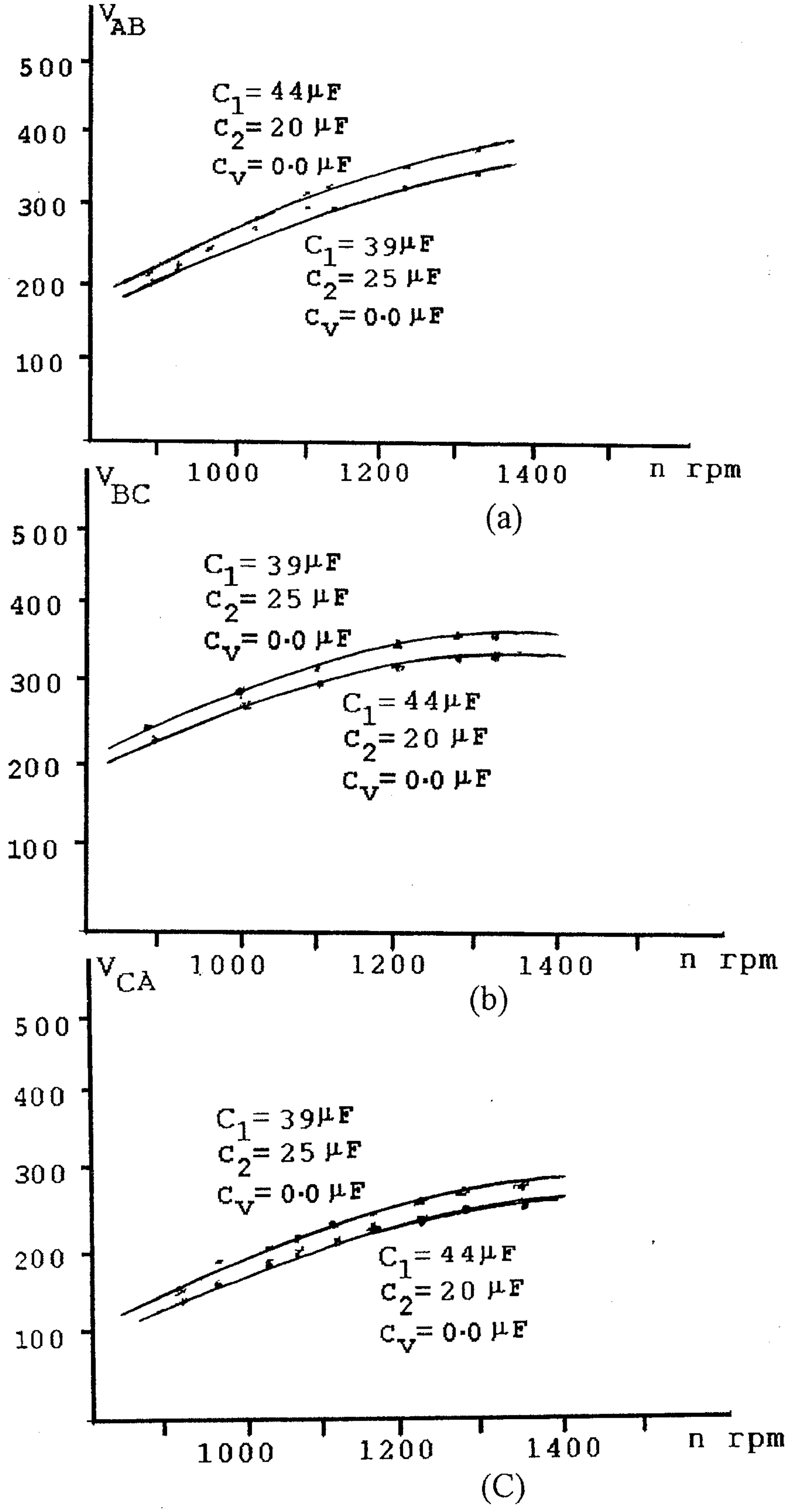
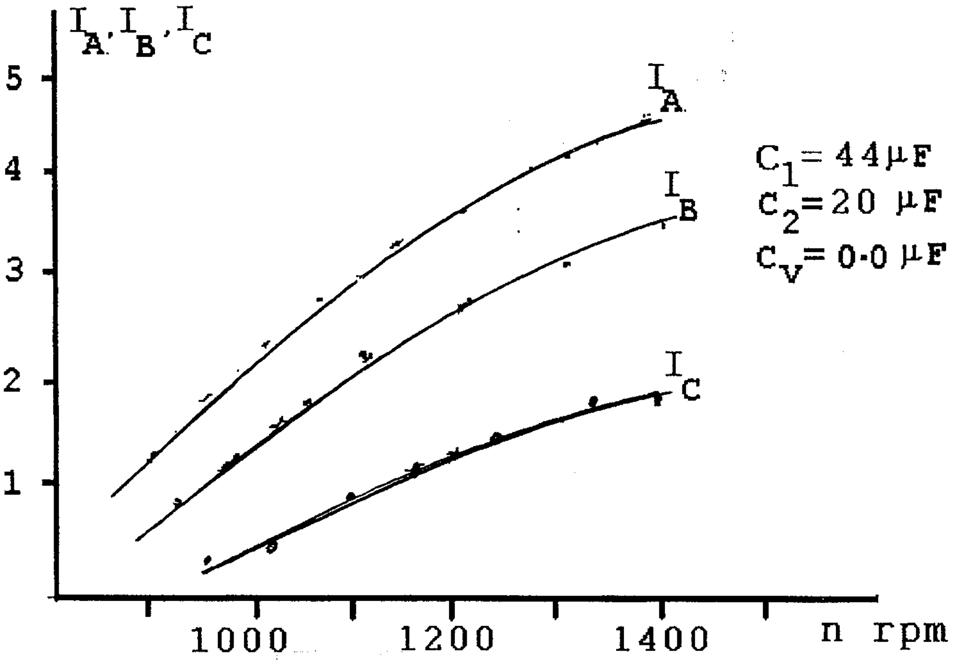


Figure (4) Variation of winding currents versus rotor speed at no load with $C_1 = 44\ \mu F$, $C_2 = 0\ \mu F$, $C_V = 0\ \mu F$)



Figure(5) Variation of the terminal voltages versus rotor speed at no load with $C_1 = 44\ \mu$ F, $C_2 = 20\ \mu$ F, $C_1 = 39\ \mu$ F, $C_2 = 25\ \mu$ F



Figure(6) Variation of winding currents versus rotor speed at no load

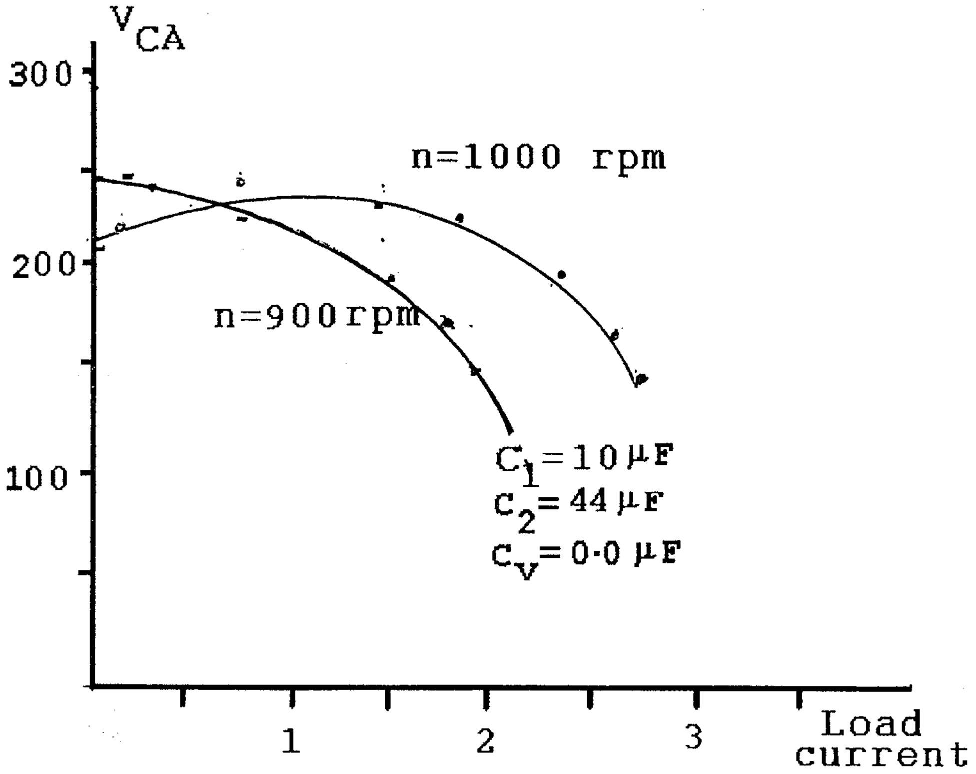


Figure (7) Variation of the terminal voltages versus load current with rotor speed = (900 r.p.m. and 1000 r.p.m).

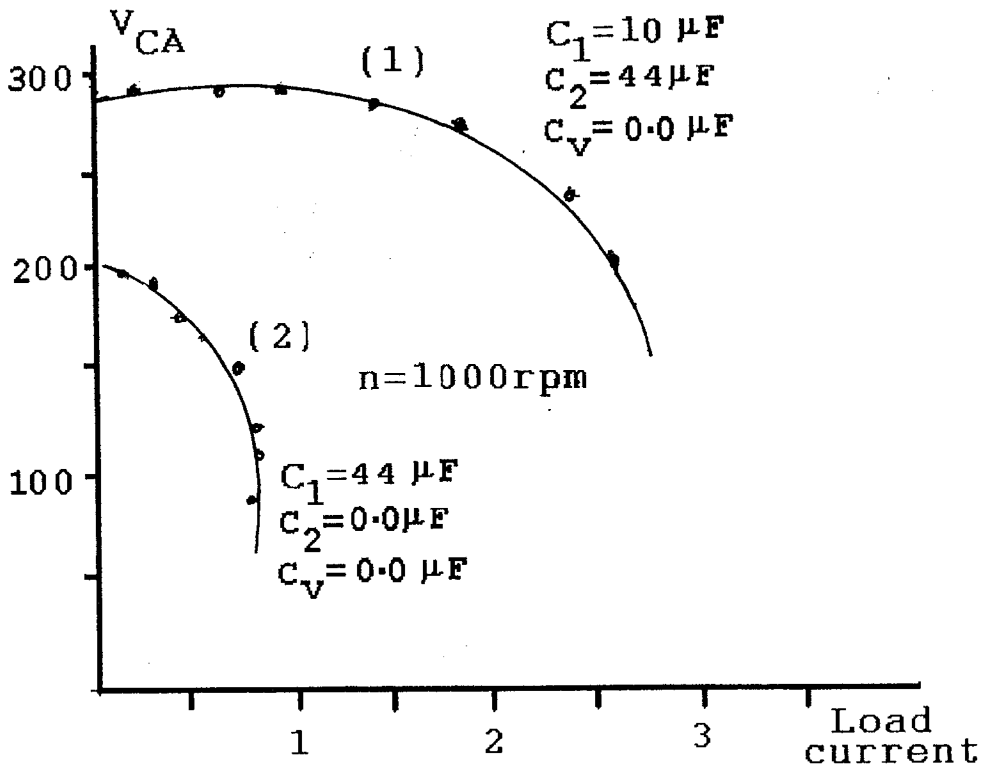
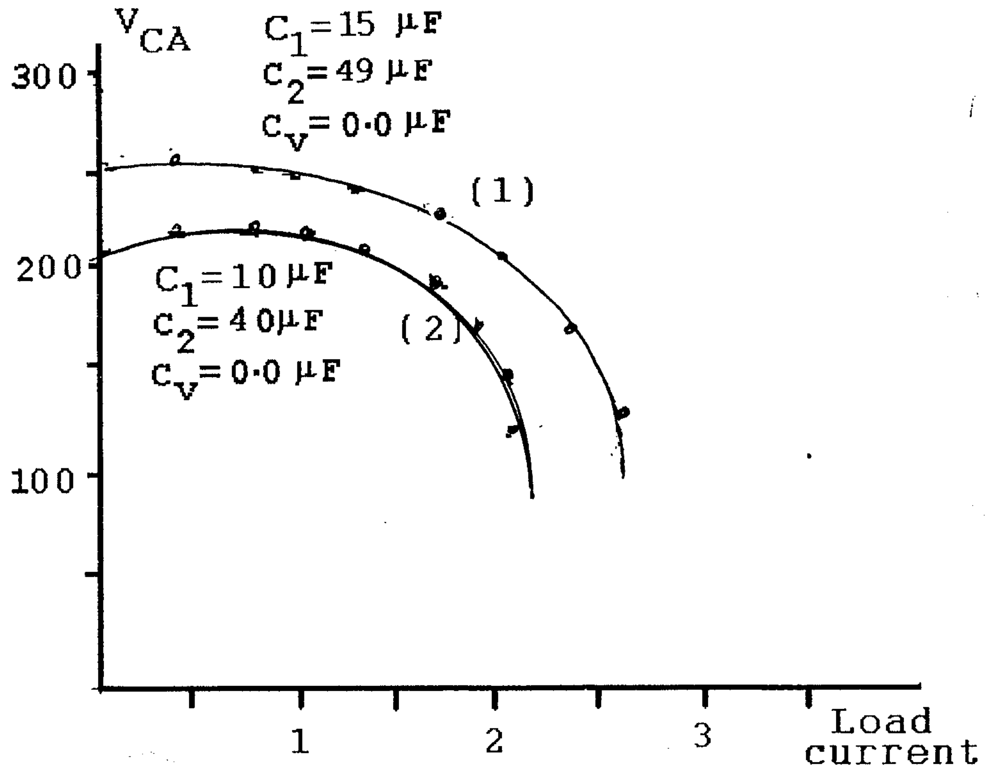
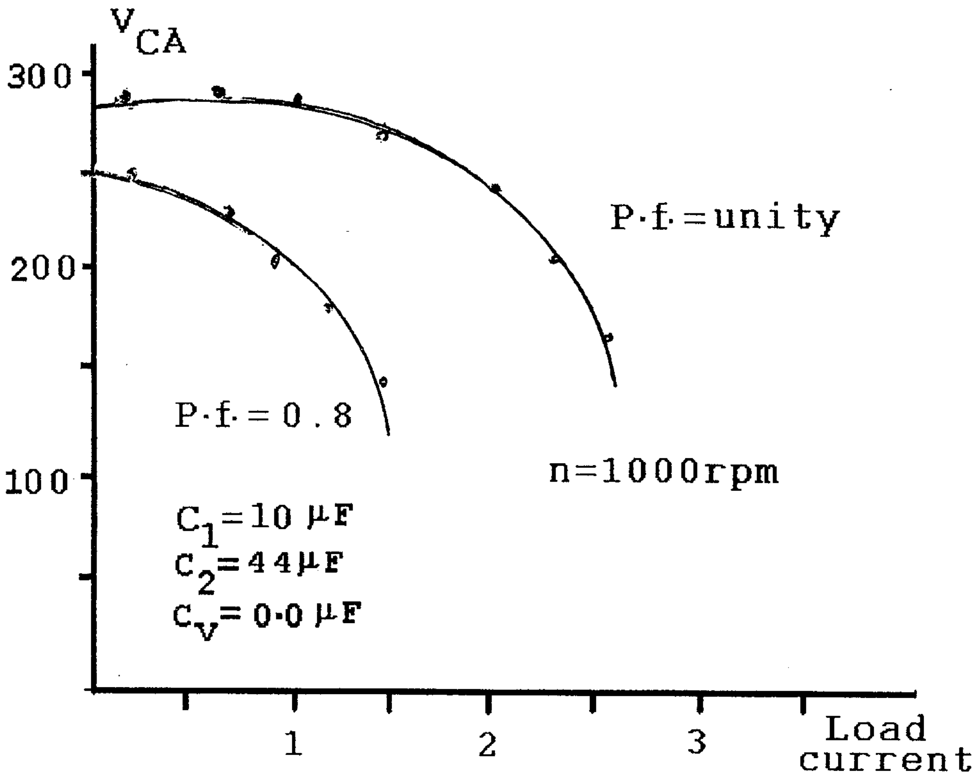


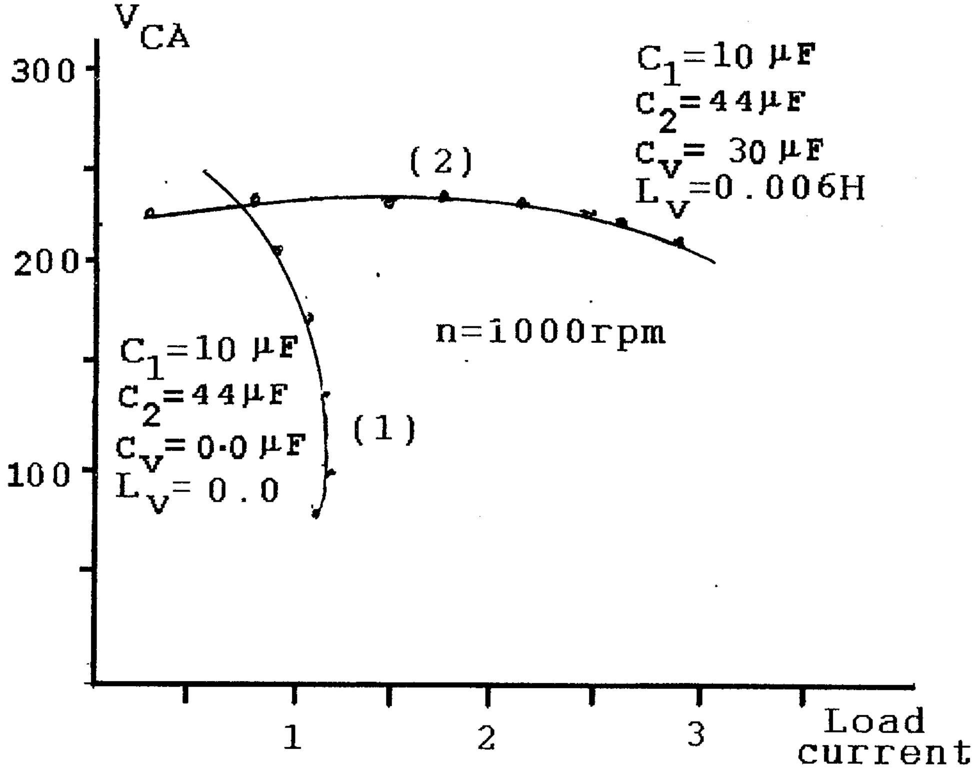
Figure (8) Variation of the terminal voltages versus load current with rotor speed =1000 r.p.m.



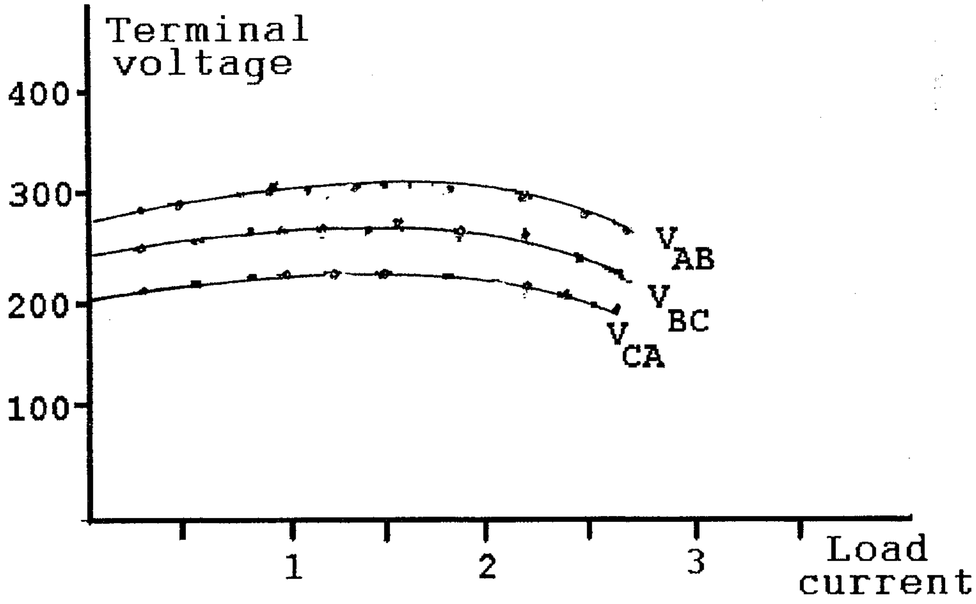
Figure(9) Variation of the terminal voltages versus load current with rotor speed =900 r.p.m. at unity power factor.



Figure(10) Variation of the terminal voltages versus load current with rotor speed =1000 r.p.m. for two different values of p.f.



Figure(11) Variation of the terminal voltages versus load current with rotor speed =1000 r.p.m. with C_1 = 10 μ F, C_2= 44 μ F at 0.8 P.F. lag. With and without voltage regulator (curves 1 and 2 respectively)



Figure(12) Variation of the terminal voltages versus load current with rotor speed =1000 r.p.m. with C_1 = 10 μ F, C_2= 44 μ F at 0.8 P.F. lag. With voltage regulator (C_V = 30 μ F and L_V = 0.006 H)

تثبيت جهد الآلة التأثيرية ثلاثية الاوجه المتصله كمولد أحادى الوجه

د/ مصطفى السيد الشبينى
قسم الهندسة الكهربية - كلية الهندسة بشبين الكوم - جامعة المنوفيه

ملخص البحث :

فى بعض الاستخدامات الصناعية خاصه فى المناطق الجبلية المرتفعه ، قد يكون من الضرورى إستخدام منبع أحادى الوجه ، وعند إنقطاع التيار الكهربى يلزم وجود وحدات إحتياطية لذلك فإن إستخدام المولد التأثيرى الثلاثى الاوجه ليعمل كمنبع أحادى الوجه بإستخدام موازنات الوجه يكون أيسر وأقل تكلفه من المولد التأثيرى ذو الوجه الواحد .

يقدم هذا البحث آلة تأثيرية ثلاثية الاوجه موصله كمنبع أحادى الوجه وذلك بإستخدام موازنات الوجه .

يتضمن هذا البحث إجمال إمكانية العمل لهذا المولد من خلال إستخدام مكثفات التغذية وتم أخذ تأثيرها وذلك عند حالى اللاحمل والحمل .

تم إستخدام النظام المعملى لدراسة تأثير سرعة المولد على التحميل . وتم تصميم وبناء نظام مقترح لتثبيت جهد المولد على التحميل . وتم تصميم وبناء نظام مقترح لتثبيت جهد المولد مكون من مكثف ثابت متصل بالتوازى مع كلا من الحمل وملف محاثه يمكن التحكم فى التيار المار به عن طريق زوجين من الثايرستور لتنظيم جهد الخرج للمولد على أطراف الحمل وجعله ثابتا وذلك بالتحكم فى زاوية إشعال الثايرستور . وقد تم الحصول على جهد ثابت وعلى مدى كبير من تغير الحمل على أطراف المولد .