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PHOTOVOLTAIC POWER SYSTEM SUPPLYING DC SERIES MOTOR

النظـــام الفوتوفولــتى كمصــدر لتغذيـــه محـرك التـــوالى

BY

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فى هذا البحث يتم دراسه الخواص الكهربيه لمحرك توالى يغذى من نظام فوتوفولستى عبر مقطـع تيـار مسـتمر ٠ يتكون النظام الفوتوفولتى المُغذى من مجموعه من الخلايا الشمـسيه تعمل دائما عند نقطه اقصى قدره ومزود بنظام لمتابعتها ٠ يستخـدم هنا مقطع التيار المستمر للتحكم فى قيمه التيار المغذى للمحرك وبالتالى يمكن التحكم فى مقدار العزم الذى يغذيه المحرك٠
وتم دراسه تأثير مستوى الاشعاع الشمسى على قيمه التيار المغذى للمحرك وذلك عند سرعات مختلفه وزوايا فتح ايضا مختلفــه للسيرستور كما تم دراسه تأثير عدد خلايا التوالى على الخواص الكهربيه للمحرك٠

وقد اوضحت الدراسه ان تيار المحرك يزداد بزياده شده الاشعاع الشمسى وايضا بزياده زمن الفتح للسيرستور ٠ وعلـى الجانب الاخر فان تيار المحرك يتناسب تناسبا عكسيا مع سرعه المحرك وقد اوضحت الدراسه ايضا ان العلاقه بين عدد الخــلايـا الشمسيه المتواليه وتيار المحرك هى علاقه خطيه٠

ABSTRACT

In this paper the electrical performance of a DC series motor supplied by a photovoltaic power supply (PVPS) through a DC chopper is evaluated.A PVPS is operated at a maximum power point.

this means that it consists of photovoltaic array and a maximum power traking system. The later is used to trak maximum power point. A DC chopper is used for controlling thr motor current and the motor torque The effect of insolation level on the motor current suppliing at different speed and at various firing angles of thyristor is preseented. The effect of series connections of solar cells on the motor performance is also studied. The effect of DC chopper-which is consider as a control unit- upon the motor performance is illustrated.The relationship between the motor current and intensity of radiation at different speed is studied. The study shows that: the motor current increases with increasing of the illumination and the main thyristor ON time. Besides. the motor current is inversely proportional to the motor speed.The effect of series combination is also illustrated. the study shows that a linear variation of motor current wiyh the number of series cells.

INTORDUCTION

The thyristor chopper is now very widly used for the control of DC series motors for traction applications. The advantages of the thyristor chopper over the conventional resistance controller are : higher efficiency. flexibility in control. regeneration down to very low speed. light-weight and smaller size. The chopper output voltage can be controlled either by using a current-limit controlled scheme or by pulsewidth control. In the current limit controlled scheme. the current is controlled between certain maximum and minimum values of current-when the current reaches the maximum value the chopper disconnects the supply from the load and reconnects it when the current reaches its minimum value [1]. In the pulsewidth control scheme chopper "on" to "of" time ratio is controlled. The chopper can be operated at a constant frequency or at a constant "on" or "off" time and variable frequency [1]. The method describes the analysis of the series motor fed by chopper using. pulsewidth control considers the chopper and motor as one system and takes into account the effect of commutation on motor voltage and consequently on motor torque [2].

The phase control is commonly used in solid state series motor drive. The novel current control scheme is proposed [3] and improve certain performances of the drive systems. In this scheme the armature current can be made continuous under all practical load conditions. This improves the dynamic response of the system. The input power factor is also improved in the current control scheme. The peak current and ripple which affect the commutating capability can be controlled in the current control scheme. These are the desirable features in commutator type motors.

Current control scheme in solid state traction motor drive looks promising and desirable over the commonly used phase control scheme, particularly in countries where weather is rough in the winter [3].

By taking appropriate precautions. it is possible to apply chopper controlled vehicles to any DC railway [4]. Technology is moving at an increasingly fast rate and new systems. such the G.T.O chopper switched variable reluctance drives and AC drives are being introduced. Although the detailed design is different. the systems engineering experience gained in the interoduction of chopper trains [4].

The present paper describes the electrical performance of pulsewidth modulated control DC series motor. The power supply which fed the motor is a photovoltaic power system.

MATHEMATICAL MODEL

a) Chopper model

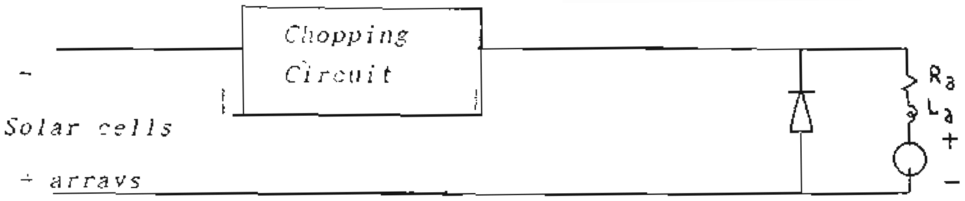

Fig.(1) Chopper circuit for DC series motor control

The chopper is used for controlling the DC series motor because the field inductance of the series motor keeps the armature current constant during the OFF period. The input current consists of pulses during the ON period and hence the supply must be capable of allowing rapid changes of current to occur. The motor receives energy from the supply during the ON period during which the voltage $(V-E_a)$. where E_a is the back e.m.f of the motor and V is the supply voltage. is impressed on the RL circuit of the armature. Also the current rises exponentially During the ON period.On the other hand the current decreases exponentially under the voltage $_a$-E applied to the RL circuit of the armature during the OFF period.

Suppose that the average value of the chopper output voltage is V_o .then

$V_o = D_r * V$

Where D_r is the duty ratio [5]

$D_r = t_{on} / T$

and $T = t_{on} + t_{off}$

where

t_{on} = ON time of a main thyristor

and t_{of} is an off time

Suppose that the motor back e.m.f is$_a$ E

$E_a = K' i_a w$

K' = motor constant

i_a = armature current

w = armature angular velocity

$$V = L \frac{d i_a}{dt} + i_a R + K' w \, i_a \qquad (1)$$

The solution of this equation is [6,7].

$$i = \frac{V}{R + K' w} + \left(I_{min} \quad \frac{V}{R + K' w} \right) e^{-\left(\frac{R + K' w}{L} \right) t} \qquad (2)$$

$$i = \frac{V}{R + K' w} \left(1 - e^{-\frac{t}{T_o}} \right) + I_{min} \, e^{-\frac{t}{T_o}} \qquad (3)$$

where

i = instantaneous value of a motor current

I_{min} = minimum value of motor current

But if the back e.m.f of a motor is given by [8]

$E_a = K_{ar} \, i \, N + K_{res} \, N$

$E_a = K_{ar} \, i \, N + K_{res} \, N$

where K_{ar} and K_{res} are motor constants

motor current is given by

$$i = \frac{E_a - K_{res} N}{R_a + K_{ar} N} \left(1 - e^{-\frac{t}{\tau}} \right) + I_{min} \, e^{-\frac{t}{\tau}} \qquad 0 < t < t_{on} \qquad (4)$$

$$i = -\frac{K_{res} N}{R_a + K_{ar} N} \left(1 - e^{-\frac{t'}{\tau}} \right) + I_{max} \, e^{-\frac{t'}{\tau}} \qquad t_{on} < t < T \qquad (5)$$

where $t' = t - t_{on}$

$$\tau = L / (R_a + K_{af} N)$$

$$I_{min} = \frac{E_a}{R_a + K_{af} N} \cdot \frac{(e^{t_{on}/\tau} - 1)}{(e^{T/\tau} - 1)} - \frac{K_{res} N}{R + K_{af} N} \qquad (6)$$

$$I_{max} = \frac{E_a}{R_a + K_{af} N} \cdot \frac{(1 - e^{-t_{on}/\tau})}{(1 - e^{-T/\tau})} - \frac{K_{res} N}{(R + K_{af} N)} \qquad (7)$$

To find the instant t_m at which the current is maximum and discontinues, put

$I_{min} = 0.0$

$$\text{and } I_{max} = \frac{E - K_{res}}{R + K_{af} N} (1 - exp(-t_{on}/\tau))$$

$$t_m = \tau \ ln (exp(t_{on}/\tau)) (1 + \frac{E - K_{res} N}{K_{res} N}) (1 - exp(-t_{on}/\tau)) \qquad (8)$$

The continuity of the motor current can be determined from the later equation once the nature of the current is known. The motor current is given by equation (4) when the chopper is ON and by equation (5) when the chopper is OFF.

The average value of the motor current (I_a) can be determined by the following equation.

$$I_a = 1/T \{ I_1 t_{on} + (I_{min} - I_1) (1 - exp(-t_{on}/\tau)) \tau + I_2 (t_m - t_{on}) +$$
$$\tau (I_{max} + I_2) (1 - exp(-(t_m - t_{on})/\tau)) \} \qquad (9)$$

The RMS value of the motor current is determined by.

$$I_{ar} = (1/T (I_1^2 t_{on} + \tau 2 I_1 (I_{min} - I_1) (1 - exp(-t_{on}/\tau)) +$$

$$\tau / 2 (I_{min} - I_1)^2 (1 - exp(-2 t_{on}/\tau)) + I_2^2 (t_m - t_{on}) -$$

$$2\pi I_2(I_{max} + I_2)(1 - exp((-t_m + t_{on})/\tau) + / 2(I_{max}^2 + I_2) *$$

$$(1 - exp(-2(t_m - t_{on})\tau / \gamma)^{1/2})) \qquad (10)$$

Where

$$I_1 = \frac{E - K_{res} N}{R_a + K_{af} N}$$

$$I_2 = \frac{-K_{res} N}{R_a - K_{af} N}$$

The motor torque is given by.

$$T_o = K_{af} I_{ar}^2$$

b) SOLAR CELL MODEL

The volt amper characteristics of a solar cell may be determined by using the following model [9].

$$I_c = I_l - I_r(exp((I_c R_s + E_c) q / A_o K T_c) - 1) \qquad (10)$$

Where I_c is the output current from a cell.

I_l is the photon current.

I_r reverse saturation current.

E_c cell output voltage.

R_s cell resistance .

q electron charge.

A_o constant depends upon solar cell type.

K BOLTZMAN'S constant.

and T_c is a cell temperature

The voltage and current at a maximum power point are

$$V_{MP} = D_1 - D_2(T_c - D_7) + D_3 \log I_H \qquad (11)$$

$$I_{mp} = D_4 I_h + D_5(T_c - D_1)$$

Where D_1, D_2, D_3, ..$_7D$ are experimental coefficients depends upon solar cell type.

I_h intensity of radiation

ALGORITHM

The purpose of this algorithm is to obtain the electrical performance of DC series motor supplied by solar cells array through a DC chopper as follows:

Inputs the motor coefficients K_a K_{res} , motor resistance R_s its inductance.coefficients of of solar cell D_1 D_2 . D_7 ....D and its series resistance.

Output the results

1) Use equation 11 to Compute the voltages and currents at the maximum power points at different insolation levels I_{h1}, I_{h2} .....I_{hn} . different speeds constant chopping frequency (120 hz) and different ON times (t_{on}).

2) set $N = N_1$ and calculate t_m from equation (8).

3) If t_m < T I_{min} (this means of the current the feds the motor discontinues .

If t_m > T t_m = T (the current is continuous).

4) Calculate I_{max} in both cases.

RESULTS

The results of the computer program are the currents and voltages at a maximum power points at different insolation levels (I_{mp} . V_{mp}) are shown in Fig.2. The voltage at maximum power point and the intensity of radiation C/C is linear for low insolation level less than .05 Kw/ m^2 . Then it has a small rate of change after .05 Kw/ m^2 insolation level. The current at a maximum power point I_{mp} and I_h characteristic is linear as shown in fig.2.

The RMS value of motor current. against intensity of radiation for constant number of series cells (N_s = 500)and constant chopping frequency (f_{ch} = 120 Hz)and for various values of α = ... T_{on} and for speed 3000 rpm is presented in Fig.3. It is obvious from Fig.2 that the chopper output current increases with increasing insolation level. The chopper current depends upon the main thyristor ON time.It is largely increased as the ON time increases. The increasing of motor current I_a with the increase of insolation level I_h is due to the increasing of minority carriers generated in the conduction band. The motor current-intensity of radiation characteristics are shown in Figs.3 to 8 For various motor speeds.

As shown from the Figs. the motor current is dependent upon insolation , motor speed and and the firing angle of thyristor. The motor draws a very high current at low speeds. The ON time period has a large effect on motor current at high values of α .

The motor current - speed characteristic is shown in fig.9 for a different insolation levels.The motor current is very high at low speed and largely decreases at high speeds. The high levels of insolation has no longer effect on motor current at very high and very low speeds.

The motor current versus α is represented in Fig.10 for different values of insolation levels. As shown in the Fig. the factor α has pronounced effect the on motor current. On the other hand, the high levels of insolation have a small effect on motor current.

The behavior of motor torque against insolation level is shows in Fig.11. The motor torque is increased with increasing of the irradiance. The motor speed has a large effect on the torque. The torque is increased as decreasing motor speed and vice versa. This due to the fact that the motor draw high current at low speeds and low currents at high speeds.

The effect of number of connected series cells upon motor current is illustrated in Figs.12 and 13 . The variation of motor current against insolation level with N_s (number of series cells) as a parameter is shown in Fig.12). A linear variations of the motor current with N_s and I_h as a parameter is illustrated in Fig.13. In this Fig. the motor current is linearly increased as the number of connected solar cells increases.

CONCLUSIONS

The electrical performance of a DC series motor supplied by photovoltaic power supply is studied. The motor current-intensity of radiation for a different speeds is also studied. The results show that for low speeds the motor current is very high and it increases with increasing intensity of radiation. The main thyristor firing angle of a DC chopper has also a pronounced effect upon motor current. Study shows that a motor current is affected by the ON time of a main thyristor and also with the insolation levels. As the ON time increases the motor current is increased. This current is also increased as increasing a level of insolation. The motor speed is a very important parameter which has a large effect on motor current. The results show that at low speed the motor current is very large. The effect of a series combination of a solar cells is illustrated in the study. A study shows that a linear variation of a motor current against *the number of series connected cells.*

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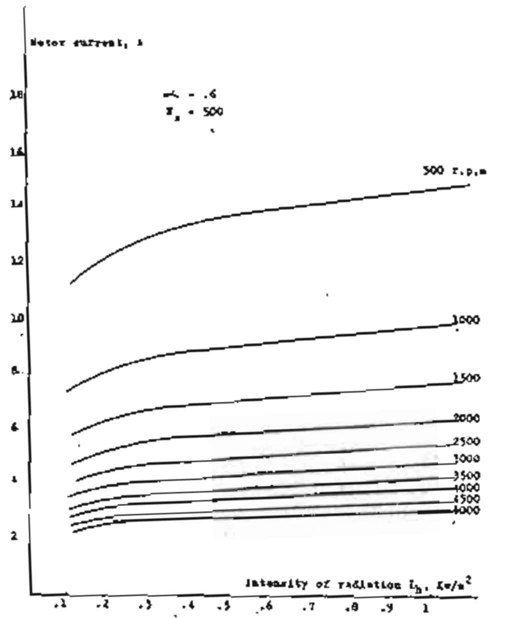

Fig.6 Motor current, intensity of radiation charmeteristics for ∝=.6 and 500 series cells and for different speeds.

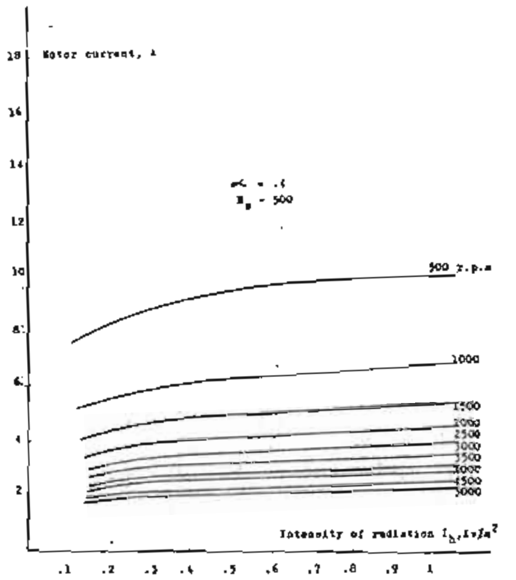

Fig.5 Motor current, intensity of radiation characteristic for ∝ = .4 and 500 series connected cells.

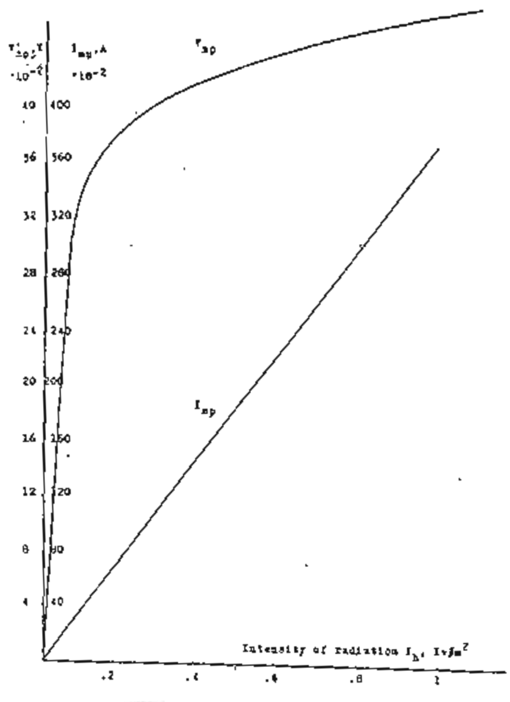

Fig.2 current and voltage at a maximum power points of a solar cell at different insolation levels.

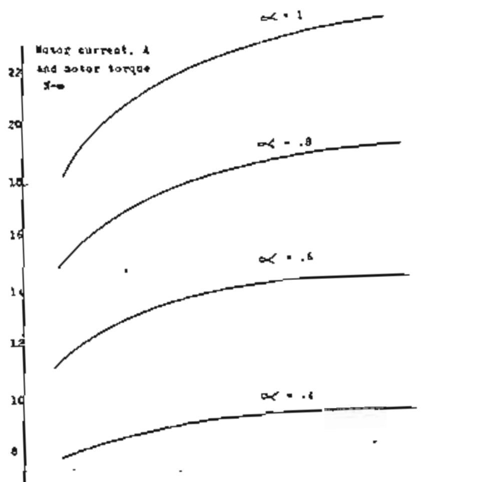

Fig.3 R.M.S value of motor torque and intensity of radiation characteristics for 120Hz chopping frequency and 500 series connected cells.

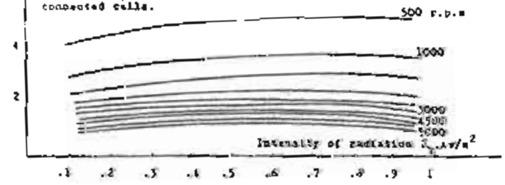

Fig.4 Motor current and intensity of radiation characteristics for ∝= .2 and 500 series connected cells.

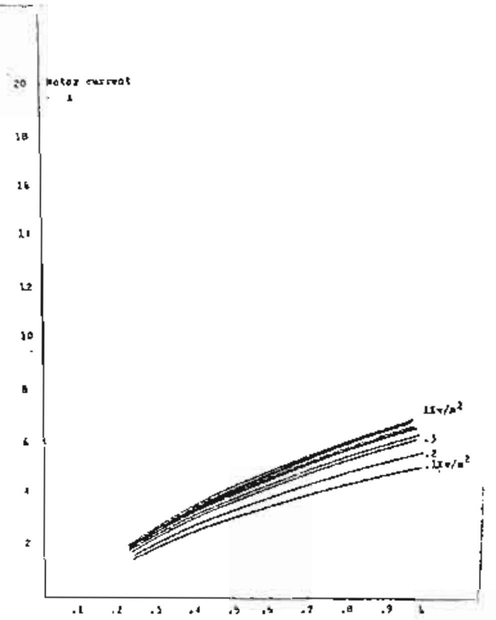

Fig.10 Motor current versus α for different insolation levels and speed N= 3000r.p.m.

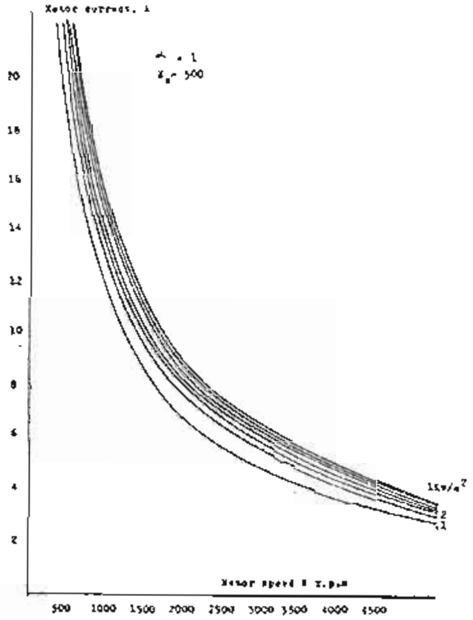

Fig.9 Motor current speed characteristics for different insolation levels, α=1 and number of connected series cells, N_s= 500.

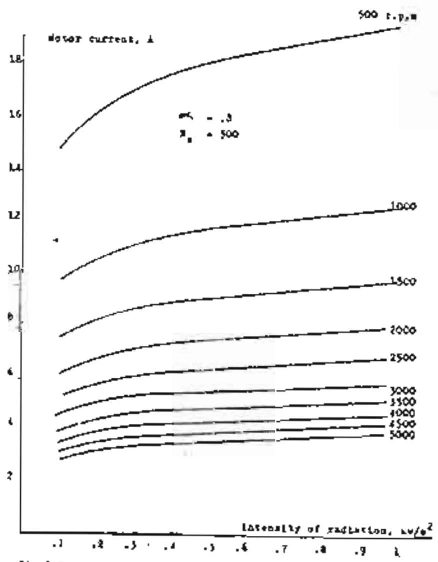

Fig.7 Motor current, intensity of radiation characteristics for α=.8, N_s 500 cells and for different speeds.

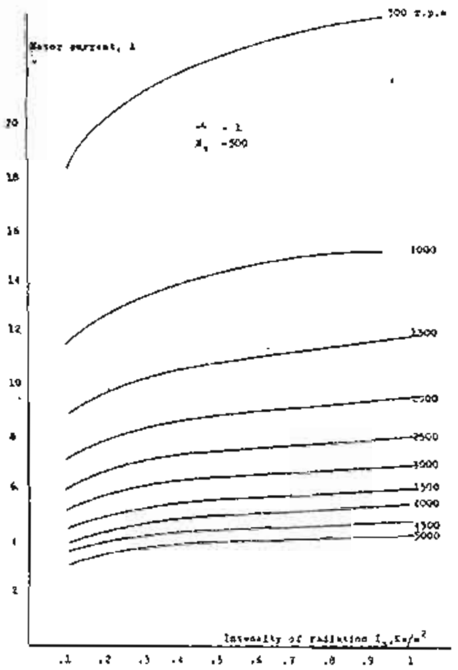

Fig.8 Motor current, intensity of radiation characteristics for α=1 and 500 series connected cells and for different speeds.

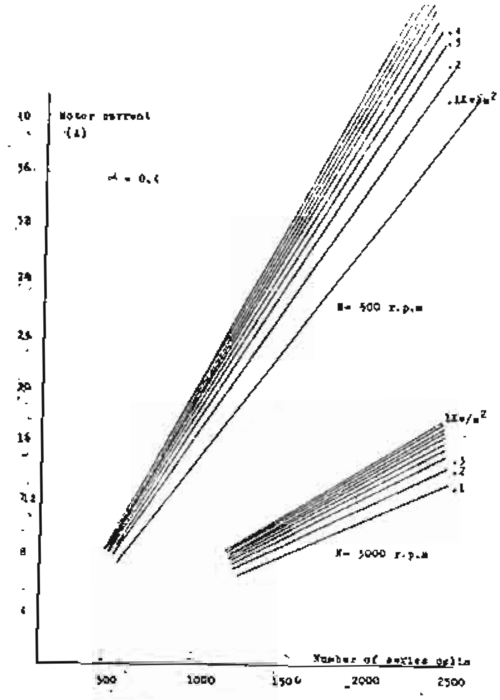

Fig.13 Effect of number of series cells on motor current for α = .6, N= 500 and 3000 r.p.m and for different levels of insolation from .1 to 1 Kw/m².

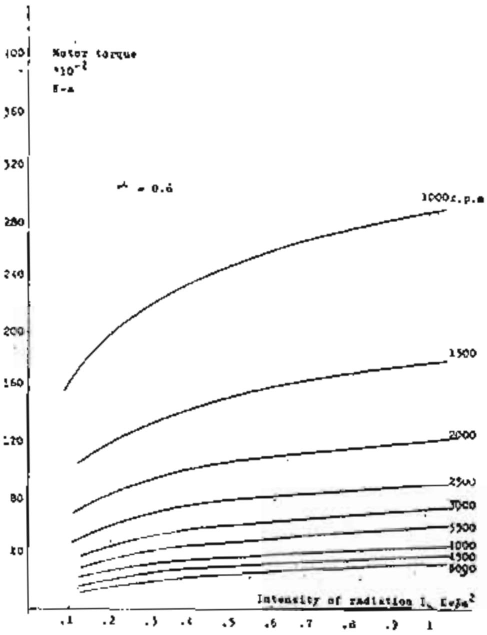

Fig.11 Motor torque, insolation level characteristic for different values of motor speed, α = 0.6

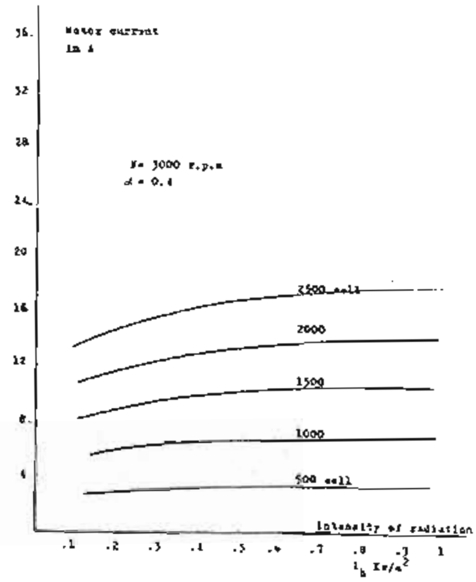

Fig.12 Effect of solar irradiance, I_h, on motor current for different numbers of series cells.