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Microprocessor Based Power Factor Improvement of Induction Motor

K.E. Addoweesh
Department of Electrical Engineering, College of Engineering, King Saud University, P.O. Box 800, Riyadh–11421, Saudi Arabia

Abstract. This paper describes the design of a microprocessor controller for a fixed-capacitor, thyristor controller reactor (FC-TCR) compensator to achieve on line and fast power factor improvement of a dynamic load. The microprocessor system monitors the power factor of the load and uses a look-up table to adjust the FC-TCR compensator to give a unity supply power factor. The results show that under all loading conditions, the power factor of almost unity is achieved automatically. The response time of the system is very fast.

Introduction

Low power factor of supply causes some disadvantages:

1) The increase in the current due to the reactive component results in larger losses causing overheating of the system components.

2) The increase in the KVA loading of source generators.

3) Poor voltage regulation at the load.

Reactive power compensators are used to improve the power factor and hence to overcome the problems associated with the poor power factor. The function of the reactive power compensators are to minimize the voltage fluctuation at a given terminal and to improve the supply power factor by absorbing the reactive power.

The developments in high power semiconductor and sophisticated electronic control techniques have led to the development of quite fast thyristor controlled static var compensators.

The static var compensators should be synchronised with the terminal voltage under all conditions. Furthermore, it must be able to control rapidly the terminal voltage by compensating the reactive power.

Methods of Reactive Power Compensation Using Power Semiconductor Devices

The Thyristor-Switched Capacitor (TSC)

In this scheme a bidirectional semiconductor switch is used with each capacitor bank as shown in Fig. 1. The number of capacitor banks required is determined by the reactive power to be absorbed. To avoid the switching on transients the semiconductor switch is turned on when the voltage across it is zero. As the capacitance variation is in discrete steps, optimum power factor improvement is not always obtained. Also, the minimum time between a switch-on and off is one cycle of the supply frequency.

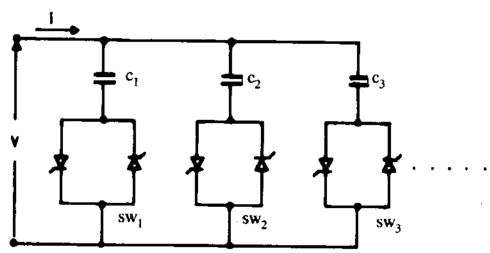


Fig. 1. TSC type compensator

Fixed-Capacitor, Thyristor Controled Reactor Compensator FC-TCR

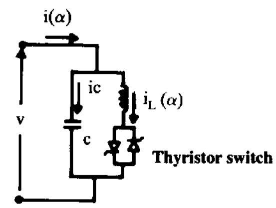
A smooth variation of capacitance required for dynamic power factor correction can be obtained by using a static compensator employing a fixed capacitor in parallel with a thyristor controlled reactor [1]. Fig. 2 shows the basic circuit diagram of such compensator. The values of the fixed capacitor (C) and the inductor (L) are selected using the following equations:

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

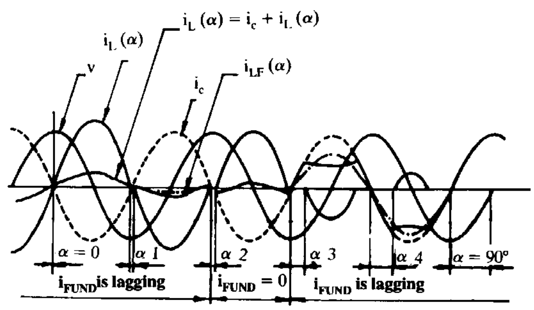
and

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

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



(a) circuit



(b) waveforms

Fig. 2. FC-TCR type compensator

The lagging current taken by the inductor can be controlled by varying the firing angle (α). Consequently, the fundamental leading rms component of the compensator current $I_F(\alpha)$ is given by:

$$I_F(\alpha) \quad = \quad \omega CV_s - [(V_s/\omega L)(2-(2\alpha/\pi) + \sin(2\alpha/\pi))] \qquad (3)$$

For optimum power factor improvement the value of α should be such that $I_F(\alpha)$ is always equal to $I_m \sin\phi$ of the motor for all operating conditions.

The current in the reactor is nonsinusoidal. The amplitudes of the harmonics as a function of angle α, are given by

$$I_{Ln}(\alpha) = \frac{V_s}{\omega L} \cdot \frac{4}{\pi} \left[\frac{\sin\alpha \cos(n\alpha) - n \cos\alpha \sin(n\alpha)}{n(n^2-1)} \right] \quad (4)$$

where $n = 2k + 1$, $k = 1,2,3,\ldots$

The maximum amplitudes of the third, fifth and seventh are 13.78%, 5.05%, 2.59%, respectively of the maximum fundamental current.

The delay angle α could be changed within a half cycle of the supply frequency.

Thyristor-Switched Capacitor, Thyristor Controlled Reactor Compensator (TSR-TCR) [2]

The single-phase TSC-TCR consists of n TSC branches and one TCR as shown in Fig. 3. The TCR is used to absorb the surplus capacitive vars. The harmonics generated by the TSC-TCR is less than that generated in the case of the FC-TCR especially when the number of capacitor banks switched in are increased. Also, the rating of the reactor is less than that in the case of FC-TCR.

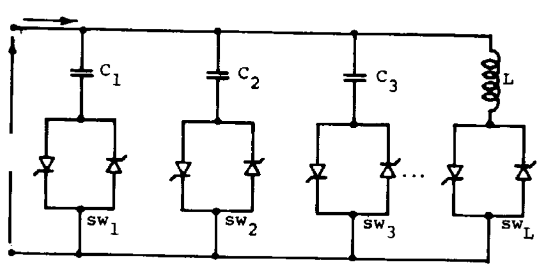


Fig. 3. TSR-TCR type compensator

Forced Commutated Compensators [3]

In all the prementioned methods the thyristors are switched off by natural commutation. Fig. 4 shows the use of the well known AC/DC converter which provides leading vars by making the input current leading the voltage. The thyristors should be forced-commutated to give such output. The firing angle could be changed to give variable leading current. The disadvantage of such arrangement is the relatively long response time and the generation of considerable amounts of harmonic currents into the AC system.

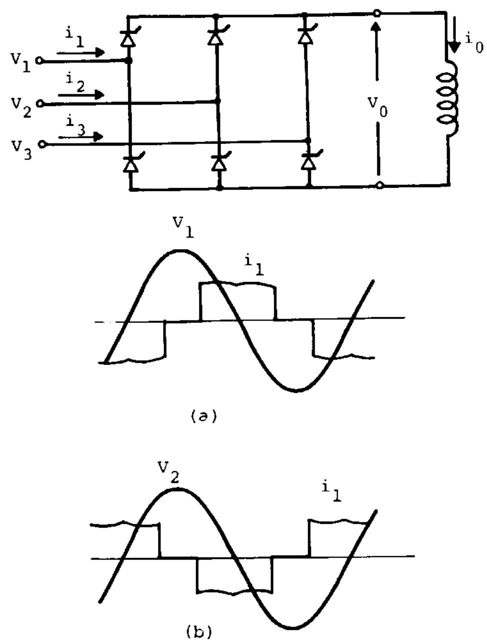


Fig. 4. Power circuit of forced-commutated compensator (a) lagging operation, (b) leading operation.

Power Factor Improvement of Induction Motor

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.

It is well known that continuous leading VAR may be obtained by using Fixed Capacitor Thyristor Controlled Reactor (FC-TCR). The design of the control scheme which utilizes the microprocessor in monitoring the load angle of the load (motor) and according to it the microprocessor sends a voltage level to an electronic circuit which generates the required angle α of the thyristors of the compensator is given in ref. [4]. This paper describes a scheme using an FC-TCR compensator in which the firing logic is completely generated by the microprocessor system to control the compensator thyristors to provide required leading VAR. The phase angle between the supply voltage and the motor current are continuously measured by the microprocessor and corresponding delayed pulses are applied to the FCT-TCR 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.

Control Scheme

The measured relation between the load angle (ϕ) and the firing angle of the FC-TCR thyristors to keep a supply power factor of unity is shown in Fig. 5.

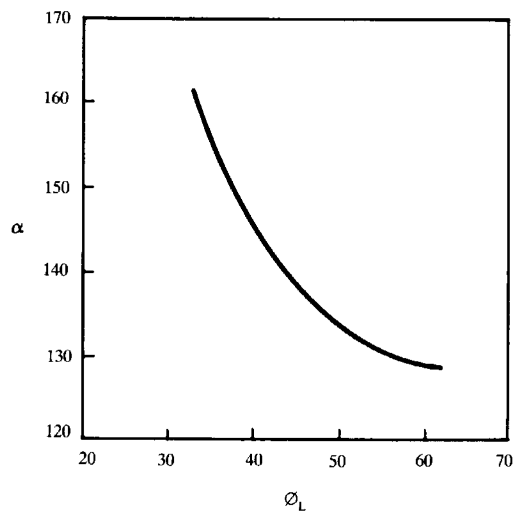


Fig. 5. Relation between the motor phase angle with α to keep unity supply power factor.

The input to the gate of the counter 2 of the 8253 is the phase angle of the load ϕ. Counter 2 is programmed to operate in rate generator mode. The rising edge of the signal input to G2 initializes counter 2. While the falling edge both stops the down counting and makes the PIO requesting an interrupt as shown in Fig. 6. The interrupt service rountine reads the contents of counter 2 (Q_o) and hence calculates the value of ϕ. By this way the phase difference is measured each half cycle. The value of α

corresponding to the measured value of ϕ is read from a look-up table containing the relation between α and ϕ. The value of α is sent to the counter 1 which already programmed to operate in rate generator mode. At each crossover instants of the supply frequency counter 1 is initialized as shown in Fig. 7. The output of counter 1 gives the width of the firing angle α as shown in Fig. 6. It is clear that the synchronization with the supply frequency is kept easily by this method. By this way the value of α corresponding to any measured phase angle ϕ is generated with the first coming half-cycle.

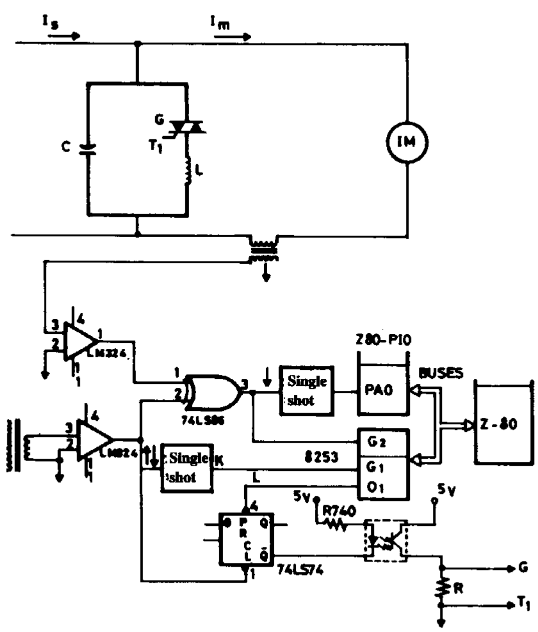


Fig. 6. FC-TCR circuit and the interfacing with the microprocessor

Performance of the Compensator

The above mentioned scheme was implemented to improve the power factor of a single phase (split phase type) 220V, 0.75 kW, 60 Hz induction motor. The laboratory tests were carried out to determine the motor performance. The power factor of this motor without compensator varied from 0.4 to 0.8 (from no load to full load).

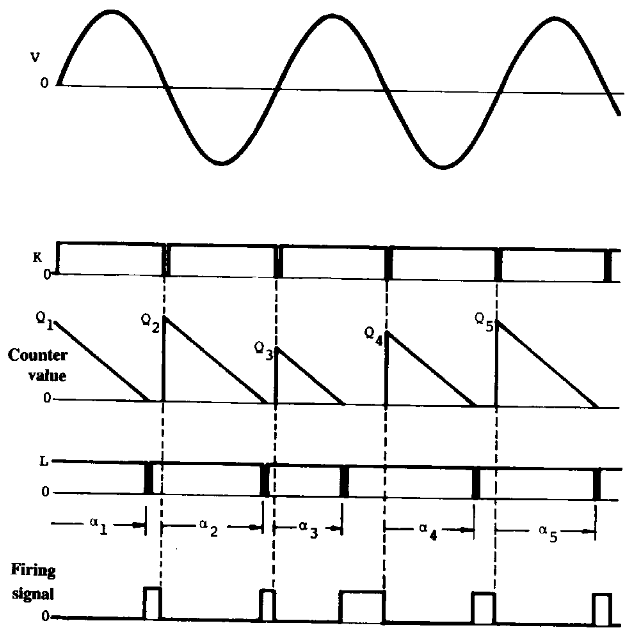


Fig. 7. Generating the firing signals

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. 8 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 of the compensator such that the displacement factor is equal to one. The power factor may be below unity depending upon the amount of harmonics in the supply current. The phase angle signal and the firing signal are shown in Fig. 9.

Fig. 10 shows the angle ϕ between V_S and I_S before and after compensation. It is clear from this figure that whereas $\phi = 60°$ and 30° for before compensation, its value is equal to zero after compensation.

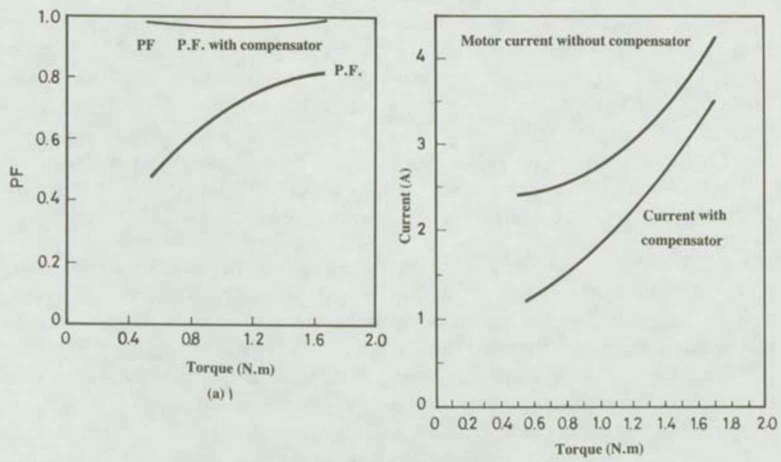


Fig. 8. Variation of
(a) power factor, (b) supply current with motor torque.

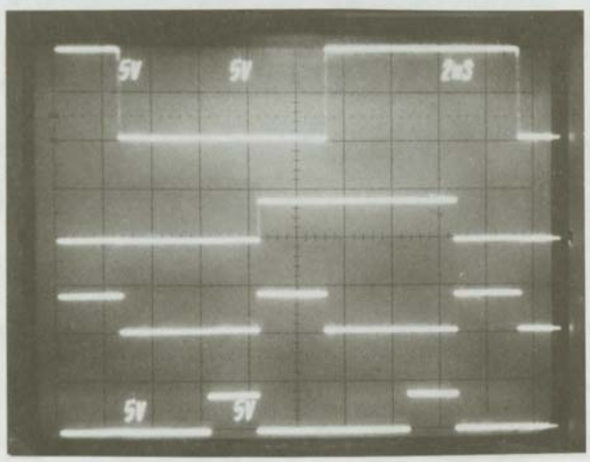


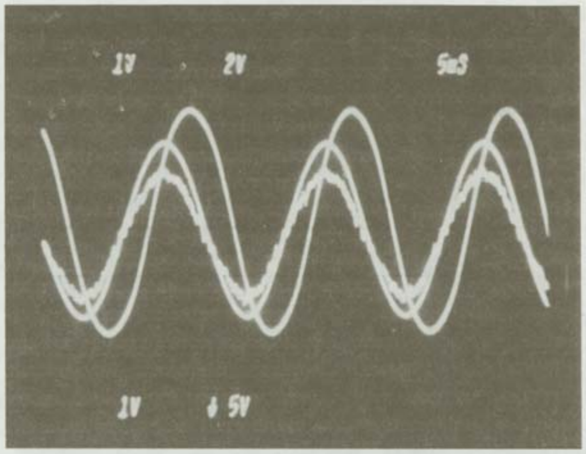
Fig. 9. Controller signals
(a) zero-crossing of motor current
(b) zero-crossing of supply voltage
(c) phase angle (ϕ) signal
(d) firing signal generated by the microprocessor.

Fig. 11 shows the oscillograms of the supply voltage and supply current for fast changing loading of the motor. It is clear that the supply current is in phase with the supply voltage all the time. Although, the change in the load and hence the phase-angle is in each half-cycle, the proposed system is keeping the unity power factor of the supply. Therefore, the response time of the system is less than 8.3 ms which is very fast for the AC power supplies. Also, this system is quite fast compared with that given in refs. [4,5] where the control circuitry of the first is based on analog devices and the second on a microprocessor beside analog devices.

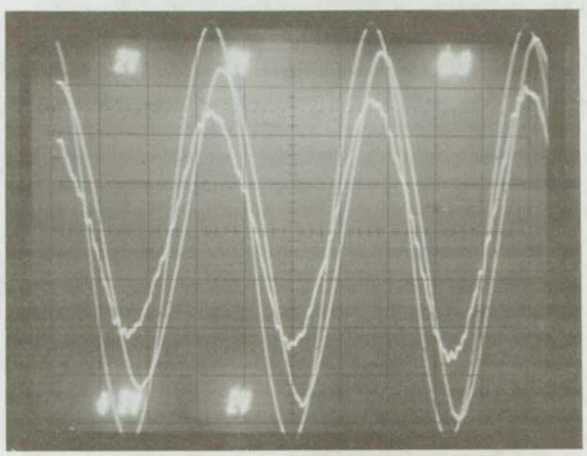
Fig. 10 shows the oscillograms of supply voltage, motor current and supply current with compensator. It is clear from Fig. 10 that with compensation the supply current and supply voltage are almost in phase. However, the supply current contains undesirable harmonics. There are two distinct causes of these harmonics. The higher frequency harmonics evident in the supply current are due to oscillations between the supply inductance and the compensator capacitor. Such harmonics are even present in the absence of thyristor controlled reactor. Therefore, such higher order harmonics are not introduced by the thyristors. These can be eliminated by introducing a suitable harmonic suppressor inductor in series with the fixed capacitor.

The second source of harmonics is the thyristor controlled reactor which introduces odd order harmonics for a single phase load. The magnitude of these harmonics descreases with the order of harmonic, which is clear from equation (4). Consequently, lower order harmonics are predominantly caused by the TCR. For a given motor, if a compensator is 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.

The most significant of these lower order harmonics may be eliminated by using LC tuned filters instead of fixed capacitors as discussed in ref. [6]. In such a scheme for LC brnach (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.

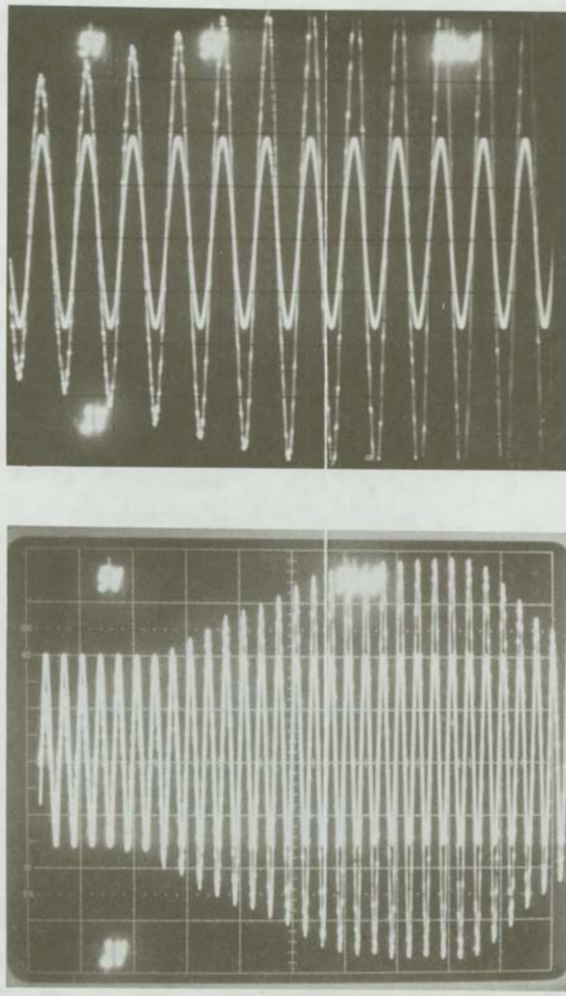


(a)



(b)

Fig. 10. Oscillograms supply voltage, supply current and motor current
(a) light load, (b) full load·



(a)

(b)

Fig. 11. Oscillograms of overall response of supply current for fast changing load (a) 20 mS/div (b) 50 mS/div .

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 as well. Such proposed scheme could be used to improve any dynamic load which the load phase angle is known. The response time of compensator for load changes is quite fast.

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تحسين معامل القدرة لمحرك حثي باستخدام المعالج الأصغر

خالد إبراهيم الدويش

قسم الهندسة الكهربائية، كلية الهندسة، جامعة الملك سعود، ص.ب ٨٠٠،
الرياض ١١٤٢١، المملكة العربية السعودية

ملخص البحث. يصف هذا البحث تصميم تحكم باستخدام المعالج الأصغر لمعوض قدرة رجعية من نوع مفاعل محكوم بالثايرستور لتحقيق تحسين فوري وسريع لمعامل القدرة عند أحمال متحركة. يقوم نظام المعالج الأصغر بمراقبة معامل القدرة للحمل ويستخدم جدول في الذاكرة لضبط معوض القدرة الرجعية كي يصبح معامل القدرة جهة منبع القدرة مساويا لواحد. تبين النتائج أنه يتم آليا تحقيق معامل قدرة يساوي الواحد عند كل أوضاع التحميل. كما تبين النتائج أن استجابة النظام سريعة جدا.