ENERGY DEVELOPMENT AND CONTROL OF ELECTRIC MOTORS AND DRIVES IN EGYPT USING MODIFIED CONVERTERS AND SVC

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ABSTRACT

Energy saving has been achieved by using different techniques to improve the power factor and energy efficiency to customers and to arrive to the best use of electricity. Integration of static VAR compensators (SVC) for power factor improvement is introduced with modified converter using switched - capacitor technique. Development of such techniques led to the requirement of many expertise teams for planning, field service and computer aided design (CAD) support to satisfy customer demand and industry requirement. Then, a more rational use of energy for sustainable development is achieved.

This paper adopts the above technique on a 3-phasc induction motor with modified phase controlled converter and SVC in cascade. The optimal power factor firing control is obtained taking into account the effect of commutation overlap between semiconductors. This work introduces firstly the concepts of concurrent and reengineering regarding energy development for industry and commerce by implementing new technologies and impact assessment policy. Then all energy measures focusing on cost saving for energy efficient motors are indicated. The role of enabling policies using energy more efficiently by modified converters and SVC for the electric motors and drives industry in Egypt is given. The adopted system is analyzed at different modes of operation to develop the control algorithm.

In conclusion, this work indicates the advantages of the proposed system for control and energy saving. Experimental as well as computer simulation shows the improvement of power factor. The paper highlights future aspect remarks of innovation and technological adoption for energy management development and control.

INTRODUCTION

Energy development and consumption is strongly related to country civilization and its technological level [1]. The importance of energy conservation, planning, management and control lies in the application of new trends and high technologies for energy - efficient economy. Efficient utilization of energy and optimal performance of electric motors has taken timely measures to cope with anticipated international developments [2]. Moreover, it is a permanent goal and a real challenge for Egypt to apply Total Energy Management (TEM) and Energy Management Systems (EMS) for energy cost saving as indicated in Fig. 1.

USAID'S Energy Conservation and Efficiency Program (ECEP) has assisted Egypt in implementing a wide variety of energy management and efficiency activities to reduce consumption and to improve saving.

Usually, in any electrical installation, there are non-linear loads beside linear loads. Static power converters, variable frequency drives, uninterruptible power supply (UPS), electrical heating, welding and traction drives create distortion and changes to the sinusoidal power supply and cause interference problems with the communication ad computerized equipment. It is important to search for improving the power factor and to eleminate current harmonics for energy saving and power quality improvement.

In this paper, a modified phase controlled converter is used to improve the power factor and efficiency of a 3-phase wound rotor induction motor as an example. Also, a static VAR compensator (SVC) or reactive power compensator (RPC) is designed using variable impedance technique to provide a wide angle of smooth control with fairly insignificant level of harmonics as another example. For the modified converter used in the first example, the optimal power factor firing control is obtained taking into account the effect of commutation overlap. With respect to the second example of the SVC, the optimum duty-cycle for VAR compensation is also determined. For the above two proposed systems, the analysis at different modes of operation is carried out to develop the control algorithm either for the modified converter (MC) or for the optimum design of the reactive power compensator (RPC). Experimental results give a good agreement with simulation analysis and indicates the improvement of power factor and efficiency as well as the elimination of harmonics.

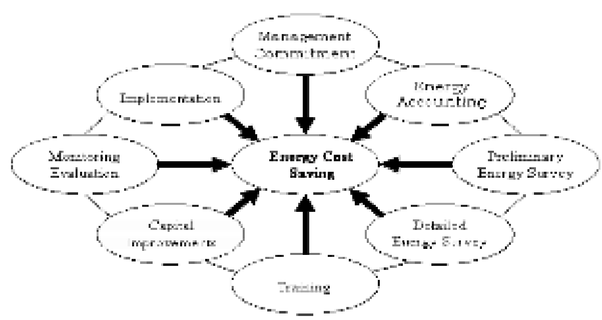


Fig. 1, Total energy management focuses on energy cost savings

ENERGY MEASURES FOR ELECTRIC DRIVES

Nowadays, the concept of energy measures for conservation and saving draws an increasingly attention from specialists of energy policy planning. The application of energy-efficient technologies using concurrent and reengineering as well as by using power conditioner equipment and automatically continuous process improvement are very important to improve economy, quality and production. The power conditioner equipment controls the electric power in distribution and industrial systems as shown by the two basic configurations in Fig. 2. The energy consumption of most equipment can be greatly reduced by introducing new efficient use technological adoptions [3]. The paper under consideration focuses on electric drives, which are common in many applications for their simplicity, long life reliability, low cost and facility for remote control. Fig. 3 illustrates the block diagram of an automatic electric drive system and its main elements. The electric power to the motor is controlled to achieve a specified characteristic waveform using a suitable type of semiconductor converter as shown in Fig. 4. Voltage and current source inverters (VSI, CSI) as well as pulse-width modulated (PWM) inverters have been utilized. The controller receives feedback signals, together with the reference or command signal to adjust the electronic converter using a microprocessor for manipulation and reliability.

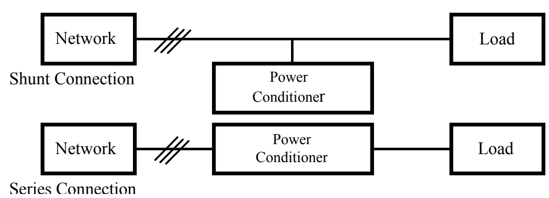


Fig. 2, Power conditioner topology variations

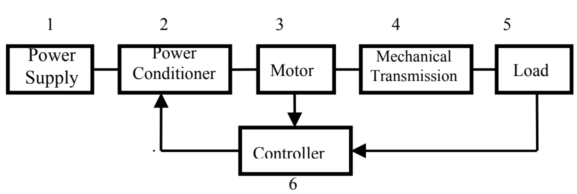


Fig. 3, Elements of an automatic electric drives system

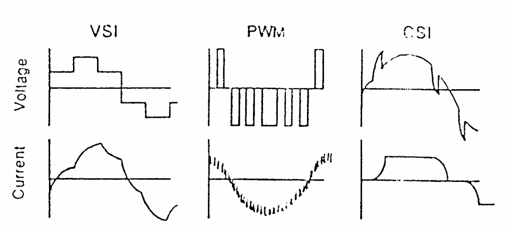


Fig. 4, Characteristic waveforms of step wave forming VSI & PWM and CSI

The use of electric drives is continuously expanding in all fields of industrial, commercial and other services activities such as electrified transport, agriculture, building construction, office ad home appliances. The rapid development in all these fields is accompanied by the use of automatic control systems for individual drive units as well as complete plants. Modem electric drives and production processes, combined with modern means of automatic control including automatic operation, regulation, and monitoring, present the following outstanding advantages :

- Productivity increase and hence a radical decrease in the production cost per unit.
- Consistent and high quality products.
- Minimum electrical energy consumption, and
- Improved working conditions in industry..

INDUCTION MOTOR MODIFIED CONVERTER CASCADE

The main circuit under consideration for slip-energy recovery system is shown in Fig. 5. A reduction of reactive power requirement is achieved by using a modified inverter with two auxiliary thyristors. This is accomplished by controlling the conduction period of each phase of the inverter and by transferring the ac current to the neutral by triggering alternately the auxiliary thyristors 7, 8. To guarantee the operation of auxiliary firing control δ, the main firing angle α must not be larger than 5 $\pi/6$

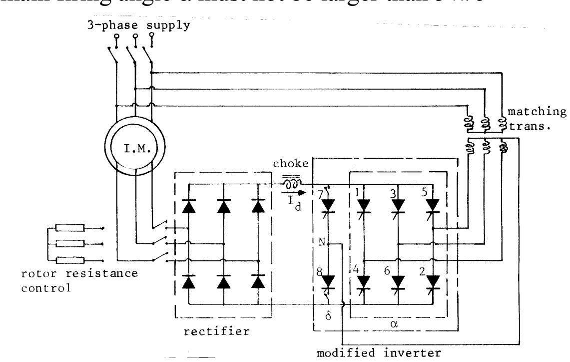


Fig. 5, Main circuit under investigation.

From the vector diagram of the modified system shown in Fig. 6, that by setting α equal to 5 $\pi/6$ and by varying the auxiliary firing angle δ, the power flow can be controlled.

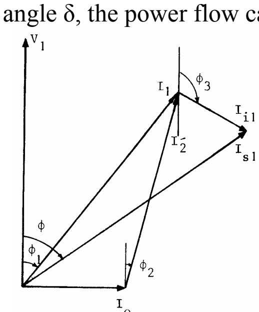


Fig. 6, Vector diagram of the system

For a desired speed, there is only one combination of α and δ which realize the optimal power factor operation [4]. Fig.. 7, shows the firing control strategy for optimal power factor together with the inverter power diagram. The reference signal, triggering pulses for main (α) and auxiliary thyristors (δ) as well as the d.c voltage are indicated in Fig. 8.
The performance of the system using modified converter compared with conventional methods is given in Figs. 9, 10, where the improvement of power factor and efficiency can easily be seen. Oscillograms of Figs. 1la,b and experimental values show good agreement with the analysis. It is notable that a fine control of firing of main and auxiliary thyristors are required during testing to ensure commutation. In this section, a modified converter slip energy recovery system is presented for reduction of reactive power demand over the operating range.

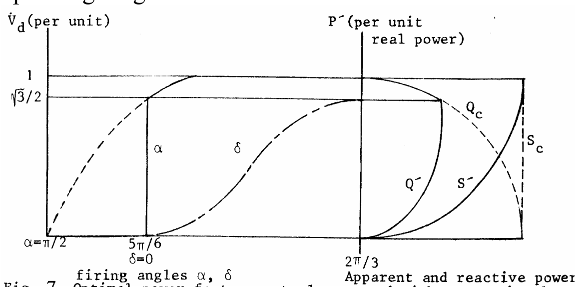


Fig. 7, Optimal power factor control compared with conventional type (c)

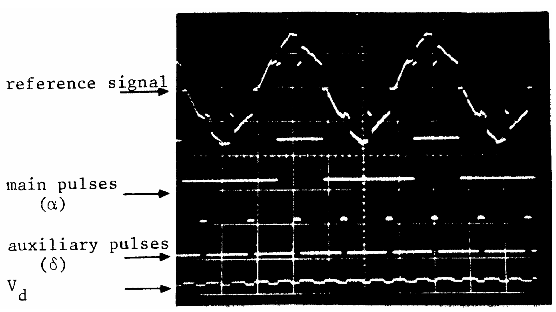
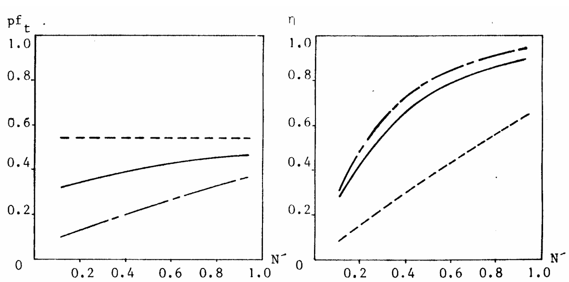
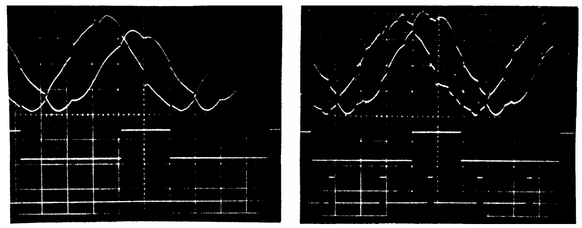


Fig. 8, Triggering pulses of main thyristors, auxiliary thyristors and dc voltage



Figs. 9 & 10, Power factor and Efficiency for full load

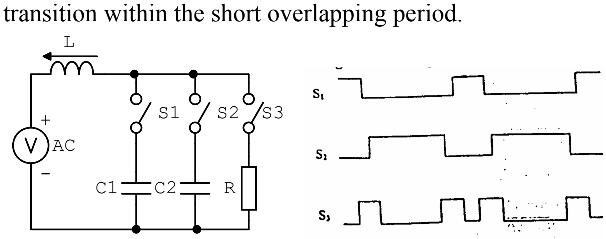
- - - - - - - Rotor resistance control
—·—·—·— Conventional cascade control
———— Modified cascade control



Figs. 11a & 11b, Phase voltage and current, Conventional (left) and modified (right) cascade system

STATIC VAR COMPENSATOR USING SWITCHED-CAPACITOR TECHNIQUE

In this technique, the triple switch-double capacitor configuration is developed to act as a variable capacitor depending on the switching duty-cycle and to provide a continuous reactive power generation. It provides an active input power factor correction for the supplies driving non-linear loads. The switched-capacitor reactive power compensator (SC-RPC) determines the optimum duty-cycle for compensation with fairly insignificant level of harmonics compared to passive filters. The triple switch circuit and its switching pattern are shown in Fig. 12a,b, where the switches S_1 and S_2, are allowed to operate in anti-phase fashion. The third branch is used to provide soft transition within the short overlapping period.



Figs. 12a & 12b Triple switch circuit and switching scheme

There are two important constraints for the circuit design :
1- The switching frequency should be selected relatively high typically 20 times the supply frequency.
2- The equivalent capacitive reactance (Xceq) is much greater than the inductive reactance (x_l) over the entire control range. Then, the triple switch is equivalent to a variable capacitance which is controlled by varying the duty-cycle. There is no resonance and the current is free of harmonics and always leads the supply voltage by nearly *π/2.* A complete simulation of the equivalent circuit model of the SC-RPC is shown in Fig. 13. It is carried out using the PSPICE as a CAD "tool and power MOSFET as a switch. The branch-ratio parameter (β) is the ratio between Xc_1 and Xc_2 for $C_1 = 40\,\mu F$, $C_2 = 80\,\mu F$, L= 10 mH and R= 10 ohm.

$$\beta = X_{C_1} / X_{C_2} = C_2 / C_1 \ , \quad \beta = 1,2,3,......$$

The switching functions controlling the switches S_1, S_2 can be expressed as [5] :
$SF_1 = \lambda$, $SF_2 = 1 - \lambda$

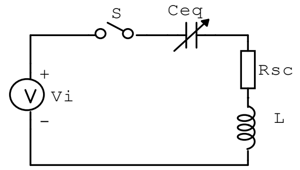


Fig. 13, The S.C RPC model

If the resistance is neglected in the voltage equation, then the optimum duty-cycle of the S-C RPC is obtained when maximum reactive power is generated from the compensator.

$$C_{eq} = (\beta/(\lambda^2\beta + (1-\lambda)^2)C_1$$

this gives $\lambda_{opt} = 1/(\beta + 1)$

A simulation program describing the non-linear load is used specifying the control parameters and using PSPICE to compute the fourier components of the input current. The non-linear load is composed of a full controlled thyristor bridge rectifier supplying a conventional R - L load.

The input P.F. = Displacement factor (D.F.) x Harmonic distortion factor (H.F.). $= \cos\phi\left[1 + (THD)^2\right]^{-1/2}$

$$\delta = \cos^{-1} P.F, \quad Q_L = S.\sin\delta = F(\alpha)$$

Where q_l is the reactive power of the non-linear load, S is the apparent power. The principal idea to bring the displacement factor nearby unity is to neutralize the effect of the reactive power associated with the non-linear load.

The compensated system equation $f(\lambda) = |f(\alpha)|$

Gives, at least, one optimum duty-cycle with the proper compensation margin. For the above example, the dynamic control parameter is chosen for $\alpha = 50°$ (between 0, $\pi/2$ as a rectifier mode). Type 3 is selected where the roots of the compensated system equation:

$\lambda_1 = 0.4626$, $\lambda_2 = 0.0428$.

The first root is selected to tune the S-C RPC, where he input power factor has been seriously improved from 0.7713 to 0.9923 by compensation. Figures 14a,b and 15a,b show the simulation and experimental results of supply voltage and current before and after compensation which clearly indicates the improvement of the power factor.

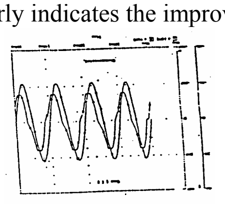


Fig. 14a, Supply voltage and current before compensation

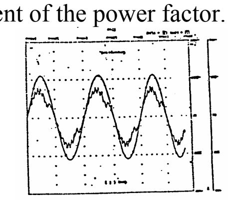


Fig. 14b, Supply voltage and current after compensation

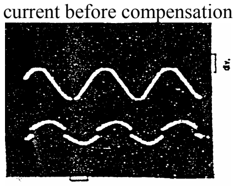


Fig. 15a, Experimental waveforms before compensation

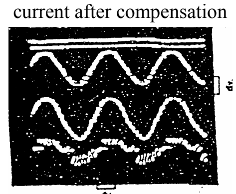


Fig. 15b, Waveforms of S_1, supply voltage, and current after comp.

CONCLUSION AND RECOMMENDATIONS

The development of energy conversion technologies, conservation, management and control strategies for electric motors and drives in Egypt is given. Reduction and/or compensation of reactive power is achieved by using auxiliary firing in the modified converter slip-energy recovery cascade system. The results of the analysis is confirmed experimentally which indicates that the circuit is safe, flexible and reliable for practical purposes. In the second case study, a complete CAD technique was presented to compensate the reactive power associated with the non-linear load using switched-capacitor reactive power compensator (S-C RPC). The optimum duty-cycle of the compensated system is determined for the active power neutralization technique. The reliability of this system is suitable to be applied by consumers for any piece of machinery or even to factory and home appliances to improve the power factor of the public network.

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