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D.C. MOTOR CONTROLLED BY CUK CONVERTER FED FROM A PHOTOVOLTAIC SYSTEM

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ABSTRACT

In this paper the theoretical and experimental investigations for both steady-state and dynamic operation of dc-dc Cuk converter powered a separately excited dc motor are presented. The analysis is extended to the photovoltaic generator supply. The effect of duty ratio for different irradiation levels on the motor performance is obtained. The relation between solar irradiation level and converter duty ratio to ensure maximum energy utilization is given. The maximum photovoltaic generator can be obtained by adjusting the converter duty ratio for certain irradiation levels with a pump load. The proposed system can be utilized in spray irrigation and green house water supply management.

تم في هذا البحث عمل دراسة نظرية وعملية لتشغيل محول تيار مستمر من طراز CUK يغذى محـرك تيـار مستمر ذى إثارة خارجية وذلك لكل من حالة الاستقرار والحالة العابرة . تم في هذا البحث أيضـا بنـاء نمـوذج عملي متطور كما تم عمل تمثيل رقمي للنظام وتمت مقارنة النتائج وقد أظهرت هذه المقارنة تطابقا كاملا بين كافة النتائج . تضمن البحث أيضا دراسة حالة التغذية بمولد طاقة شمسية حيث تم التصميم ليغذى مضخة مياه كحمل . وقد وجد أن أقصى قدرة لمولد الطاقة الشمسية يمكن الحصول عليها بضبط نسبة التشغيل ولمختلـف مسـتويات الإشعاع .

يلاحظ أن التمثيل المقترح له القدرة على التنبؤ بمستوى التحكم في مستوى الإشعاع طبقا للشكل المختار .

يمكن الاستفادة من النظام المقترح في عملية الري عن طريق الرش وإدارة نظم رى الدفيئات المحمية.

Keywords : Solar cells .dc-dc converter ,Cuk converters ,Photovoltaic generators , dc- motor.

1. INTRODUCTION

The photovoltaic energy is one of the alternative sources which is free and available in most parts of the world. This source has proved to be an economical source of energy in many industrial applications [1]. Direct current motors are used in photovoltaic (pv) drive systems[2]. For example , in cooling applications and in water pumping systems for irrigation or water supply [3]. The solar cell array is connected to the motor load via a direct coupling. These systems are simple and its operation is inexpensive [4-5]. This system can be used to supply uncritical loads such as water pumps. These loads do not need continuous operation and water output can be stored easily. So, this arrangement is used in rural villages and deserts. A report studying the starting and steady state performance of different types of dc- motors driving water pumps, directly connected to a photovoltaic generator is as shown in [5]. The performance parameters of pumping system powered by solar cells array have been previously predicted theoretically and confirmed experimentally in reference [6]. The maximum power operation has been achieved by interchanging the series parallel connections of solar cell modules within the photovoltaic array [7]. Also, the maximum power tracking has been achieved by using controlled dc-dc converters [8-10].

Experimental implementation of fuzzy logic control for photovoltaic maximum power tracking is given in reference [11]. The effect of the cell temperature on the performance of photovoltaic generator feeding series and separately excited dc motors is investigated in reference [12].

This paper presents a solar energy feeding a separately excited dc motor driving a pump load through a dc-dc Cuk converter. A modeling and numerical simulation for this system are given to obtain steady-state and dynamic performance characteristics. The modeling and simulation results are compared with the experimental results while the system is supplied from a constant dc supply. The modeling and simulation include the design of photovoltaic array driving a pump load through a Cuk converter.

2.SYSTEM DESCRIPTION

The schematic diagram of the system is shown in figure (1). The system consists of a photovoltaic array , a dc-dc Cuk converter using one MOSFET and a separately excited dc motor driving a pump load. The dc-dc converter with a variable duty ratio that regulates the power supplied to the motor is either a step-up or step-down converter. An LC filter is connected between the converter and the dc motor. This filter is used to smooth out the voltage input to the motor. The MOSFET is driven by an impulse generator of a linear timing voltage. The pulses are generated when the control voltage (Vc) is equal to or greater than the timing voltage (ωa) as shown in Figure (2). The duty ratio (K) varies with the variation of the control voltage in order to obtain the desired output. The duty ratio k is defined as the ratio between the on period of the MOSFET to the total period of the pulse.

3.SYSTEM MODELING

3-1 Modeling of Photovoltaic Array

The chosen array is taken to have two parallel strings , where each string contains 36 cells. The overall voltage of the photovoltaic generator V is expressed in the following form |8| :

$V = (0.0731 . N_s . Z1) - (0.05 . N_p . I)$ (1)

where $Z_1 = Ln (XX - I + YY)/YY$

$XX = I_{ph} . N_p . \%\text{irradiation level}$

$YY = 0.0005 . N_p$

V and I are the average terminal voltage and current from cells , respectively, IPh is the photovoltaic current. This current is chosen to have a value of 0.8 ampere which is proportional to an irradiation level that equals 100%(1000watt / cm2), while the open circuit voltage is taken as 0.54 Volt. Figure(3) shows the V-I characteristics of the photovoltaic generator used in this study.

The maximum power delivered is obtained using the well known definition: $(d/dt)(V.I) = 0.0$ (2)

3-2 Motor Simulation and Modeling

Figure (4) shows the two modes of operations for the system under study. The equations of each mode are in the following form :

Mode (1)

The MOSFET in this mode is turned on. The differential equations describing this mode are :

$di_1/dt = (v - i_1 . r_1)/L_1$ (3)

$de/dt = - i_2 / c_1$ (4)

$d i_m/dt = (v_m - R_m.i_m - K_m.\omega_m)/L_m$ (5)

$d \omega_m/dt = (K_m. i_m - B . \omega_m - T_1)/J$ (6)

$dv_m/dt = (i_2 - i_m) / c_2$ (7)

$di_2/dt = (e - i_2 \cdot r_2 - v_m)/ L_2$ (8)

Mode (2)

The MOSFET in this mode is turned off. The differential equations describing this mode are :

$di_1/dt = (v - i_1 . r_1 - e)/L_1$ (9)

$de/dt = - i_1 / c_1$ (10)

$di_m/dt = (v_m - R_m. i_m - K_m. \omega_m)/L_m$ (11)

$d\omega_m/dt = (K_m. i_m - B .\omega_m - T_1)/J$ (12)

$dv_m/dt = (i_2 - i_m)/c_2$ (13)

$d i_2/dt = (- i_2 . r_2 - v_m)/L_2$ (14)

3-3 Impulse Generator Modeling

The timing voltage is represented by the equation:

$\omega_a = A[1.0-(x/T)]$ (15)

where A is the maximum voltage (12 volt), x is any instant which changes from zero to π in radians, and T is the chopping period in radians and has the form

$T = \omega(1 / f_s$ (16)

The system parameters are given in the appendix.

4. SIMULATION AND EXPERIMENTAL RESULTS

The proposed system is built in the laboratory. A comparison between the numerical simulation results for the proposed system with the experimental results of a constant load torque and constant dc supply input has been made. The comparison showed a very good agreement between them .

4 -1 Steady - State Characteristics

The effect of varying the converter duty ratio for a constant voltage source at half full load torque for the motor voltage (v_m), capacitor voltage (e), input current (i_1), motor speed (ω_m), supply voltage(v), and control voltage (v_c) is shown in Figure (5). Figure (6) shows the waveforms for these parameters.

4 -2 Starting-Up Characteristics

Figure (7) shows the starting behaviour for a duty ratio equal to 0.5 at half full load for the motor current (i_m), motor voltage (v_m), supply current (i_1), and motor speed (ω_m). The results reveal the validity of the dynamic model.

5. PHOTOVOLTAIC SYSTEM FEEDING THE PUMPING LOAD

The motor pump load torque equation is taken as

$$T_L=0.005+0.00004\omega+0.001\omega^{1.8} \quad (17)$$

Figures (8,9) show the variation of the average photovoltaic voltage and current , respectively , with the percentage irradiation level according to different values of duty ratio for the system shown in Figure (1). It is noticed that the average photovoltaic voltage has decreased with the increase in the duty ratio, while it has increased with increasing the percentage irradiation level. Figures (10,11,12) show the variation of the motor average voltage , average current and motor speed , respectively , against the percentage solar irradiation with respect to different values of duty ratio when there is a pump load. It is observed that the motor characteristics vary with the duty ratio variation of the percentage irradiation level.

Figure (13) shows the relation between the duty ratio and the solar irradiation level in order to achieve the maximum photovoltaic generator power.

Figure (14) shows the starting behaviour with a solar irradiation level of 60 % while the duty ratio is adjusted at a value of 75% in order to give a maximum photovoltaic power.

6. CONCLUSIONS

Both the starting-up and dynamic behaviour of dc-dc Cuk converter supplied from constant dc voltage supply and feeding a separately excited dc motor have been investigated. The modeling and numerical simulation results have been compared with the experimental results. It is noticeable that there is very good agreement between the simulation and experimental results. A study has been made to include the case of photovoltaic generator supply input where the photovoltaic is designed to feed a pump load. It has been found that the maximum photovoltaic generator power can be obtained by adjusting the duty ratio for certain irradiation levels. The proposed simulation has the advantage of predicting the control range for the irradiation level according to the chosen configuration .

7. APPENDIX

7-1 Motor Parameters

The testing motor is a separately excited dc-motor. 50 Volt, 55 watt, 1 Ampere, 3000 r.p.m.. It has the following measured parameters:

r_m=10.5Ohm, L_m =0.06H, R_f =550 Ohm, B=0.0001 Nm / (rad./sec.), J=0.00015 Kg.m2, K_m=0.127 Volt/rad/sec

7-2 Cuk Converter Parameters

The parameters of the designed system are: L_1 =0.025H, r_1=2Ohm, L_2 = 0.22H, r_2 =2Ohm, C_1=5 μF , C_2 =1200μ F

8. REFERENCES

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9-NOMENCLATURE

A	Maximum value of the timing voltage.
B	Viscous friction coefficient.
C_1	Energy storage/ transfer capacitance.
C_2	Capacitance of the filter.
e	Capacitor voltage.
f_s	Switching frequency .
i_m	Instantaneous armature current.
i_1 , i_2	Instantaneous supply and filter currents.
J	Moment of inertia.
K_m	Back e.m.f. coefficient.
L_m,R_m	Armature inductance and resistance.
L_1,r_1	Inductance and resistance of the coil connected with supply.
L_2,r_2	Filter inductance and resistance.
R_f	Field resistance.
T_L	Load torque.
v,V	Instantaneous and average supply voltage.
V_c	Control voltage.
v_m	Motor voltage.
ω_m	Motor angular speed.
N_S	Number of cells in series.
N_P	Number of parallel strings.

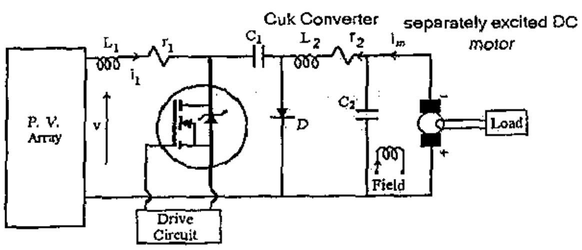


Fig. (1) : Schematic Diagram of the System

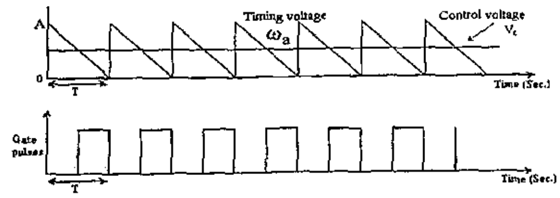


Fig. (2) : Output of the Impulse Generator Drive Circuit

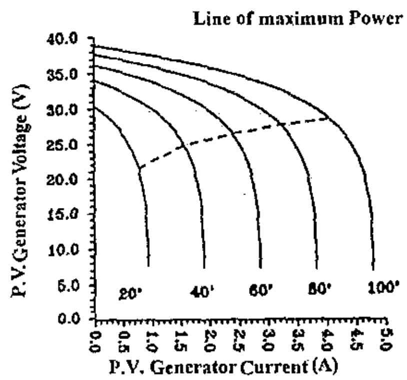


Fig.(3):V-I Charcteristics of the P.V.Generator

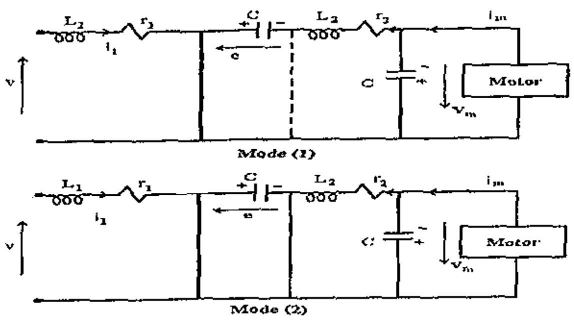
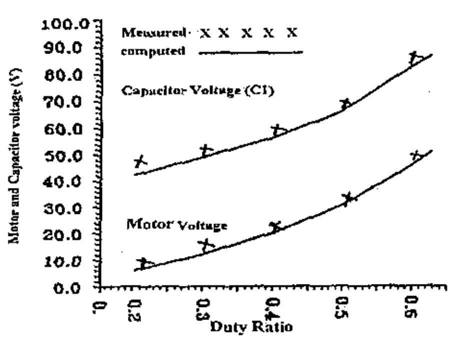
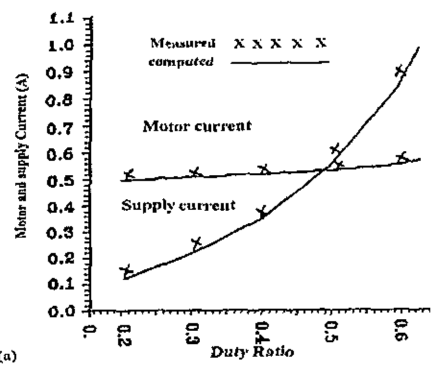
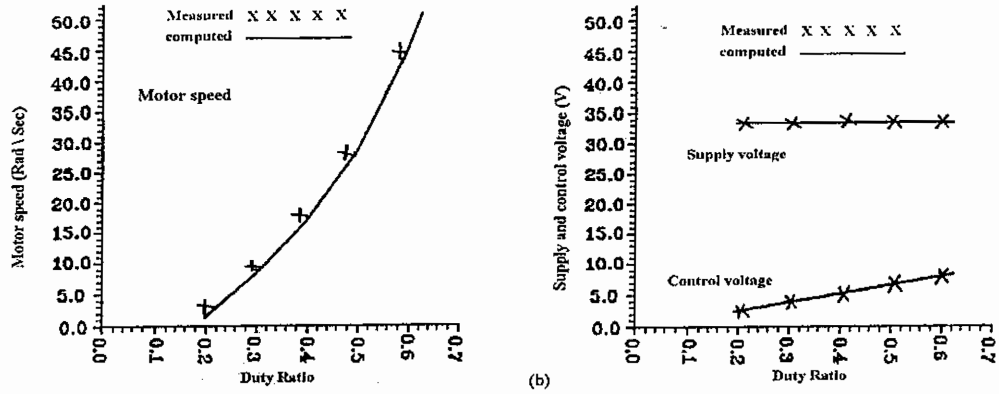


Fig. (4): Operation Modes of the System

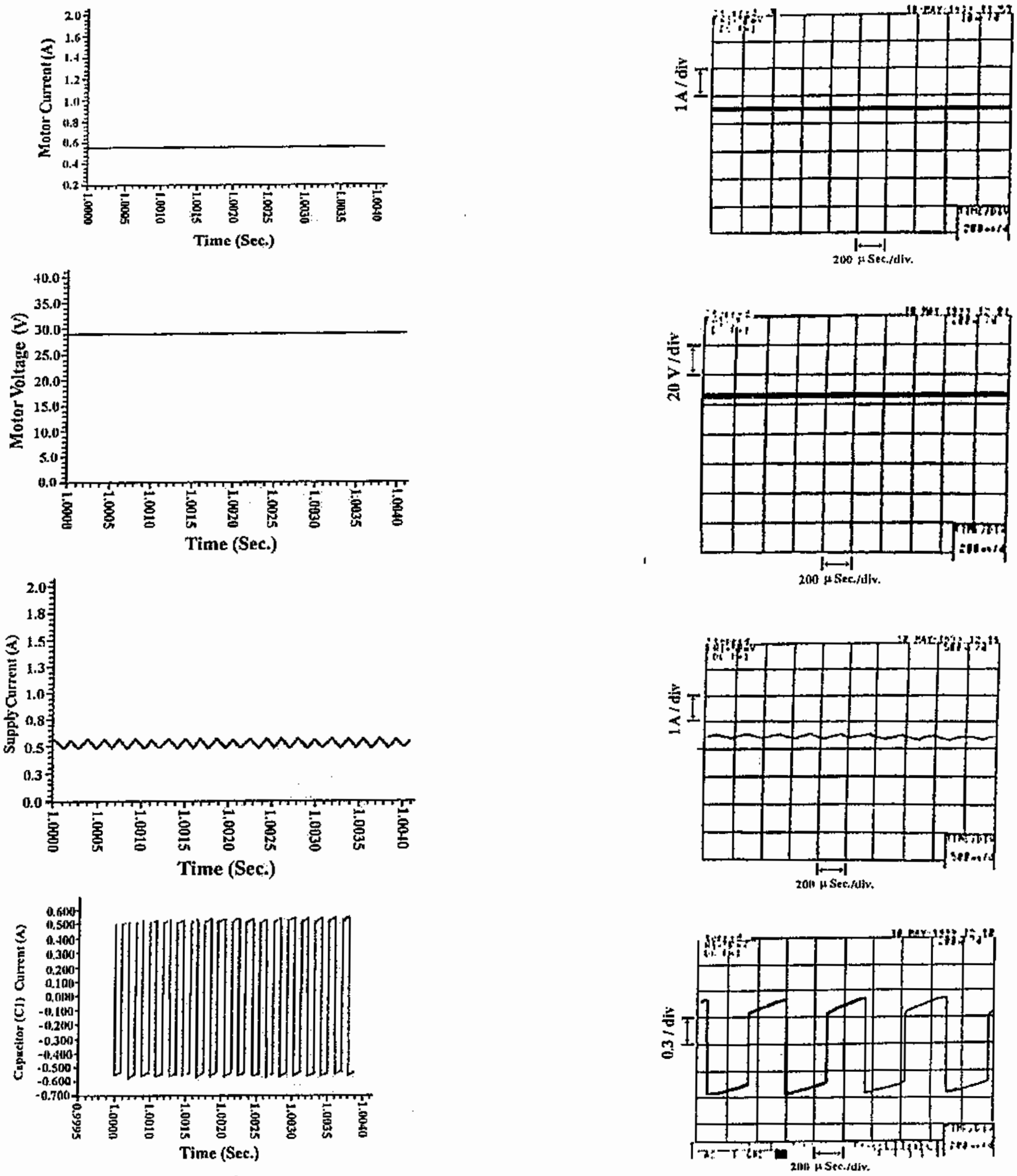




(a)

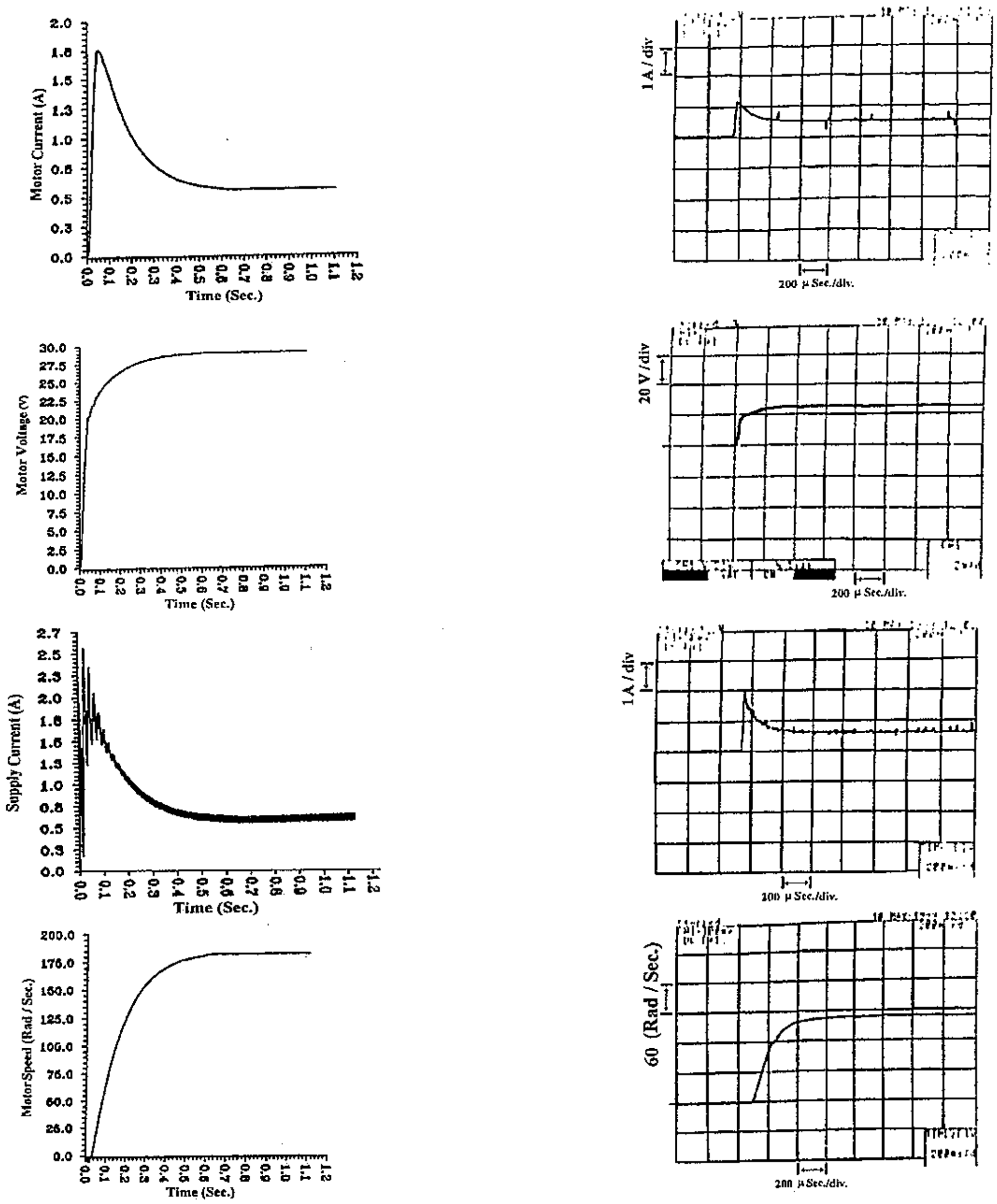


(5) : Effect of Varying the Converter Duty Ratio at a Constant Voltage Source and half full load torque



Simulation Experimental

Fig. (6) : Steady state Waveforms at Half Full Load for a Duty Ratio = 0.5



Simulation

Experimental

Fig. (7) : Starting Up characteristics at Half Full Load for a Duty Ratio = 0.5

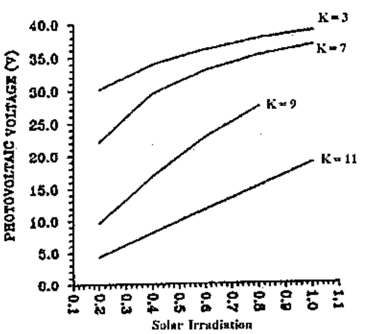


Fig. (8): Photovoltaic Voltage Versus Percentage Solar Irradiation Level

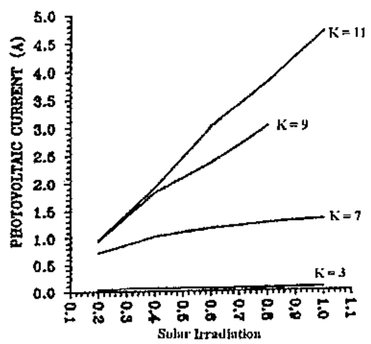


Fig. (9): Photovoltaic Current Versus Percentage Solar Irradiation Level

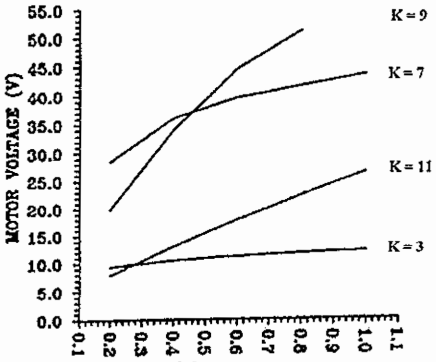


Fig.(10) Motor Average Voltage Versus Percentage Solar Irradiation Level

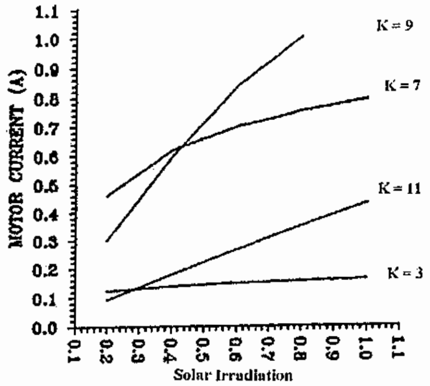


Fig. (11): Motor Avarage Current Versus Percentage Solar Irradiation Level

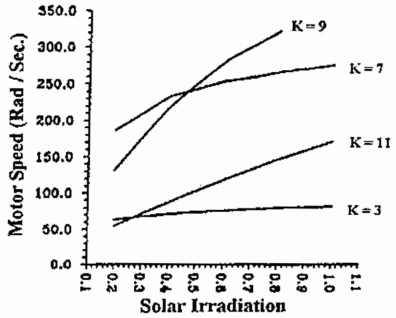


Fig. (12) Motor Speed Versus Percentage Solar Irradiation Level

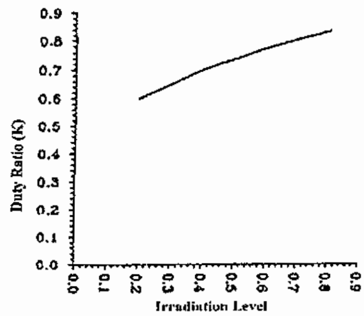


Fig. (13): Relation Between the Duty Ratio and the Irradiation Level for a Pump Load at Maximum P.V Power Operation

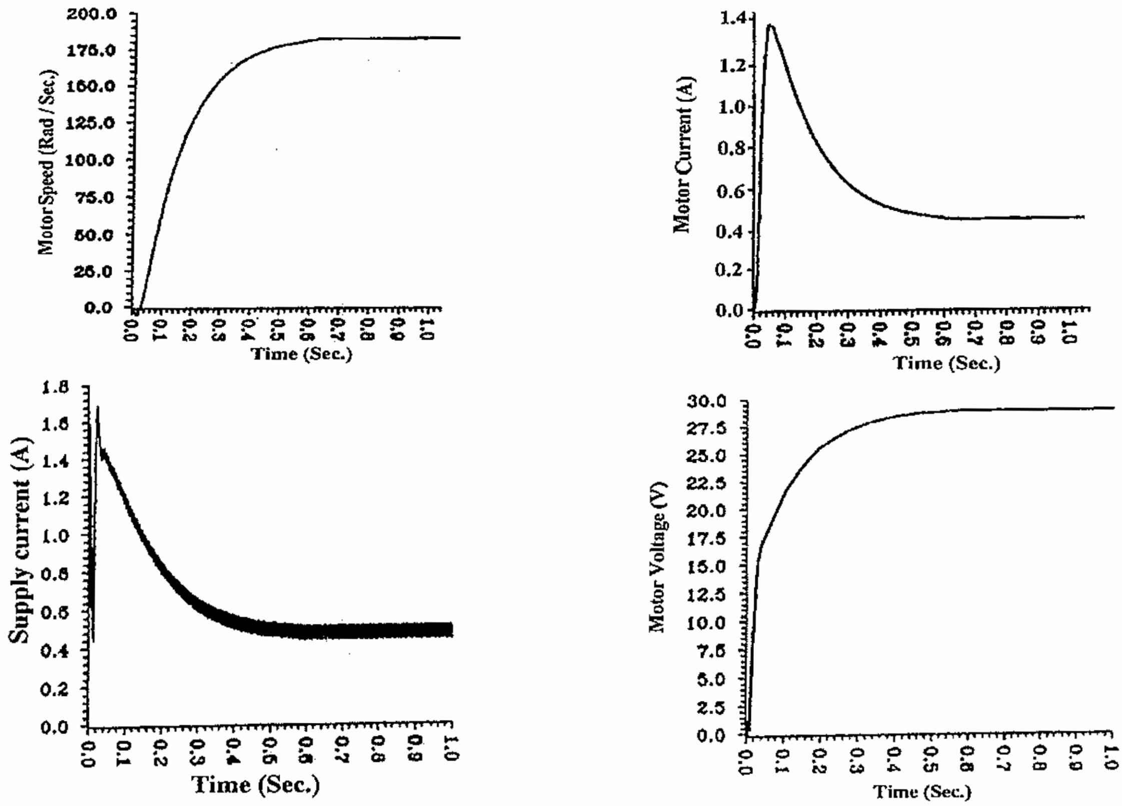


Fig. (14) : Starting Behaviour for a Pump Load at Irradiation Level = 60%, Duty ratio = 0.75 and Maximum Photovoltaic Power