Power Factor Improvement of Induction Motor Using Microprocessor Controlled FC-TCR Compensator

K.E. Ad'doweesh*, M.S. Smiai* and Syed Enamul Haque

**Electrical Engineering Dept., College of Engineering, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia; **University of Technology, Karachi, Pakistan.*

Abstract. This paper describes the design and implementation of a scheme using a microprocessor to achieve on line and dynamic power factor improvement of a single phase induction motor subjected to variable load. The proposed scheme employs an FC-TCR type of power factor compensator along with associated control circuits. The results show that, under all loading conditions, the power factor of almost unity is achieved automatically. Furthermore, the waveform of supply curent can be kept almost sinusoidal. The response time of the proposed scheme to motor load changes is very fast.

1. Introduction

Induction motors are commonly used in domestic, industrial and commercial applications. It is well known that the power factor of such motors is usually low (in the range of 0.5 to 0.8) and depends upon the load and the motor parameters. If the motor is coupled to a fixed load, its power factor can be improved by a single fixed capacitor connected across the motor terminals. For variable load drives, the power factor may be improved by using switched capacitors. Such a scheme, however, only provides capacitance variation in discrete steps and therefore optimum power factor improvement is not always obtained.

It is well known that continuous leading VAR may be obtained by using Fixed Capacitor Thyristor Controlled Reactor (FC-TCR). This paper describes a scheme using a FC-TCR compensator in which the firing angle of controlled thyristors is varied by microprocessor to provide required leading VAR. The displacement angle between the fundamental components of the supply voltage and the motor current is continuously measured by the microprocessor and corresponding delayed pulses are applied to the FC-TCR keeping the displacement angle always equal to zero. Therefore, this proposed scheme allows fast and dynamic power factor improvement. The experimental results indicate that with the compensator, the power factor of almost unity is achieved under all loads and response is very fast.

2. FC-TCR Compensator

An effectively smooth variation of capacitance, required for dynamic power factor correction, can be obtained by using a static compensator employing a fixed capacitor in parallel with a thyristor controlled reactor [1]. Fig. 1 shows the basic circuit diagram of such a compensator. The values of the fixed capacitor C and the inductor L are selected using the following equations:

$$\omega C V_s = (I_m \sin\phi)_{max} \tag{1}$$

and

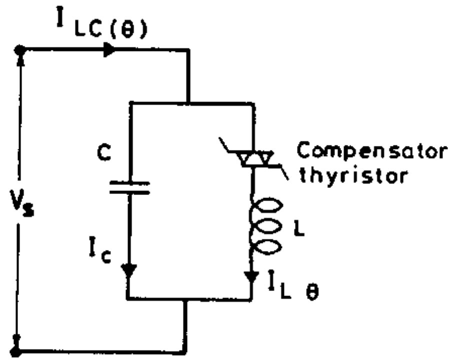
$$V_s/\omega L = (I_m \sin\phi)_{max} - (I_m \sin\phi)_{min} \tag{2}$$

where ω is the supply frequency and $(I_m \sin\phi)_{max}$ and $(I_m \sin\phi)_{min}$ are respectively the maximum and the minimum possible lagging reactive currents taken by the motor under any loading conditions.

The lagging current taken by the inductor can be controlled by varying the firing angle θ. Consequently, the fundamental leading rms component of the compensator current $I_{1LC}(\theta)$ is given by:

$$I_{1LC}(\theta) = \omega C V_s - (V_s/\omega L)\left[(2-(2\theta/\pi)) + (\sin(2\theta/\pi))\right] \tag{3}$$

For optimum power factor improvement the value of θ should be such that $I_{1LC}(\theta)$ is always equal to $I_m \sin\phi$ of the motor for all operating conditions.



3. Control Scheme

The proposed circuit schematic for the self compensating, high-power factor controller is shown in Fig. 2. The bandpass filters BPF_1 and BPF_2 extract the fundamental components of the supply voltage (V_{SF}) and that of motor current (I_{MF}) respectively. BPF_1 takes care of the distortion of the supply voltage, if any, and compensates for phase changes introduced by BPF_2 in extracting the fundamental component of motor current. Outputs of BPF_1 and BPF_2 are fed to a phase detector which gives a pulse of width proportional to the phase difference ψ between V_{SF} and I_{MF}. The rising edge of the pulse triggers the timer (CTC) to start the down count, while the falling edge of the phase detector output is fed to single shot of 5 μsec duration to give a low pulse to the PIO (Pin PAϕ) which requests an interrupt. The interrupt service routine (ISR) reads the contents of the timer at that instant. The number of counts (NC) proportional to the phase difference angle (ψ) is used as an address for a table which contains the values proportional to the required control DC voltage. This DC voltage output of the D/A converter is used to give the required delayed firing pulses (θ) to the compensator thyristors. The flow charts of the main programme and ISR are given in Fig. 3. The variation of θ controls the leading VAR of the compensator in such a way that the angle ψ approaches zero.

4. Performance of the Compensator

The above mentioned scheme was implemented to improve the power factor of a single-phase (split-phase type) 220V, 1.5 kW, 60Hz induction motor. The laboratory tests were carried out to determine the motor performance. The power factor of this motor without compensator varied from 0.5 to 0.9 (from no load to full load). The maximum and minimum values of the lagging reactive component of the motor current, $I_m \sin\phi$, were found to vary between 3 and 2 amperes respectively. Fig. 4 shows the power factor and supply current with and without the compensation. It is obvious that the compensator is able to keep the power factor at almost unity under all operating conditions. It is to be noted that the controller is designed to adjust the firing angle θ of the compensator such that the displacement factor $\cos\psi$ is equal to one. The power factor may be below unity depending upon the amount of harmonics in the supply current.

Fig. 5. shows the angle ψ between V_{SF} and I_{MF} before and after compensation for light load and full load respectively. It is clear from the figure that whereas $\psi=60°$, and 30° for light load and full load respectively, their values are equal to zero after compensation.

Fig. 6. shows the oscillograms of supply voltage, motor current and supply current with compensator for the motor on light load. It is clear from Fig. 6 that with compensation the supply current and supply voltage are in phase. However, supply current contains undesirable harmonics. There are two distinct causes of these har-

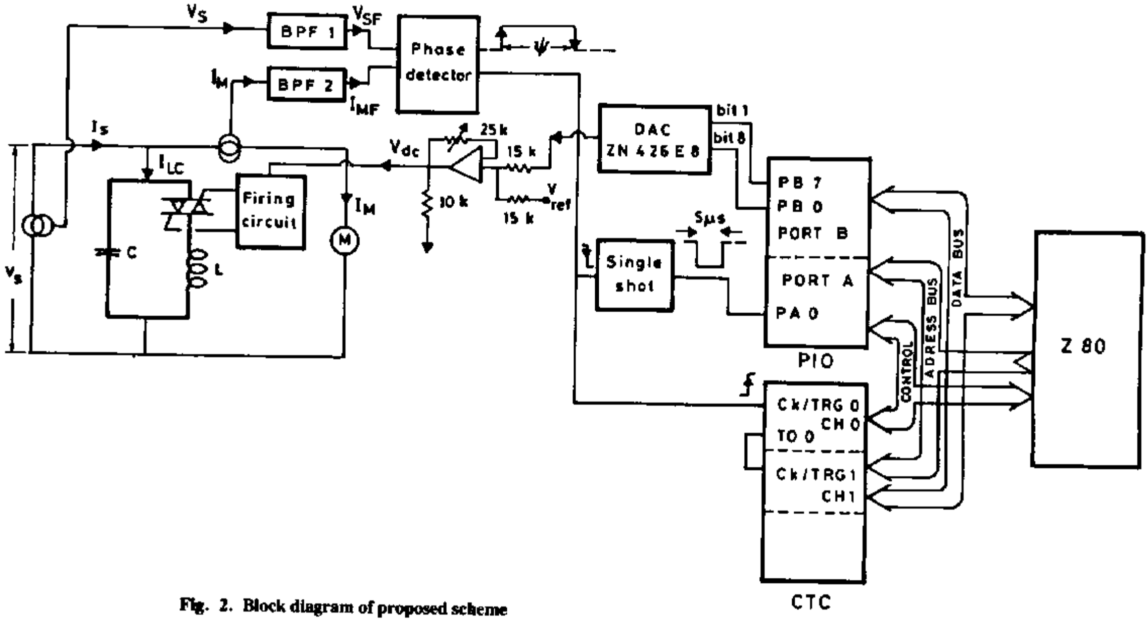


Fig. 2. Block diagram of proposed scheme

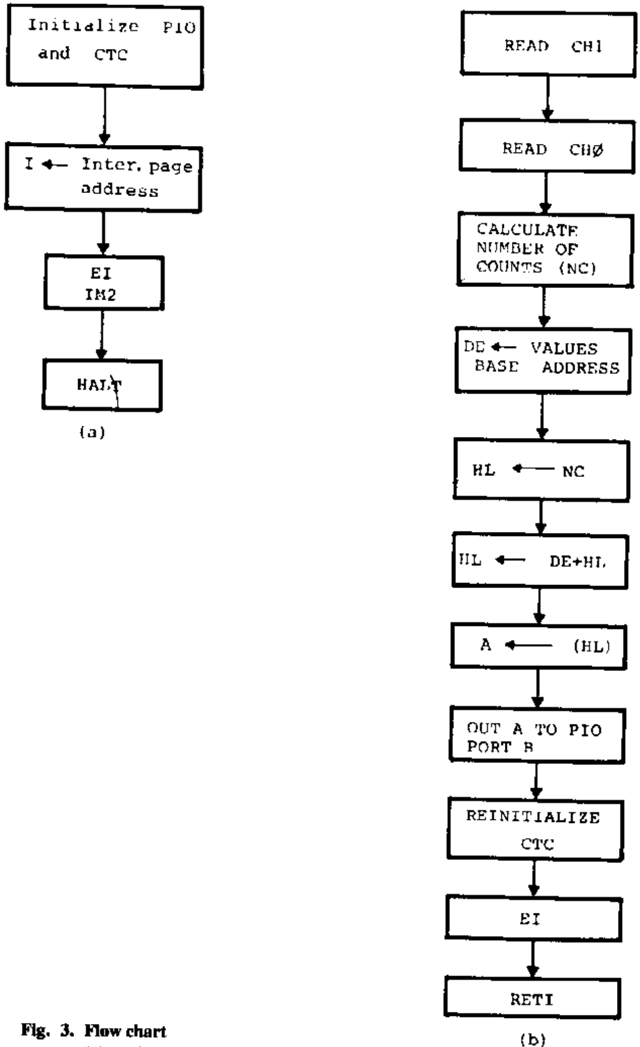


Fig. 3. Flow chart
(a) main program (b) ISR

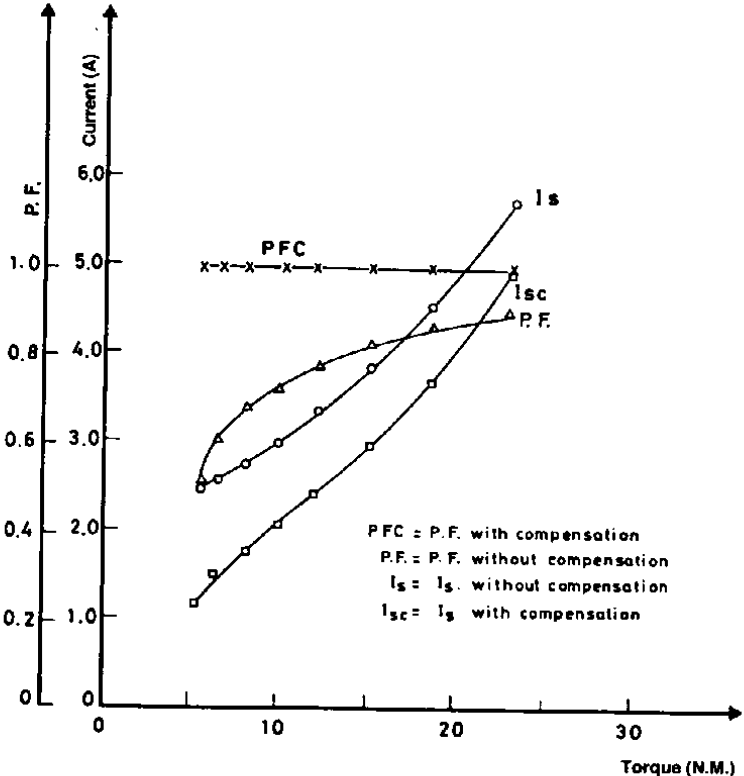


Fig. 4. Variation of power factor and supply current with motor torque

monics. The higher frequency harmonics evident in the supply current are due to oscillations between the supply inductance and the compensating capacitor. Such harmonics are even present in the absence of thyristor controlled reactor. Therefore, such higher order harmonics are not introduced by the thyristors and could be eliminated by introducing a suitable harmonic suppressor inductor in series with the fixed capacitor [1].

The second source of harmonics is the thyristor controlled reactor which introduced odd order harmonics for a single-phase load. The magnitude of these harmonics decreases with the order of harmonic. Consequently lower order harmonics are predominantly caused by the TCR. For a given motor, if a compensator is

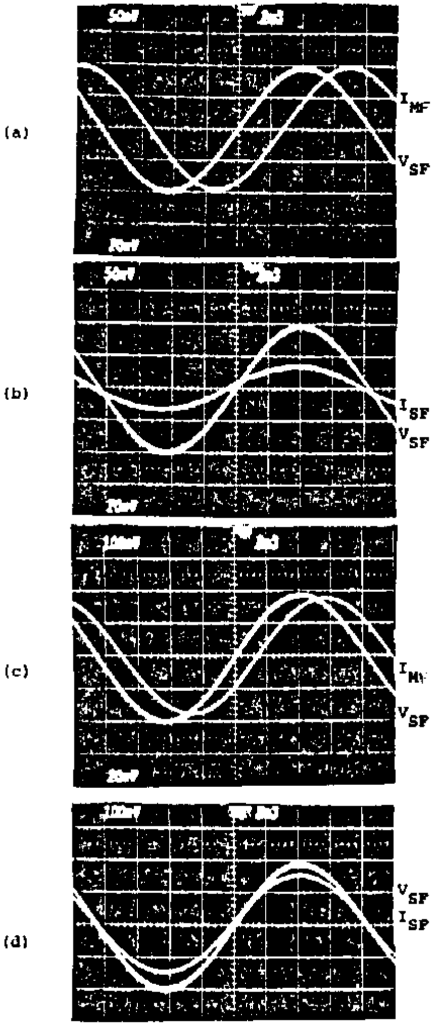


Fig. 5. Oscillogram of supply voltage and supply current
(a) before compensation
(b) after compensation for light load
(c) before compensation
(d) after compensation for full load

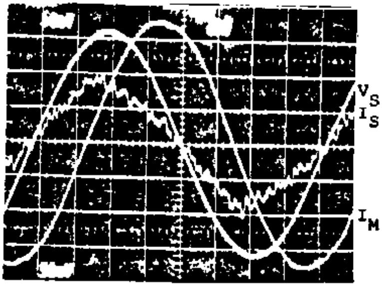


Fig. 6. Oscillograms of supply voltage V_S, motor current I_M, and supply current I_S.

designed following equations (1) and (2), such harmonics will be negligible at extreme load conditions (no load and full load) and they are expected to have the highest per-unit values at about half the load. This is due to the fact that the amplitude of TCR generated harmonics vary in a non-linear fashion with the TCR firing angle [2].

The most significant of these lower order harmonics may be eliminated by using LC tuned filters instead of fixed capacitors as discussed in reference [3]. In such a scheme the LC branch (or branches) have the dual functions of supplying the required leading VARs at the fundamental frequency and also shunting the particular harmonic (3*rd* or 5*th* etc.). Consequently the supply current can be maintained nearly sinusoidal under different operating conditions in addition to the automatic power factor improvement offered by such a scheme.

Fig. 7 shows the oscillograms of the variation of DC control voltage and the supply current when a sudden change in the motor load from full load to light load occurs. The total response time of the whole control scheme is less than 0.2 sec. which is very fast as compared to that given in reference [1], the control circuitry of which is based completely on analog devices.

5. Conclusions

The simple scheme for dynamic and automatic power factor correction of a single-phase induction motor presented in this paper shows a good performance. The proposed scheme can be easily extended for three-phase motors. The response time of the compensator for step load changes is quite fast.

Acknowledgement: The authors would like to thankfully acknowledge the support and facilities provided by King Saud University, Riyadh, Saudi Arabia to carry out this work.

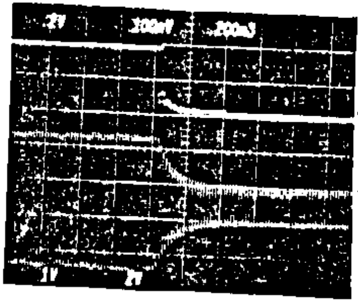


Fig. 7. Oscillograms of overall response time in control voltage V_{dc} supply current for a sudden change from full load to light load

References

[1] Haque, S.E. *et al.* "Power Factor improvement of Induction, Motor Using FC-TCR Compensator." Proceedings of the *IEEE sponsored First Symposium on Electric Power Systems*, in Fast Developing Countries, Riyadh, Saudi Arabia, March 21-24 (1987), pp. 371-374.

[2] Haque, S.E. "Power Factor Improvement of Thyristor Controlled Load." *Ph.D. Thesis*, University of Bradford, England (1982).

[3] Haque, S.E. and Malik, N.H. "Analysis and Performance of A Fixed Filter-Thyristor Controlled Reactor (FF-TCR) Compensator." IEEE/PES Paper No. 86 SM-360-2, *presented at 1986 Summer Meeting*, Mexico City, Mexico, July 20-25 (1986).

(*Manuscript Received:* 22.1.1988; *Accepted:* 29.5.1988)

المكثف الثابت المتوازي
مع حث محكوم بالثايرستور محكوما بالمعالج الأصغر

خالد إبراهيم الدويش*، محمد السميعي*، سيد إنعام الحق**

*قسم الهندسة الكهربائية، كلية الهندسة، جامعة الملك سعود، ص.ب ٨٠٠، الرياض١١٤٢١، المملكة العربية السعودية و** الجامعة التقنية، كراتشي، باكستان

ملخص البحث. هذا البحث يضيف تصميما لنظام يستخدم المعالج الأصغر لتحقيق تحسين لمعامل القدرة لمحرك حثي أحادي الطور معرض لأحمال متغيرة. النظام المقترح يوظف معوض معامل قدرة من نوع «المكثف الثابت المتوازي مع حث محكوم بالثايرستور»، إضافة إلى دوائر التحكم المصاحبة. توضح النتائج أن معامل القدرة يحقق آليا ليساوي الواحد تقريبًا عند جميع أحوال التحميل. كما أن شكل موجة تيار المنبع جيبي. زمن استجابة النظام المقترح لتغير الأحمال سريع جدًا.