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Reactive Power Control Scheme Based On Correlation Coefficients for Voltage and Current Signals

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.***Abstract*:** In modern digital protection and control systems, a correlation technique has recently become the workhorse of quantitative research and analysis. In this paper, a correlation technique is developed for calculation of original power factor on-line, active and compensation reactive powers and determination of the required number of capacitor banks to get the desired power factor. Cross-correlation coefficients are calculated between phase voltage and current signals of power supply. The proposed technique is able accurately to identify the required capacitor rating to get the desired power factor under different loading levels. The suggested technique performs the task of cross-correlation coefficients calculations within one-cycle. Thus, the algorithm is well suited for implementation in a digital reactive power control scheme. Alternative transient p

***Keywords*:** power system, power factor correction, correlation coefficient, Reactive power control relays, ATP software, MATLAB.

I. Introduction

Power Factor (PF) Is A Measure Of Electrical Efficiency And Is Given By The Ratio Of Active Power Consumed By The Load To Apparent Power Delivered To The Load. The Power Factor Is Also Calculated As The Cosine Of The Angle Between The Active Power And Apparent Power. The AC Waveforms Of Voltage And Current Also Calculates The Power Factor As The Cosine Of The Angle, However This Time The Angle Is The Difference Between Zero-Crossing Positions Of Each Waveform On The X-Axis. It Varies With Load And It Has A Value From 0 To 1.

It Is Important To Know That In Power Factor Improvement, The Reactive Power Required By The Load Does Not Change. It Is Supplied By Some Device In Local. For The Dimensioning Of The Capacitor Bank To Be Installed In Order To Improve The Power Factor Of A Plant, It Is Necessary To Calculate Correctly Power Factor According To The Consumption Or To The Load Cycle Of The Plant. To Carry Out Distributed Or Group Power Factor Correction, It Is Necessary To Calculate The *Cos(Φ)* Of The Single Load Or Of The Group Of Loads; This Can Be Carried Directly, Through Direct Measuring By Means Of A Power Factor Meter Or Indirectly, Through The Reading Of The Active And Reactive Energy Meters Or Through The Reading Of The Voltmeter, Ammeter And Wattmeter.

Improving Energy Efficiency Is One Of The Key Goals Of Smart Grid Initiatives Across The Globe. In Practice, A Significant Portion (5-10%) Of Generated Energy Is Lost In Transmission And Distribution (T&D) System. In Some Countries Like India T&D Loss Is As High As 26% [1]. Hence, There Is Immense Potential To Improve The Energy Efficiency By Minimizing The Transmission And Distribution Loss In The Grid. Power Factor Correction Not Only Reduces System Loses But Also Releases System Capacity And Improves Voltage Regulation Which Enables The Utility To Provide Cheaper And Easier Services Of The Quality Desired In Modern Industry [2][3]. Power Factor Correction (PFC) Schemes [4] Have Been Proposed For Quite Some Time In The Field Of Power Electronics. The Main Aim Of This PFC Has Been To Reduce Total Harmonic Distortion (THD) And Thereby Improving The Power Factor. Recently, There Is A Growing Trend For Providing Incentive For Good Power Factor And/Or Penalty For Poor Power Factor. Similarly Power Factor Correction Can Also Be Achieved Using Other Equipment Like Battery Energy Storage System (BESS) [5]. The Paper In [6] Introduces An Approach Method DC-Modulation That Implements DC/DC Conversion Technology Into The AC/AC Converters. The DC-Modulated Single-Stage Power Factor Correction AC/AC Converters Effectively Improved The Power Factor Up To PF = 0.999 And The Power Transfer Efficiency Up To 97.8 %. A New Digital Control Strategy Of Parallel Duty Cycle Control (PDC) For Power Factor Correction (PFC) Is Presented And Analyzed In Paper [7]. Based On This Control Strategy, The Duty Cycle Determination Algorithm Includes The Current Term And The Voltage Term, Which Can Be Calculated In Parallel. So, As Compared Conventional Digital PFC Control Methods, The PDC Control Can Achieve Higher Switching Frequency, Lower Cost, Lower Calculation Requirement And Better Performance. Paper [8] Introduces A Single-Phase Digital Power-Factor Correction (PFC) Control Approach That Requires No Input Voltage Sensing Or Explicit current-loop compensation, yet results in low-harmonic operation over a universal input voltage range and loads ranging from high-power operation in continuous conduction mode down to the nearzero load. The controller is based on low-resolution A/D converters and digital pulse width modulator, requires no microcontroller or DSP programming, and is well suited for a simple, low-cost integrated-circuit realization, or as a hardware description language core suitable for integration with other power control and power management functions. The method introduced in paper [9] analyzes and studies the Active Power Factor Correction (APFC) based on the three-phase rectifier. The results of APFC showed that the grids-side input current wave is changed with a sine wave, has the same phase with the grid-side input voltage wave. Another proposed scheme avoids use of additional costly hardware like capacitor/inductor bank. This scheme achieves power factor correction with minimal extra hardware through intelligent scheduling of electrical loads [10]; this is processed by using capacitive loads located in power system. A conceptual design of microcontroller based Automatic Power Factor Correction (APFC Relay) is proposed in [11]. The design of this auto adjustable power factor correction is to ensure the entire power system always preserving almost unity power factor and thus optimizing the current consumption and compared with predetermines reference value. The method in [12] presents the design, development and implementation of active power factor corrector comprising microcontroller based hardware and compatible software which will be able to control the power factor of both linear and non-linear loads.

This paper proposes a reactive power control scheme based on correlation technique. The technique measures phase voltage and line current drawn from power supply. It calculates cross-correlation coefficients between the phase voltage and line current for power factor correction. The control scheme inserts the required capacitor banks to get the desired power factor. The suggested technique can operate accurately during one-cycle period of the fundamental frequency.

Proposed technique

In this paper, ATP software [13] is used to get reliable simulation results before, during and after capacitor bank insertion for power factor correction. The suggested reactive power control scheme is based on correlation concept [14-15] in order to determine the current power factor of power system and improve poor power factor. Phase voltage and current signals of power supply are obtained and stored in a file; this data is in the discrete sampled form. These voltage and current samples are processed in MATLAB to estimate cross-correlation coefficients between them.

Basic principle

Correlation is the cosine of the angle between the variables as vectors of mean-deviation data [16-19]. Cross-correlation detects any phase difference between any two electrical signals in power system; thus it is a good tool to propose a technique for making reactive power control relay against poor power factor, where the calculated cross-correlation between voltage and current signals can recognize a phase shift between them and to operate in response to it.

Correlation Coefficients Calculation

The cross-correlation coefficient (r_s) is calculated between two windows in the two sampled signals obtained from two different transducers or directly from electric circuit, where the two windows are shifted from each other with a time interval $h\Delta t$. The cross-correlation function of two signals (v_s and i_s) is given by Equation (1). Our proposed technique uses the two signals shifted from each other when the time interval $h\Delta t = 0$, where $h = 0$ (h is the number of samples between the two windows which are shifted from each other and Δt is the time interval of one sample).

$$r_s = \frac{\sum_{k=1}^{m} v_s(k) i_s(k+h\Delta t) - \frac{1}{m}\sum_{k=1}^{m} v_s(k)\sum_{k=1}^{m} i_s(k+h\Delta t)}{\left(\sqrt{\sum_{k=1}^{m}(v_s(k))^2 - \frac{1}{m}(\sum_{k=1}^{m} v_s(k))^2}\right)\times\left(\sqrt{\sum_{k=1}^{m}(i_s(k+h\Delta t))^2 - \frac{1}{m}(\sum_{k=1}^{m} i_s(k+h\Delta t))^2}\right)} \quad (1)$$

This technique estimates cross-correlation coefficients between phase voltage and current signals (v_s, i_s) at power supply side; these coefficients are considered as the cosine of the angle difference, $cos(\varphi)$, between the two signals. Correlation coefficient is a dimensionless quantity and it does not depend on the units employed. The value of correlation is such that $-1 \leq r_s \leq +1$.

Power Factor Correction Procedures

Flow chart for reactive power control scheme algorithm based on correlation technique is shown in Fig. 1. The algorithm has the following procedures:

1- Read discrete sampled voltage and current signals (v_s and i_s) for phase ''s'' at power supply terminals (obtained from ATP tool).

2- Calculate cross-correlation coefficient (r_s) (by using MATLAB tool), Cross-correlation coefficient (r_s) is estimated between *m* samples for a phase ''*s*'' voltage (v_s) signal and the corresponding *m* samples for the same phase ''*s*'' current (i_s) signal at power supply side. The selected *m* samples are the number of samples per cycle which are used as a correlated window in our algorithm to obtain and correct the original power factor. The proposed algorithm calculates cross-correlation coefficient (r_s) as shown in Equation (2).

$$r_s = \frac{\sum_{k=1}^{m} v_s(k) i_s(k) - \frac{1}{m}\sum_{k=1}^{m} v_s(k) \sum_{k=1}^{m} i_s(k)}{\left(\sqrt{\sum_{k=1}^{m}(v_s(k))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} v_s(k)\right)^2}\right) \times \left(\sqrt{\sum_{k=1}^{m}(i_s(k))^2 - \frac{1}{m}\left(\sum_{k=1}^{m} i_s(k)\right)^2}\right)} \quad (2)$$

Where,
r_s: Cross-correlation coefficient estimated between *m* samples for a phase ''*s*'' voltage (v_s) signal and the corresponding *m* samples for the same phase ''*s*'' current (i_s) signal at power supply terminals.
s: the phase designation *A, B or C*.
m: the number of samples per window to be correlated used in the algorithm (N = the number of samples per cycle, $N = m$ selected in our algorithm).
$v_s(k)$: the sampled voltage values at instant *k* measured at power supply terminals of phase ''*s*''.
$i_s(k)$: the sampled current values at instant *k* drawn from power supply of phase ''*s*''.
3- Obtain the original power factor,

$$P.F. = Cos(\phi_1) = r_s \quad (3)$$

4- Determine the original maximum values of sampled voltage (v_s) and current (i_s) signals (for each cycle) for phase ''*s*'', v_{smax} and i_{smax}, respectively.
5- Calculate the active power (p_s), out from power supply, for phase ''*s*'' by using the calculated cross-correlation (r_s) and the maximum values (v_{smax} and i_{smax}) of voltage and current signals; this is processed for each cycle).

$$p_s = \frac{v_{s\max} \times i_{s\max}}{2} \times r_s \quad (4)$$

6- Calculate the reactive power compensation (Q_c) to get the desired power factor by using Equation (6), which is derived as follows:

$$Q_c = k_1 \times p_s \quad (5)$$

$$k_1 = \tan(\phi_1) - \tan(\phi_2)$$

$$k_1 = \tan(\cos^{-1}(r_s)) - \tan(\phi_2)$$

$$Q_c = [\tan(\cos^{-1}(r_s)) - \tan(\phi_2)] \times \left[\frac{v_{s\max} \times i_{s\max}}{2} \times r_s\right] \quad (6)$$

When the desired *P.F.*= *cos*(ϕ_2) *= 1, then tan*(ϕ_2) *= 0, Then*

$$k_1 = \tan(\cos^{-1}(r_s))$$

$$Q_c = \tan(\cos^{-1}(r_s)) \times \left[\frac{v_{s\max} \times i_{s\max}}{2} \times r_s\right] \quad (7)$$

$$C_r = k_2 \times p_s \quad (8)$$

$$k_2 = \left[\frac{k_1}{(2\Pi f \times (v_{srms})^2)}\right]$$

$$k_2 = \left[\frac{k_1}{(\Pi f \times (v_{s\max})^2)}\right]$$

Where,
k_1 = a factor depends on the original and desired power factors.
k_2 = A factor depends on the original and desired power factors, the magnitude and frequency of phase voltage.
C_r = required capacitance in Farad to obtain desired *PF*.

$\Phi 1 = \mathrm{Cos}^{-1}(r_s)$, (where, $Cos(\Phi 1)$ = the actual operating power factor before P. F. correction).
$\Phi 2$ = desired and selected power factor angle, (where, $Cos(\Phi 2)$ has a value from 0.95 to 1 and the selected $Cos(\Phi 2)$ = 1in our proposed algorithm).
v_{srms} = RMS phase voltage in Volt (where, v_{srms} = the nominal RMS phase voltage of power supply).
f = 50 Hz, (where, f = the nominal frequency for power supply voltage)
л = 3.14159
It is noticed from Equations (3), (4) and (6), Cross-correlation coefficient (r_s) is used for calculations of current power factor, the active power drawn by load (p_s) and the reactive power compensation (Q_c).
7- Determine the required number of capacitor banks (N_r) according to the available reactive power rating (Q_u) of one capacitor bank.

$$N_r = Q_c / Q_u \qquad (7)$$

8- Reactive power control relay sends closing signals, for CBs of the required number of capacitor banks, to get unity power factor.
9- Action of capacitor banks insertion, by the scheme, relies on the following rules:
(a) If $r_s setting \leq r_s \leq 1$ (for all phases), $r_s setting = 0.95$, then this case is normal operation condition with desired power factor.
(b) If $r_s < r_s setting$ (for any phase), then this case requires a certain number of capacitor banks to get unity power factor.
The action of scheme is blocked in cases of abnormal conditions (such as undervoltage, overload/overcurrent, switching, current transformer saturation and inrush current). These conditions are detected by a transition for cross-correlation coefficient if $\Delta r_s(calculated) > \Delta r_s$setting (the selected setting in our proposed algorithm is 003); or by a transition for voltage and current signals of power supply if $\Delta v_s < 20\%(V_n)$ or $\Delta i_s > 20\%(I_n)$, as V_n are the nominal voltage and current of power supply, respectively.

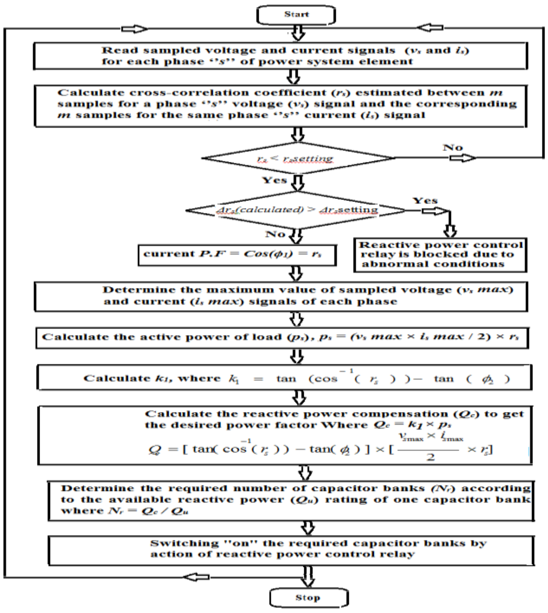


Fig. 1 Flow Chart for Reactive Power Control Relay Algorithm Based on Cross-Correlation Technique.

Electric Circuit Description

The simulated circuit for power factor correction under study is shown in Fig. 2.

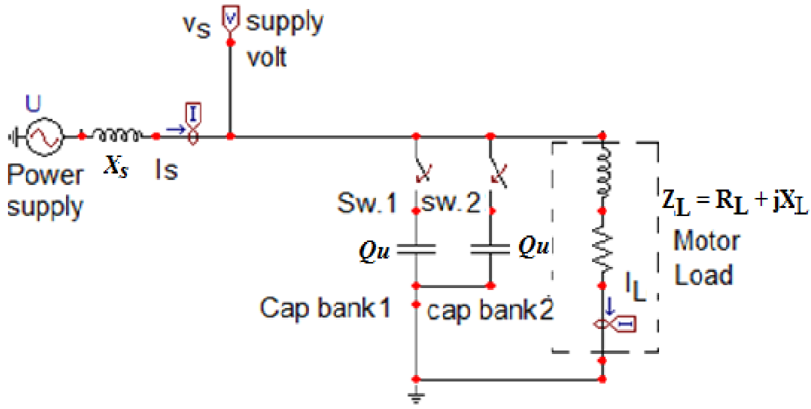


Fig. 2 The simulated circuit for power factor correction.

The circuit parameters are obtained from the name plate of three phase induction motor and are given in Table (1).

Simulation results

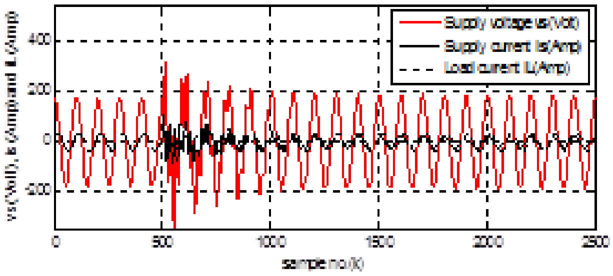
The voltage and current signals (v_s and i_s), from ATP software, generated at sampling rate of 100 samples per cycle, this gives a sampling frequency of 5 KHz. The total simulation time is 0.5 Sec (i.e. the total number of samples is 2500). The inception time for capacitor bank(s) connection is 0.1 Sec (i.e. at sample number 500) from the beginning of simulation time. The proposed technique takes into consideration the wide variations of operating conditions such as different loading levels.

Case 1: PF Correction by using two capacitor banks

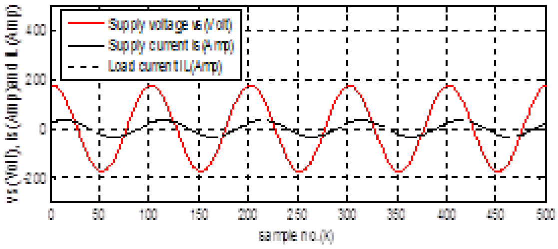
The operating conditions of the simulated electric circuit are shown in Table-1-. Figures 3 (a-f) show the simulation results for power factor correction in case of load impedance of Z_L = 3.6504+j 3.544 and using two capacitor banks. The Figures present the instantaneous phase voltage and current signals of power supply, their cross-correlation coefficients, instantaneous phase load current, maximum values of voltage and current of power supply, active and compensation reactive powers and the calculated capacitance before, during and after PFC. In this case, it is noticed that the maximum value of phase voltage (v_{smax2}) for power supply after PFC is higher than the maximum value of phase voltage (v_{smax1}) before PFC; their values after and before PFC are nearly 187.4 Volt and 175.4 Volt, respectively as shown in Fig. 3(c);whereas the maximum value of total current (i_{smax2}) drawn from power supply after PFC is lower than the maximum value of total current (i_{smax1}) before PFC; their values after and before PFC are nearly 26.44 Amp and 34.46 Amp, respectively as shown in Fig. 3(d). The cross-correlation coefficients (r_{s2}) calculated between voltage and current at power supply side are equal and close to unity after PFC; whereas their values (r_{s1}) is lower and close to 0.717 before PFC as presented in Fig. 3(b). The algorithm calculates cross-correlation coefficient between each two corresponding windows for voltage and current signals at the power supply side, where the duration time of the correlated window is one cycle. The calculated active powers (P_{s1}) are close to 2168.2 Watt before PFC, and they (P_{s2}) increase to 2473.8 Watt after PFC as shown in Figure 3(e). But the calculated compensation reactive powers (Q_{c1}) are close to 2105.6 VAR before PFC, and they (Q_{c2}) decrease to 5.978 VAR after PFC (see Figure 3(e)). Figure 3(f) shows the required capacitance (C_r) in Farad before, during and after PFC; their values are nearly 435.81 µFarad and 0 µFarad, respectively. The maximum value of load current (i_L) is not approximately changed before and after PFC, their values are 34.46 Amp and 36.86 Amp, respectively, as shown in Fig. 3(a).

From the shown results, it is clear that the cross-correlation coefficient before and after PFC is good measurement to determine the value of current power factor (i.e. PF Meter). The proposed scheme has also power meter algorithm for measuring active and reactive powers. Besides it has an algorithm of digital reactive power control relay to obtain desired power factor. The action of the control relay depends on the cross-correlation values; if their values are less than pre-setting value (r_s *(setting)* = 0.95 is selected) then its algorithm estimates the required number of capacitor banks (N_r) by using the calculated reactive power compensation (Q_c) and the available reactive power rating (Q_u = 1052.8 VAR) of one capacitor bank; and hence an electrical signal is sent for connecting the circuit breakers (CBs) for required number of capacitor banks. This case needs two capacitor banks (N_r = 2) and making signal is issued for connecting the two CBs of the two capacitor banks in order to get unity P.F., as shown in Table (2).

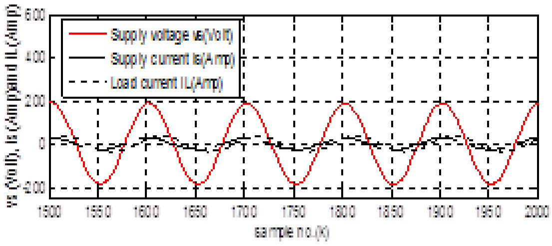
As shown in Tables (2-3) the frequencies (f_1, f_2) of power supply voltage is not changed before and after PFC, their values are 50 Hz. There are distortion harmonics with high frequency injected in the voltage and current signals of power supply with insertion of the two capacitor banks; it is clear their effects on the electrical signals from sample number of 500 to 1400, see Figures 3(a-f).



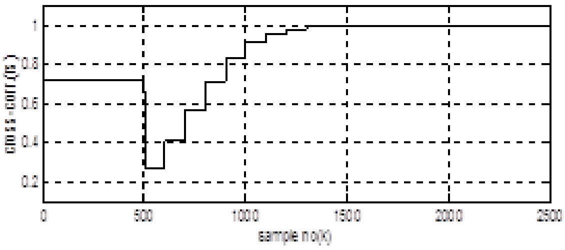
(a) The supply voltage, total supply current and load current signals.



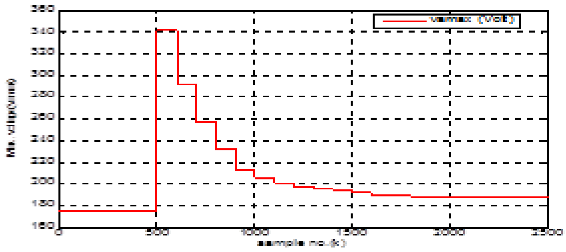
(a-1) The supply voltage, total supply current and load current signals before PFC.



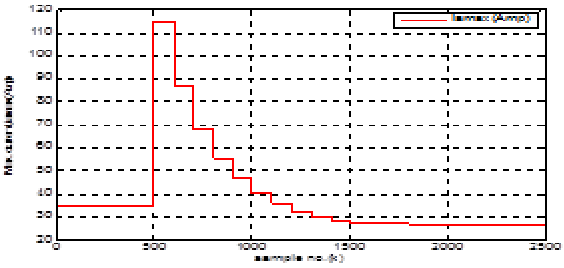
(a-2)The supply voltage, total supply current and load current signals after PFC.



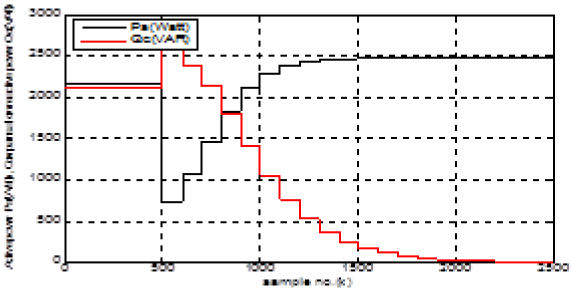
(b) Cross-correlation coefficient between phase voltage (v_s) and current signal (i_s).



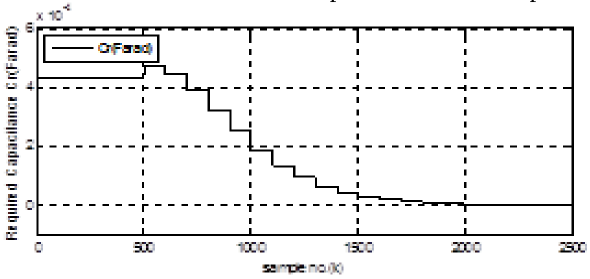
(c) The maximum value of supply voltage per each cycle ($v_s max$).



(d) The maximum value of total supply current per each cycle ($i_s max$).



(e) The calculated active and compensation reactive powers.

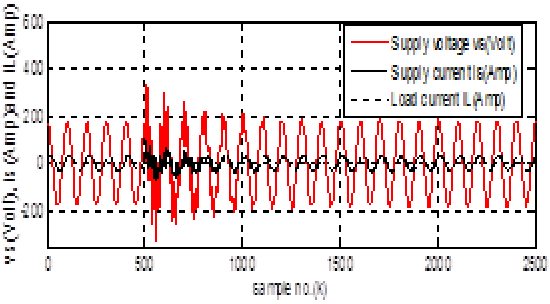


(f) The required capacitance (c_r) in Farad.

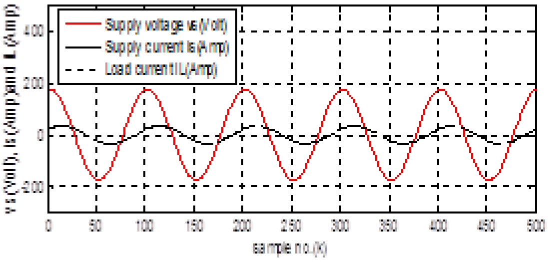
Figures 3 (a-f) the simulation results in case of power factor correction by using two capacitor banks.

Case 2: PF Correction by using one capacitor bank

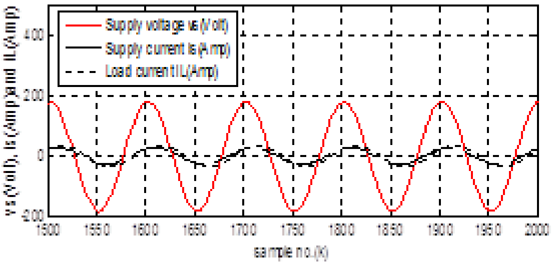
In this case, all parameters are kept as in case 1 except that only one capacitor bank is connected. Figures 4(a-f) show the simulation results for case 2 by using load impedance of Z_L = 3.6504+j 3.544 and only one capacitor bank. The Figures present the instantaneous phase voltage and current signals of power supply, their cross-correlation coefficients, instantaneous load current, maximum values of voltage and current of power supply, active and compensation reactive powers and the calculated capacitance before, during and after PFC. In this case, it is noticed that the maximum value of phase voltage (v_{smax2}) for power supply after PFC is higher than the maximum value of phase voltage (v_{smax1}) before PFC; their values after and before PFC are nearly 181.3 Volt and 175.4 Volt, respectively as shown in Fig. 4(c);whereas the maximum value of total current (i_{smax2}) drawn from power supply after PFC is lower than the maximum value of total current (i_{smax1}) before PFC; their values after and before PFC are nearly 28.41 Amp and 34.46 Amp, respectively as shown in Fig. 4(d). The cross-correlation coefficients (r_{s2}) calculated between voltage and current at power supply side are equal and close to 0.899 after PFC; whereas their values (r_{s1}) is lower and close to 0.717 before PFC as presented in Fig. 4(b). The calculated active powers (P_{s1}) are close to 2168.2 Watt before PFC, and they (P_{s2}) increase to 2313.3 Watt after PFC as shown in Figure 4(e). But the calculated compensation reactive powers (Q_{c1}) are close to 2105.6 VAR before PFC, and they (Q_{c2}) decrease to 1123.2 VAR after PFC (see Figure 4(e)). Figure 4(f) shows the required capacitance (C_r) in Farad before, during and after PFC; their values are nearly 435.81 µFarad and 217.9 µFarad, respectively. The maximum value of load current (i_L) is not approximately changed before and after PFC, their values are 34.46 Amp and 35.61Amp, respectively, as shown in Fig. 4(a). As listed in Tables (2-3) the frequency (f_1, f_2) of power supply voltage is not changed before and after PFC, their values are 50 Hz. There are distortion harmonics with high frequency injected in the voltage and current signals of power supply with insertion of one capacitor bank; it is clear its effect on the electrical signals from sample number of 500 to 1400, see Figures 4(a-f).



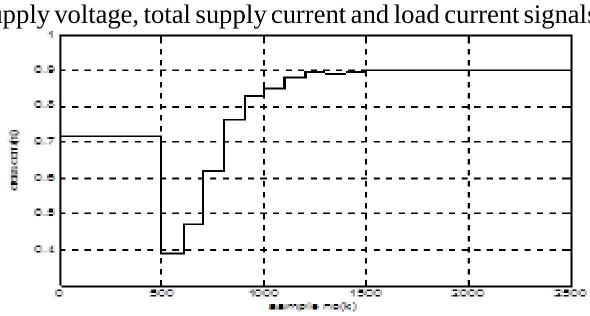
(a) The supply voltage, total supply current and load current signals.



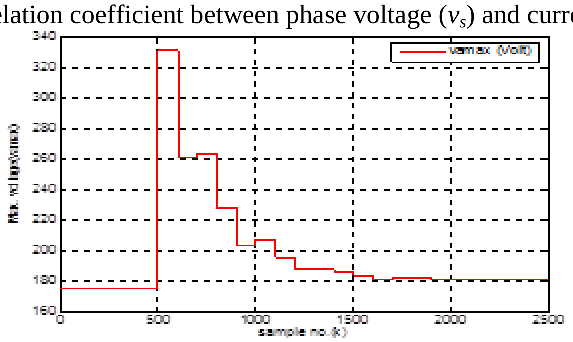
(a-1) The supply voltage, total supply current and load current signals before PFC.



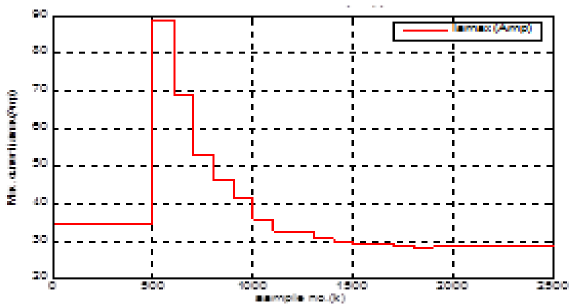
(a-2)The supply voltage, total supply current and load current signals after PFC.



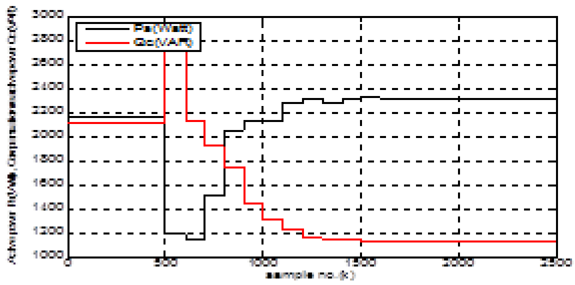
(b) Cross-correlation coefficient between phase voltage (v_s) and current signal (i_s).



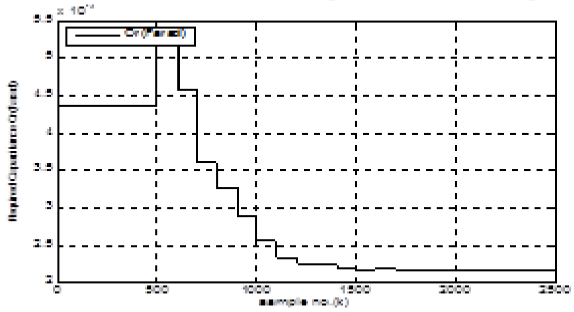
(c) The maximum value of supply voltage per each cycle ($v_s max$).



(d) The maximum value of total supply current per each cycle ($i_s max$).



(e) The calculated active and compensation reactive powers.



(f) The required capacitance (c_r) in Farad.

Figures 4 (a-f) the simulation results in case of power factor correction by using one capacitor banks.

Summary of frequencies (f_1, f_2), cross-correlation coefficients (r_{s1}, r_{s2}) calculated between voltage and current signals, maximum values of voltage and current (v_{smax1}, v_{smax2}, i_{smax1}, i_{smax2}) at power supply side, active and compensation reactive powers (P_{s1}, P_{s2}, Q_{c1}, Q_{c2}) and the required capacitance (C_r) are obtained before and after PFC in cases of different conditions of load currents/operating power factors; results of these case studies are listed in Tables (2-3). The results showed the following information:

(a) The measured supply voltage magnitude (at power supply side) is increasing after PFC.
(b) The measured supply current magnitude (out from power supply) is decreasing after PFC.
(c) The measured active power at power supply side is increasing after PFC.
(d) The measured reactive power at power supply side is decreasing after PFC.
(e) The calculated power factor is increasing after PFC (from 0.717 lag to 0.899 lag with using one capacitor bank and to unity with using two capacitor banks); this means power factor correction is verified.

From the obtained results, it clearly appears that the proposed technique based on cross-correlation algorithm succeeded in power factor calculation besides identification of the required number of capacitor banks to get improved and desired power factor. The technique has also the advantage of auto adjustable power factor correction to ensure the entire power system always preserving almost unity power factor and thus optimizing the current consumption.

II Conclusions

In this paper, a reliable and efficient technique has been presented for automatic power factor correction by using correlation algorithm. ATP software has been used for generating fault data and then processed in MATLAB to get cross-correlation coefficients between voltage and current signals obtained at power supply side. These coefficients are used in the proposed algorithm to obtain original power factor and then to determine the amount of reactive power compensation is needed. Results of case studies of power factor correction at different loading levels are presented. Case study results show that the technique used correctly determines the operating power factor and the required number of capacitor banks based on the calculated cross-correlation coefficients to get desired power factor.

The suggested scheme has the following features:

1. Introduced a new technique based on correlation algorithm for calculation of current power factor on-line and acts as a power factor meter.
2. Has the advantage of using the algorithm of cross-correlation coefficients calculation between voltage and current signals; whereas most conventional power factor correction algorithms require another algorithm for determining phase shift whether by detecting zero-crossing or by determining peaks points for voltage and current signals.
3. Succeeded in determination of required capacitor rating and number of capacitor banks, based on cross-correlation coefficients, to obtain new power factor desired.
4. It is auto adjustable power factor correction to ensure the entire power system always preserving almost unity power factor and thus optimizing the current consumption**.**
5. The suggested cross-correlation technique is characterized by being simple, fast, reliable and accurate and can be implemented practically, thus it can be used as a base for implementing a cheap and reliable digital reactive power control relay in power system.
6. It can control the proposed algorithm sensitivity (initiation of reactive power control relay) by selecting cross-correlation setting.
7. Independent on the parameters of power system elements or transducers (i.e. VT and CT, if they are available).
8. The action of the scheme is blocked in case of abnormal conditions occurrence, in power system, which are detected by a transition for correlation coefficients.

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TABLE (1) Electric Circuit Parameters Data

Electric Circuit Parameter	Data
Power Supply (as Voltage Source): Nominal voltage Nominal Frequency Source Reactance(X_s)	230 V 50 Hz 0.5 Ohm
Three Phase Induction Motor (as inductive load): Rated active power Nominal voltage Rated current Frequency Rated speed	7.46 kWatt (10 HP) 220/380 Volt 26.1/15.1 Amp 50 Hz 3470 r/min
Single phase fixed capacitances: (connected parallel with load)	114 Micro Farad

Table (2) Recorded Readings in Different Cases of Power Factor Correction.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
	Z_L = 3.6504+j 3.544		Z_L = 3.6504+j 2.544		Z_L = 3.6504+j 1.544	Z_L = 7.3008++j 3.544
	One Capacitor Bank	Two Capacitor Banks	One Capacitor Bank	Two Capacitor Banks	One Capacitor Bank	One Capacitor Bank
f_1 (Hz)	50	50	50	50	50	50
f_2 (Hz)	50	50	50	50	50	50
$cos(\phi_1) = r_{s1}$ (Pre PFC)	0.7174	0.7174	0.8203	0.8203	0.9210	0.8996
$cos(\phi_2) = r_{s2}$ (post PFC)	0.8996	1.0000	0.9487	0.9990	0.9919	0.9914
v_{smax1} (Volt)	175.4	175.4	175.7	175.7	177.9	182.6
v_{smax2} (Volt)	181.3	187.4	181.5	187.7	183.8	188.9
i_{smax1} (Amp)	34.46	34.46	39.51	39.51	44.88	22.5
i_{smax2} (Amp)	28.41	26.44	35.2	34.65	43.06	21.12
p_{s1} (Watt)	2168.2	2168.2	2848.7	2848.7	3677.2	1848.0
p_{s2} (Watt)	2313.3	2473.8	3039.7	3250.6	3926.2	1977.3
Q_{c1} (Var)	2105.6	2105.6	1985.9	1985.9	1555.8	897.3762
Q_{c2} (Var)	1123.2	5.9787	990.0658	148.6175	504.1616	261.3893
C_r (μFarad) for desired PF	435.81		409.08		312.92	171.32
N_r	2		2		1	1
Number "1" Denotes Recorded Readings Pre-PFC Number "2" Denotes Recorded Readings Post-PFC				Desired PF = Selected From 0.95 To 1		

Table (3) Recorded Readings in Different Cases of Power Factor Correction.

Electrical Parameter	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12	Case 13
	Z_L = 3+j 3.544		Z_L = 2.6504+j 3.544		Z_L = 2+j 3.544		
	One Capacitor Bank	Two Capacitor Banks	One Capacitor Bank	Two Capacitor Banks	One Capacitor Bank	Two Capacitor Banks	Three Capacitor Bank
f_1 (Hz)	50	50	50	50	50	50	50
f_2 (Hz)	50	50	50	50	50	50	50
$cos(\phi_1) = r_{s1}$ (Pre PFC)	0.6460	0.6460	0.5988	0.5988	0.4914	0.4914	0.4914
$cos(\phi_2) = r_{s2}$ (post PFC)	0.8231	0.9811	0.7685	0.9509	0.6362	0.8421	0.9944
v_{smax1} (Volt)	173.2	173.2	171.9	171.9	169.4	169.4	169.4
v_{smax2} (Volt)	179.2	185.2	178.3	184.1	177.9	182.7	185.7
i_{smax1} (Amp)	37.29	37.29	38.83	38.83	41.61	41.61	41.61
i_{smax2} (Amp)	30.31	26.36	31.39	26.52	34.05	26.74	24.33
p_{s1} (Watt)	2085.7	2085.7	1998.3	1998.3	1731.9	1731.9	1731.9
p_{s2} (Watt)	2222.7	2375.8	2127.3	2274.2	1834.2	1966.9	2116.3
Q_{c1} (Var)	2464.7	2464.7	2672.9	2672.9	3069.9	3069.9	3069.9
Q_{c2} (Var)	1533.4	468.8514	1771.0	740.4316	2224.4	1259.8	225.4637
C_r (μFarad) for desired PF	523.21		575.96		681.10		
N_r	2		2		3		
Number "1" Denotes Recorded Readings Pre-PFC Number "2" Denotes Recorded Readings Post-PFC					Desired PF = Selected From 0.95 To 1		