Load Voltage Stabilization Based On The Series Compensation

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Abstract:

Power factor is related to line current harmonics, many types of filters are used to improve the input power factor. Some of these circuits are used to eliminate the line current harmonics and others are used to compensate the reactive power , hence they improves the input power factor. This paper introduces a series compensation by using controlled capacitor in series with static /dynamic load. The proposed system improves the input power factor, reduces the input line current harmonics and can be operate as voltage controller to regulate the load voltage without discontinuity in the current. The proposed system can be operated as boost regulator. Hystersise controller and PI controller are used to control the power electronic elements operation to control the capacitor effect. Simulation and experimental results are in good agreement and show the effectiveness of the system with static or dynamic loads.

Introduction:

Solid state control of ac power using thyristor and other semiconductor devices is in an extensive use in a number of applications such as adjustable speed drives and furnaces. These power converters behave as nonlinear loads with respect to ac supply system and cause harmonic injection, lower power factor and poor voltage regulation.

Power factor correction is related to line current harmonics, several alternatives are available in order to improve the input waveforms quality of power converters. Passive and active power factor correction circuits have been explored. Passive circuits which use passive filters at the front end of the converter require a large inductor[1]. Also, these circuits have some limits as the power can not exceed 1.2 kw if the current harmonics must respect to the European standards. Due to their smaller size and lower cost, active power factor correction circuits are more adapted to different applications than passive circuits. The shunt-active filter can easily eliminate high frequency current ripples accompanying ac/dc power conversion, however, it is difficult to reduce low frequency current ripples caused by a supply voltage flicker[2-4] .

Recently, some resonant converter topologies with a fixed frequency operation and PWM control have been proposed. Series resonant inverters using the principle of phase-shift with zero voltage switching have been very attractive and widely used in industrial applications. By using an integral feedback control compensation a high precision has been achieved. Current driven resonant converters use bi-directional voltage switches as a series combination of a controllable switch and diode gives a noticeable improvement . The conscious control of energy storing and restoring processes allows more efficient application of inductor and capacitors[5-7].

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Using controlled capacitor/ inductors can generate not only positive inductance which exists naturally, but can also produce negative reactance that cancels undesired inductance included in transient state of the system. Negative inductance can decrease the circuit impedance without any additional complicity [8].

In order to improve the supply quality and power factor, controlled capacitor used in series with inductive load (static or dynamic). The proposed system can operate as ac voltage controller to control the load voltage without any discontinuity in the supply current, also it can operate as boost ac chopper when the capacitor reactance is greater than the circuit inductive reactance. Using controlled capacitor in the proposed system improves the transient performance of the dynamic loads, also the proposed system used the series compensation technique to improve the supply quality.

System description:

The proposed system is shown in fig.(1), the supply impedance is taken into account, the load is inductive static or dynamic load. Series controlled capacitance used to eliminate the load and supply inductance effect without any discontinuity in the supply current. The capacitance effective value can be controlled from zero to maximum value through four IGPT's. Analog drive circuit is used to generate tow groups of pulses to control the IGPT's operation. Control voltage will control the duty cycle of pulses to control the capacitor current. Maximum value of the capacitor can be calculated from:

$$C = \frac{1}{X_t \cdot \omega} \quad (1)$$

Where : ω is the angular frequency

X_t: is the total equivalent series inductance of the load and supply

The system can be operated at lagging power factor ($x_t > x_c$) , with low duty cycle, or at leading power factor ($x_t < x_c$), with high duty cycle . There are two modes of operation, the first is charging mode where Q_1 and Q_3 are switched on (Q_2 and Q_4 are off). The capacitor current is the supply current so:

$$V_s = i \cdot R_t + L_t \cdot \frac{di}{dt} + V_c$$
$$V_s = i \cdot R_t + L_t \cdot \frac{di}{dt} + \frac{1}{c} \cdot \int i \cdot dt \quad (2)$$

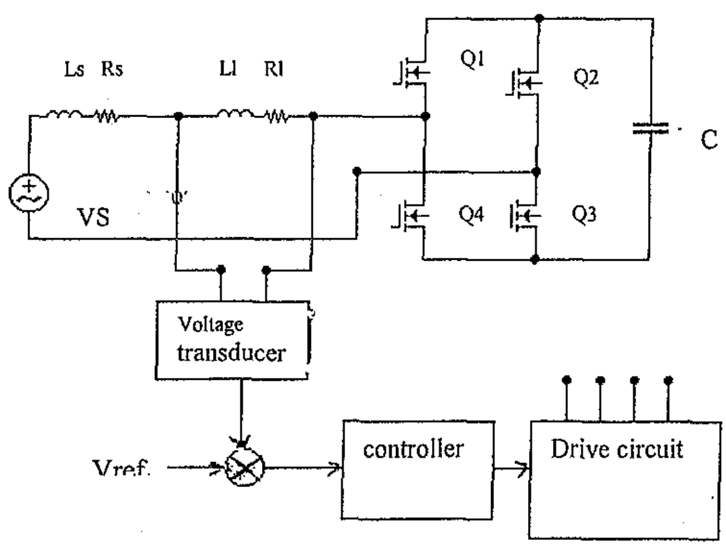


Fig.(1) The proposed system

When Q_1 and Q_3 are switched off, Q_2 and Q_4 are switched on and the capacitor voltage opposes the supply voltage (discharge mode) so:

$$V_s = i \cdot R_t + L_t \cdot \frac{di}{dt} - V_c \qquad (3)$$

The system parameters are shown in the appendix. The drive circuit generates two groups of pulses where each pair of IGPT is switched alternatively. The duty cycle can be varied by varying the control voltage and compared with saw-tooth carrier waveform, to generate the required pulses. The block diagram of the driving circuit is shown in fig.(2)

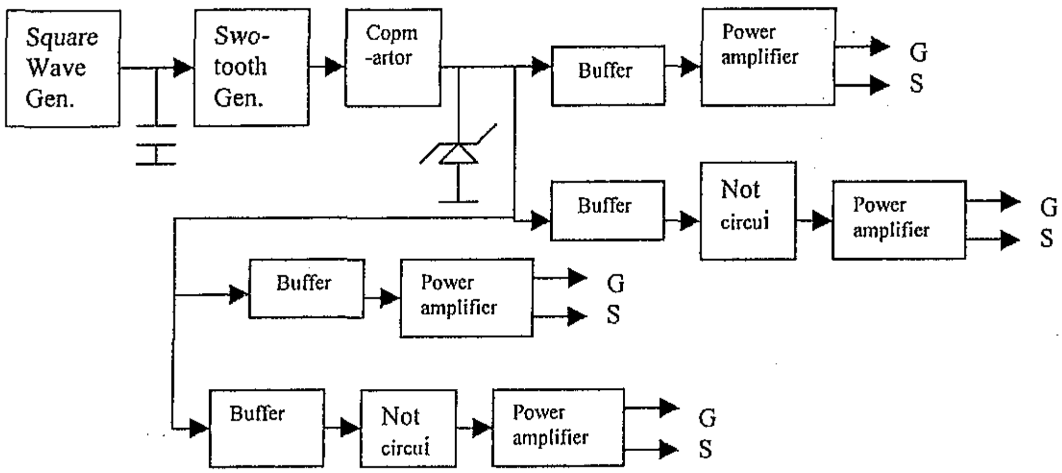


Fig.(2) Drive circuit block diagram

The capacitor-run single- phase induction motor seems to be one of the most appropriate system for variable speed fractional horse power drives. Control of applied voltage is a simple method for changing the capacitor–run motor speed, so stabilization of the motor applied voltage will fixes the motor speed.

For running capacitor motor, the motor equations in d-q axis (fig. 3), can be written as follows:

$$V_m = i_m \cdot R_m + L_m \cdot \frac{di_m}{dt} + M \cdot \frac{di_\alpha}{dt}$$

$$V_m - V_c = i_a \cdot R_a + L_a \cdot \frac{di_a}{dt} + A_s \cdot M \cdot \frac{di_\beta}{dt}$$

and

$$0 = M \cdot \frac{di_m}{dt} - A_s \cdot M \cdot i_a \cdot \frac{d\theta}{dt} + i_\alpha \cdot R_r + L_r \cdot \frac{di_\alpha}{dt} - L_r \cdot i_\beta \cdot \frac{d\theta}{dt}$$

$$0 = M \cdot i_m \cdot \frac{d\theta}{dt} + A_s \cdot M \cdot \frac{di_a}{dt} + L_r \cdot i_\alpha \cdot \frac{d\theta}{dt} + R_r \cdot i_\beta + L_r \cdot \frac{di_\beta}{dt}$$

The capacitor voltage is:

$$V_c = \frac{1}{c} \cdot \int i_a \cdot dt$$

the instantaneous electromagnetic torque may be expressed in terms of substitute variables as:

$$T_e = p \cdot M \cdot (i_\beta \cdot i_m - i_\alpha \cdot i_a \cdot A_s)$$

the mechanical equation of the motor is:

$$J \cdot \frac{d\omega_r}{dt} = T_e - T_l - k \cdot \omega_r$$

the present model is valid for both steady- state and transient conditions.

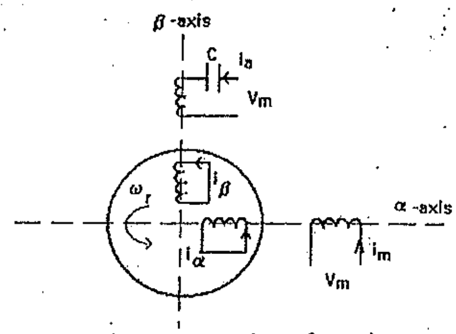


Fig.(3) d-q axis representation of running capacitor single phase induction motor

Controller:

The performance of the inverter system largely depends on the quality of the control strategy. Therefore, current control of PWM inverter is one of the most important subjects of modern power electronics. A variety of control methods had been studied and reported in [10-12].

The hysteresis control scheme provides appropriate dynamic performance because it acts quickly. The technique does not need any information of the system parameters. In order to form a sinusoidal output waveform, the inverter switches are driven in such a way that the output voltage is confined between the two sinusoidal waves:

$$\frac{V_m}{K_p} \sin \omega \cdot t + \frac{H}{2},$$

$$\frac{V_m}{K_p} \sin \omega \cdot t - \frac{H}{2}$$

where: K_p is the sensing control circuit coefficient

H is the hysteresis band.

The hesteresis band can be programmed as a function of the load and supply parameters in order to maintain a fixed modulation frequency. Figure (4) , shows the block diagram of the hysteresis controller.

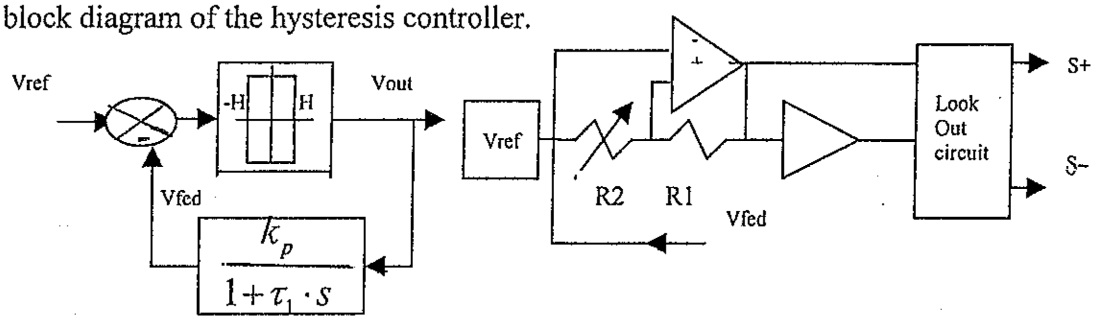


Fig. (3) Hysteresis controller block diagram and electronic circuit

The results gives the performance of the described system for $K_p = 1$, $H = 0.5$,it is noticed that the controller output is used to maintain the output voltage in the tolerance band.
The closed loop with PI controller is used for stabilization of load voltage. Fig.(4), shows the PI controller block diagram for closed loop control. Where, feed back voltage is compared with the reference voltage. Error is fed to the integral unit to give signal U that compared with the same feed back voltage, the result signal is fed to the proportional unit. The control voltage is responsible for changing the duty cycle of switches operation to control the capacitor value that stabilize the load voltage at the value corresponds to the reference voltage, the controller represented by :

$$\tau_1 \cdot \frac{du}{dt} = V_{ref} - K_v \cdot V_l$$

and

$$V_c = K_1(U - K_v \cdot V_l)$$

The controller parameters are calculated from the open and closed loop transfer functions of the controller.[12]

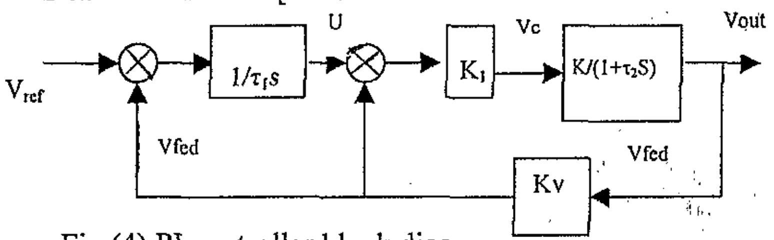


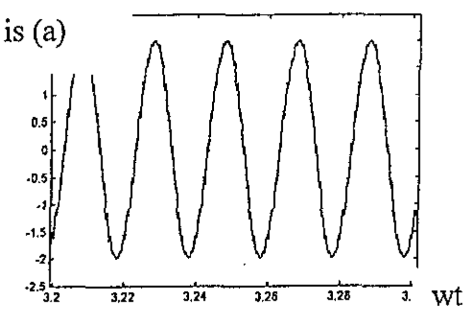
Fig.(4) PI controller block diagram

Simulation and Experimental Results:

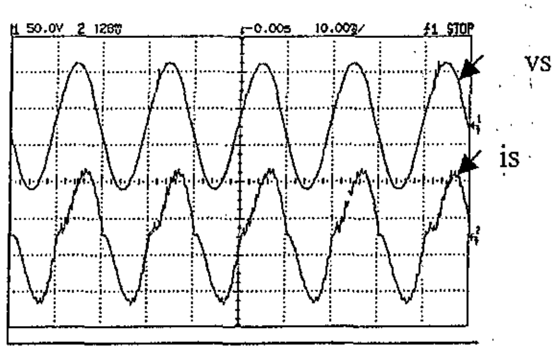
Simulation results of the system in open and closed loop is obtained with simulink program . Analog circuits of Hysteresis , PI controller and drive circuit of the switches are built and tested in the laboratory with prototype system to obtain the exprimental results.

1-Static load:

Figure(5), shows the simulation and experimental waveforms of the supply current, fig.(6) shows the load current and voltage for the same condition. It is noticed that the supply current is nearly sinusoidal and changing the duty cycle of the switches operation will change the currents waveforms.

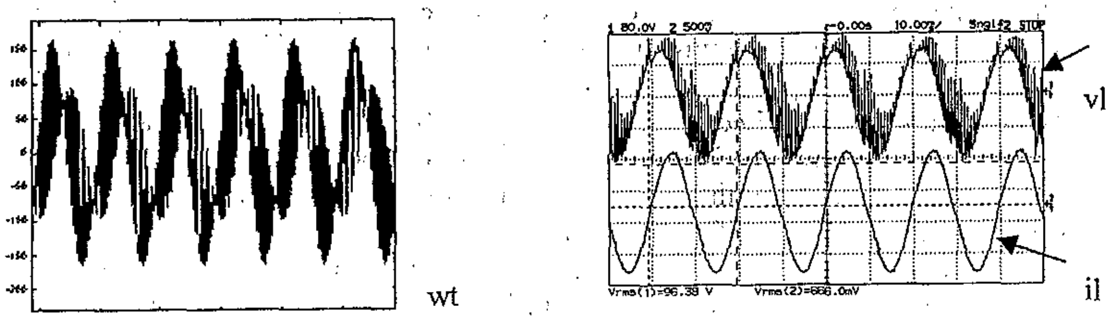


a-Simulation



b- Experimental

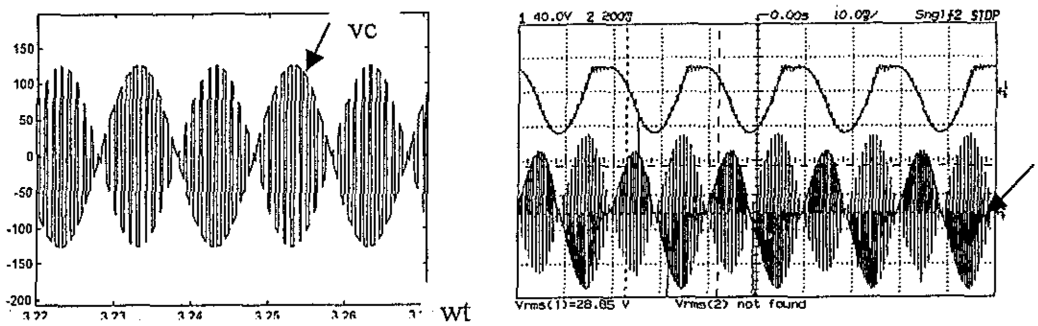
Fig.(5) Supply current with hystersis controller



a-simulation b- experimental

Fig.(6) Load current and Voltage

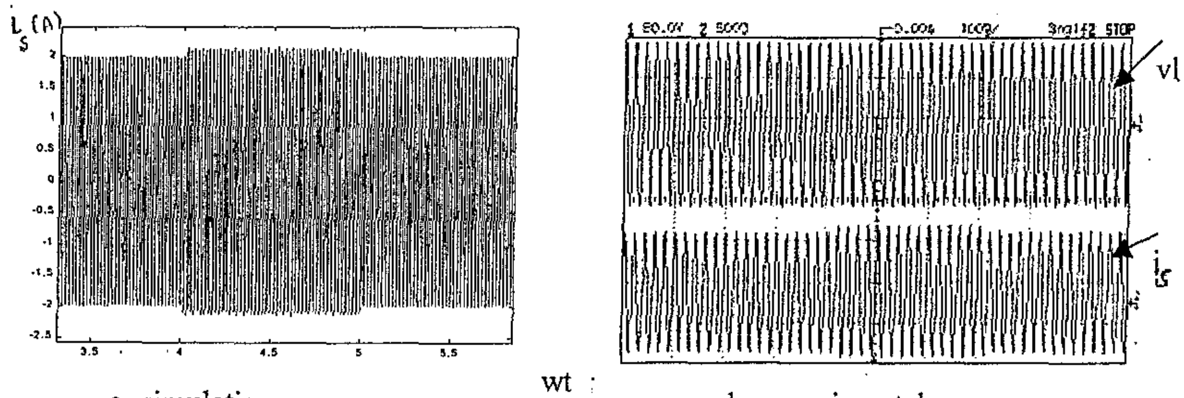
Figure (7) shows the capacitor voltage and current in steady state operation with static load and PI controller with load voltage as feedback. It is noticed that voltage is ac voltage because the capacitor will charge as the IGBT are on and discharge through unti-parallel diodes in the same half cycle of the supply voltage as the IGBT are off. To stabilize the load voltage, the capacitor current may be unsymmetrical during the same half cycle.



a- simulation b- experimental

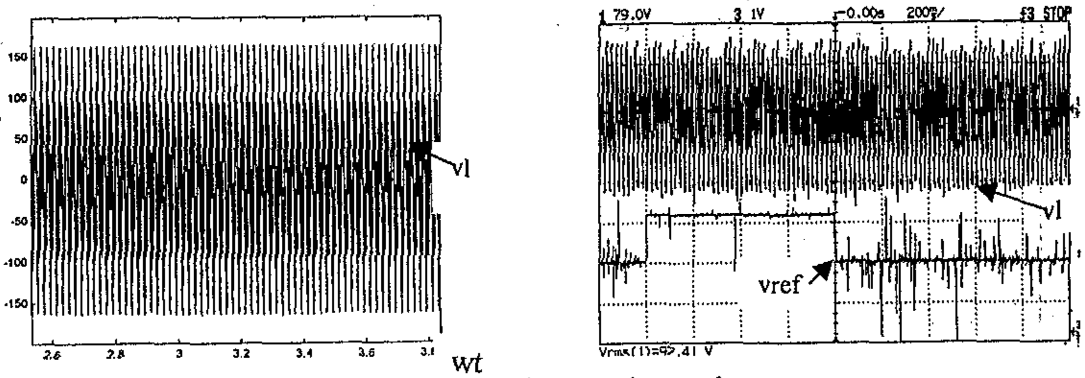
Fig.(7) Capacitor voltage and current

During step change in the load by increasing or decreasing the load current within certain limits 15% of the full load value the proposed system will keep the load voltage constant as shown in fig.(8). As the reference voltage increase or decrease within certain limits (25%) the stored energy in the capacitor will compensate the load voltage to remain constant as shown in fig.(9). From simulation and experimental results it is noticed that the load voltage will be stabilized as the load or reference voltage changed



a- simulation b- experimental

Fig.(8) Supply current with step change in the load 15 %



a- simulation b- experimental

Fig.(9) Load voltage with step change in the reference voltage 25%

The load voltage stabilization is achieved by closed loop control system. In open loop system the change of capacitor value will change the load voltage and the load current as shown in fig. (10). Also, the capacitor value depend on the load parameters, as the load impedance changing the capacitor value must be changed as shown in fig.(11)

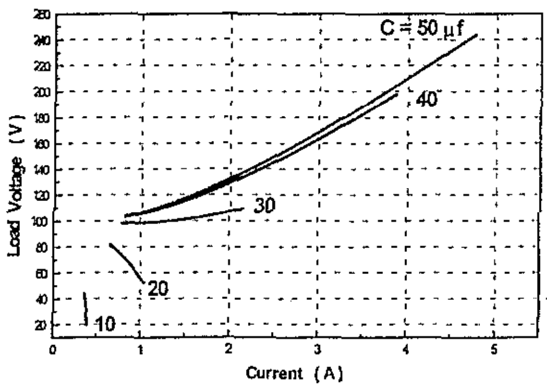


Fig.(10) relation between load voltage and current at different C

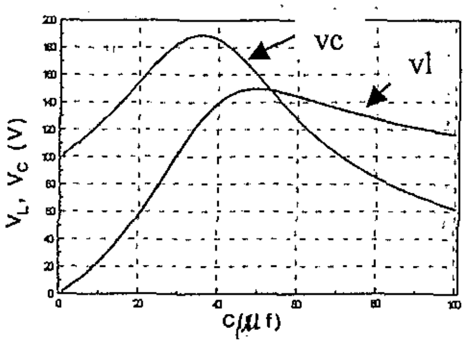
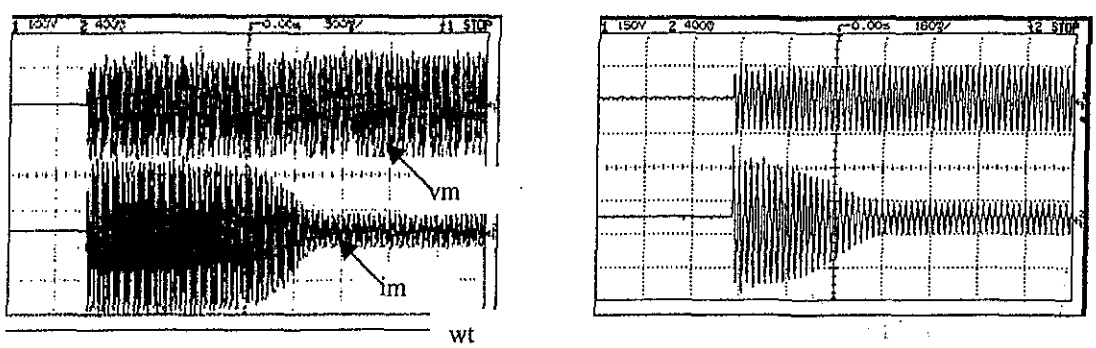


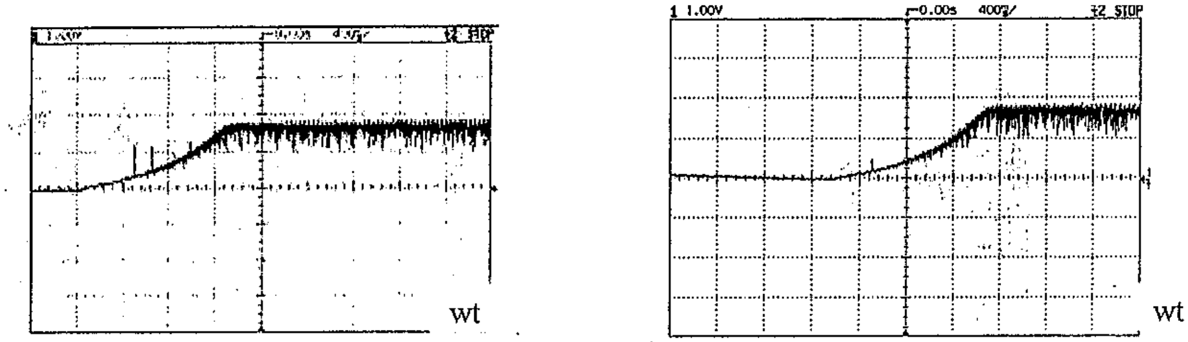
Fig.(11) relation between capacitor value and load, capacitor voltage

Single phase induction capacitor- run motor (parameters in appendix) is used as load in the proposed system . the motor performance in run up period is shown in figs(12-13). From figures, the motor run up period with PI controller is less than open loop condition. Speed oscillation in closed loop is less than in open loop.



a-Without controller b- with PI controller

Fig.(12) Motor voltage and current during starting(experimental)



a- Without controller b- with PI controller

Fig.(13) Motor speed response (experimental)

Conclusion:

The proposed system used controlled capacitor as series compensator to reduce the supply current harmonics and improve the input power factor. With PI controller and load voltage feedback the proposed system stabilizes the load voltage. The proposed system can also operate as voltage controller to regulate the load voltage without discontinuity of the supply current. The capacitor value affects in the system performance. When the capacitor value is greater than the total system reactance, the proposed system operates as boost voltage regulator. Series compensation with proposed technique improves the dynamic performance of the dynamic loads.

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Appendix:

F : is the supply frequency =50 Hz

V : r.m.s supply voltage = 100 v

R_S : the supply resistance = 5 Ω

L_S : the supply inductance =0.05 H

R_l : the load resistance =35 Ω

L_l : the load inductance =0. 155H

C : maximum value of controlled capacitance = 50 μ f

For single phase running capacitor induction motor

L_m : the motor inductance = 62.5 mH

R_m : *the motor resistance* = 78 Ω

B : the motor frication coefficient = 0.001

J :is the motor inertia constant = 0.005

C: running capacitor = = 7 μ f