New method for resonance elimination in capacitor banks

Mojtaba Nasiri† Mehrdad Rostami† Seyed Hamid Fathi‡ Sajad Hoseinnia†
†Department of Electrical Engineering, Shahed University, Tehran, Iran
‡Department of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran
M_nasiri_tehran@yahoo.com Rostami@shahed.ac.ir fathi@aut.ac.ir hoseinnia@ieee.org

Abstract—**In this paper a new control algorithm to remove parallel resonance in the power factor correction capacitor banks is presented. The proposed system is based on series inverter with capacitor banks in each phase. The main advantage of this method is fast response to eliminate resonance. Another advantage is the use of a low gain proportional controller, rather than a PI controller, to control the dc link voltage. It is shown that P controller improves the transient response of the system to the load changes. Also, THD of voltage at the point of common coupling and the capacitor bank current is significantly reduced.**

I. Introduction

Most industrial loads in power systems are inductive. The inductive loads absorb reactive power and work with a power factor less than unity. To improve power factor, power capacitor is the common [1].

Recently, the number and rating of non-linear loads, such as static power converters and adjustable speed drives, are steadily growing, generating increased voltage and current harmonics. These harmonics cause various problems [2], [3]. The most serious problem may be "harmonic resonance", which can cause significant amplification of voltage and current amplitudes. This phenomenon is caused by series and/or parallel resonance between the line inductance and power capacitor banks [4].

Due to these facts, individual customers must design the shunt capacitors carefully before installing them, to avoid harmful resonance. A common solution is adding series reactors to exciting capacitors [5], [6]. This combination forms a filter tuned to a frequency slightly below the most dominant harmonic frequency, usually the fifth harmonic. However, the system parameters are dynamically changed with the power system configurations and loads variations, therefore, the harmonic resonance may still occur [7].

This paper proposes a new control algorithm for anti-resonant transformer less hybrid delta connected capacitor system. Three single phase inverters are connected in series with capacitor banks and act like a resistance at the resonance frequency. The proper control circuit has been used to control the inverters. This control circuit uses the capacitor current to damp resonance, resulting in significant reduction in PCC voltage and capacitor current THD. Simulation results verify the viability and effectiveness of the proposed configuration for reactive power compensation and reducing total harmonic distortion of the source current and capacitor current.

In section II, resonance phenomenon and how to deal with that is presented. Section III, discusses about Hybrid Capacitor Bank. In Section IV, simulation results of a sample electrical power network are presented. In section V, conclusion is presented.

II. Analytical Discussion

A. *Description of problem*

Figure (1) shows a single phase equivalent circuit of a three phase power system in resonance frequency with a nonlinear load that has been modeled by the harmonic current source . Power factor correction capacitor is connected in parallel with load. PFCC[1] is depicted by the capacitance C_{Comp}. The PFCC and the short circuit impedance of the supply side which is presented by inductance, L_s create a resonant circuit. All ohmic losses are neglected. Calculating the transfer function between capacitor current (i_C) and nonlinear load current (i_h) yields

$$\frac{i_C}{i_h} = \frac{1}{L_s C_{Comp} s^2 + 1} \qquad (1)$$

[1] Power Factor Correction Capacitor

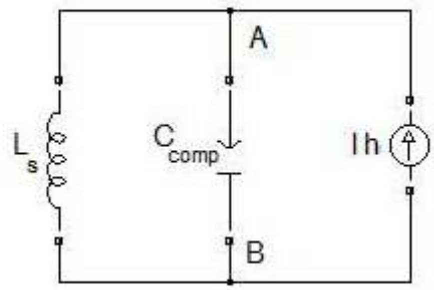

Figure 1. Single phase equivalent circuit of a three phase power system in a resonance frequency

Parallel resonance occurs in above transfer function poles. The resonance frequency can be derived as

$$f_{parallel} = \frac{1}{2\pi\sqrt{L_s C_{Comp}}} \quad (2)$$

In this frequency, equivalent impedance from AB points is infinite. Hence, if harmonic current (i_h) with low amplitude is injected, the voltage amplitude (V_{AB}) will be infinite. In this case, source current and capacitor current gains infinite amplitude, theoretically. In practice, devices may receive high amplitudes of these currents which may damage the capacitor banks.

B. Solution to eliminate resonance

Resistors are best choices to damp fluctuations in the power systems. But it acts in all frequencies including fundamental power system frequency which creates losses.

If some elements with zero resistance in main frequency be used, but has some values in other frequencies, the resonance can be eliminated in each harmonic frequency beside of maintaining system efficiency. So, we can use series inverter in the capacitor branch to apply such characteristics. Figures (2) and (3) show series resistance with the capacitor and series inverter with the capacitor [4], respectively, that acts as infinite resistance at harmonic frequencies.

III. HYBRID CAPACITOR BANK

A. System Configuration

Figure (4) shows common low voltage industrial system. This system has three-phase power source including 380V, source inductance, linear and nonlinear loads.

Source inductance includes the transformer (leakage) inductance along with line inductance. If not using power factor correction capacitors, power factor is equal to 0.65 lagging. After using the capacitor bank C, 2.3kVAR, for a linear load of 3.8kVA, Power factor will be increased to 0.95. The active power of nonlinear load is 500 W.

Since the fifth voltage harmonic and current harmonic in power systems is common and causes serious problems, values have been designed so that parallel resonance occurs at the fifth harmonic frequency.

The linear load is a resistive load in Y configuration and an inductive load is inductances in same connection. Both resistive and inductive loads are connected in parallel to be able to change active and reactive power. A three-phase diode rectifier with output resistors is used as the nonlinear load.

Parallel resonance frequency with the parameters in Table I is calculated as follows:

$$f_{parallel} = \frac{1}{2\pi\sqrt{LC}} = 259.9Hz$$

In Figure (5), parallel resonance frequency is shown by different frequency spectrum.

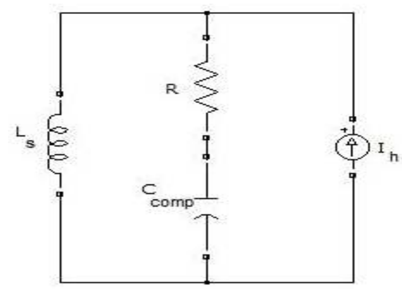

Figure 2. Series resistance with the capacitor

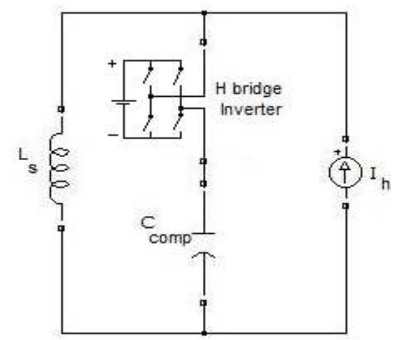

Figure 3. Series inverter with the capacitor

TABLE I. PARAMETERS SPECIFICATION

Source Impedance	
Source Inductance	7.5 mH
Source Resistance	0.15 Ω
Capacitor bank	
Capacitor rating	2.3 kVAR
Capacitor C	16.7 µF
Connection type	Delta
Inverter	
Inverter rating	100 VA
DC capacitor	4700 µF
DC bus voltage	20 V
Switching frequency	8.5 kHz
Switching – ripple filter	
Filter capacitor	1 µF
Filter inductance	1 mH
Note: 3Φ, 380 V, 50 Hz	

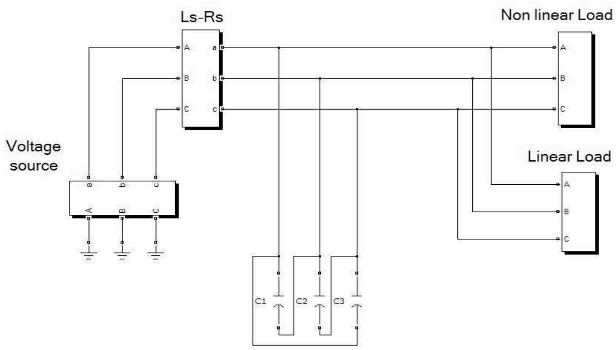

Figure 4. Common low voltage industrial system

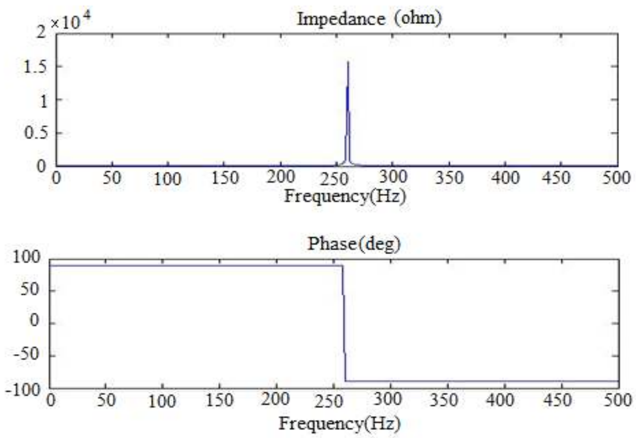

Figure 5. Frequency spectrum to find parallel resonance frequency

Resonance frequency is near the fifth harmonic frequency. Since on nonlinear harmonic was multiplication of $6n \pm 1$ are produced, a parallel resonance between the source inductance and the power factor correction capacitor occurs.

B. Using anti-resonance capacitor circuit in the power system

Figure (6) shows a typical power system with anti-resonance devices. As discussed in former section, series inverter can be used in power factor correction capacitor to eliminate parallel resonance. The inverter's Switches have the low power losses. Type of switches used in the inverter are power MOSFET, and they can flow up to 100VA.

In case that resonance does not happen, lower legs of inverters should be continuously on.

C. Anti-resonance inverter control circuit

Figure (7) shows anti-resonance inverter control block diagram.

As seen in Figure (7), the signals are measured and then transfer to dqo space. The main signal component converting AC to DC signal can be easily filtered using a HPF[1]. These fluctuations are separated from the DC signal.

[1]High Pass Filter

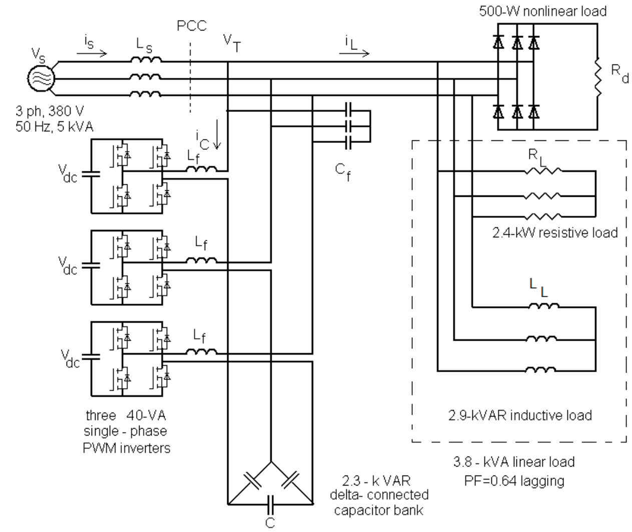

Figure 6. Sample of power system with anti-resonance device

Resultant signals invert into abc space from dqo space. Consequently, the resultant signals add to derived signals from dc capacitor control. Resultant signals are applied to the switches and same signals in the power line are produced.

a) K value determination

K value is the most important value in such control circuits, which must be set to dominate harmonics. It has been defined as resistance value against harmonics. This amount is 1. K factor can be obtained experimentally by trial and error.

b) P controller

In "dc capacitor voltage control" of controller, only one gain exists (Figure (7)).

In the most circuits, PI controller has been used to control the dc voltage and dc capacitor charging time that has slower response and may be created instability condition.

Following studies and simulations show that P controller instead of PI controller can be used in the control circuit of resonance damper, give proper results including faster response and improve the transient response due to load changes.

Using P controller make dc capacitor be charged in 2 to 3 cycles and let it soon be operational, which in comparison with PI controller (7 to 8 cycles[4]) is much faster and better.

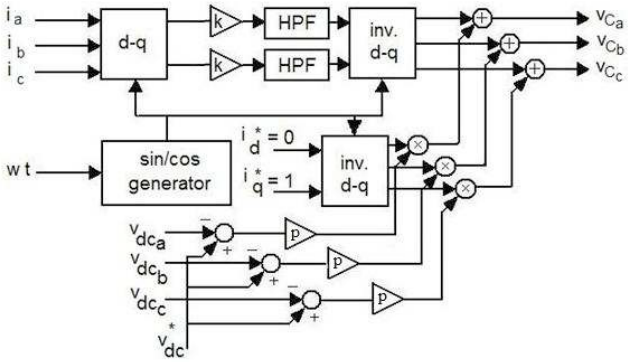

Figure 7. General scheme of anti-resonance control circuit of the inverters

TABLE II.

Voltage and currents	Load with only capacitor				Load with hybrid capacitor bank			
	1st	*5th*	*7th*	*THD*	*1st*	*5th*	*7th*	*THD*
V_{PCC} [V]	216	9	1.17	4.23%	216	1.86	1	1.33%
I_c [A]	3.42	.81	.17	24.49%	3.42	.08	.05	4.08%
I_s [A]	4.5	.77	.07	17.11%	4.5	.16	.06	3.9%

IV. SIMULATION RESULTS

Figures (8) and (9) show simulation results. Capacitor current waveforms before and after employing series inverters with capacitor banks have been simulated. Before using anti-resonance system, current THD was considerably high.

Table II compares values of the source current (I_s), capacitor current (I_c) and voltage of common coupling point (V_{PCC}) THD before and after using anti-resonance capacitor.

Figure (10) shows the dc capacitor charging signal from the moment of starting to full charge, which is about 3 cycles.

Figure (11) shows the dc capacitor voltage and capacitor current transient response due to load changes, which stayed constant with no measure change.

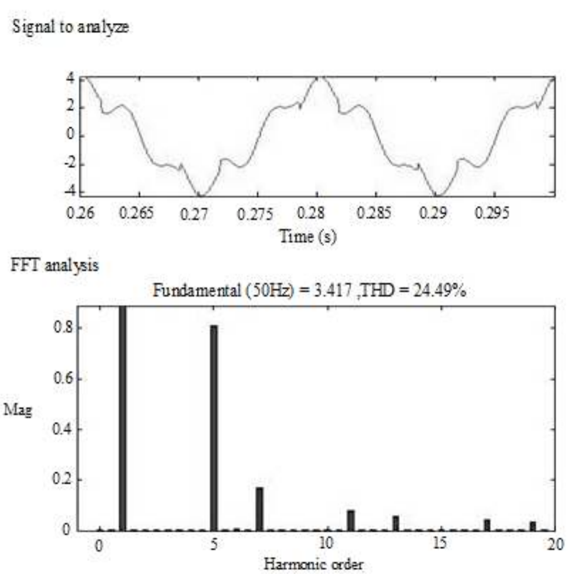

Figure 8. Capacitor current waveform before employing inverters

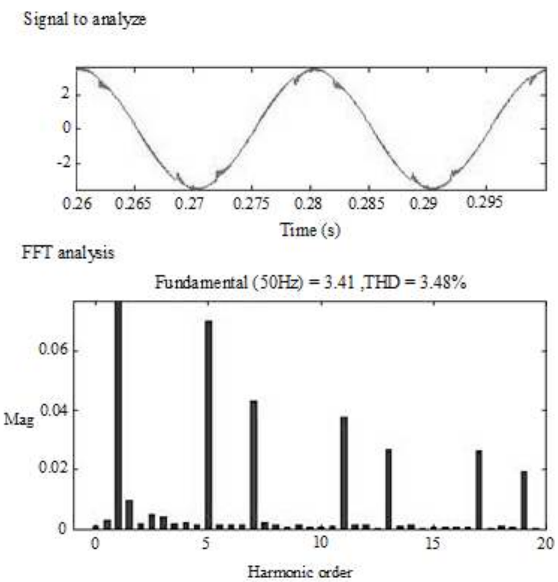

Figure 9. Capacitor current waveform after employing inverters

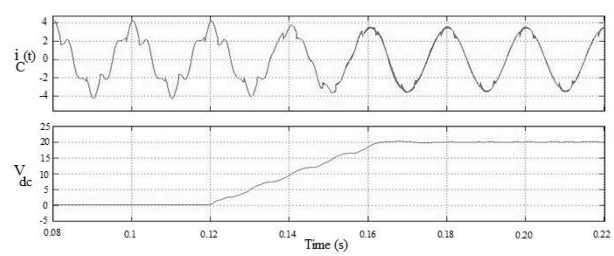

Figure 10. Dc capacitor voltage charging from dead state to full charge

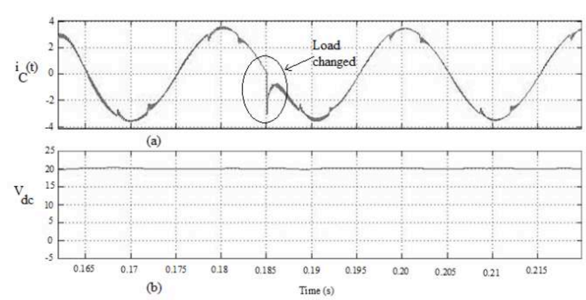

Figure 11. a) capacitor current and b) Dc capacitor voltage transient response due to load changes

V. CONCLUSION

In this paper, an optimized method to eliminate resonance in power factor correction capacitor banks is discussed.

The first advantage of the proposed system is using the P controller instead of common PI controller (to fix dc link voltage in constant value).

As the second advantage of this system, the capacitor recharges quickly from zero to full charge. Full charge of capacitors is essential for proper invertors operation.

The third advantage of this system is change in transient response of circuit due to load changes which significantly has been improved.

As the last advantage of proposed system, it has been experienced that THD of the capacitor current, source current and point of common coupling voltage is significantly reduced.

REFERENCES

[1] Jinn-Chang Wu, Hurng-Liahng Jou, Kuen-Der Wu, and N. C. Shen, "Power Converter-Based Method for Protecting Three-Phase Power Capacitor From Harmonic Destruction," *IEEE Transactions on power delivery*, vol.19, no. 3, pp. 1434-1441,July. 2004.

[2] Joep Jacobs, Andreas Fischer, Dirk Detjen, and Rik W.De Doncker, "An Optimized Hybrid Power Filter and VAR Compensator," *Industry Applications Conference, 2001. Thirty-Sixth IAS Annual Meeting. Conference Record of the 2001 IEEE,* vol. 4, pp. 2412-2418, Oct.2001.

[3] D. Detjen, J. Jacobs, R. W. De Doncker, H.-G. Mall, "A New Hybrid Filter to dampen Resonances and Compensate Harmonic Currents in Industrial Power Systems With Power Factor Correction Equipment, *"IEEE Transactions on Power Electronics,* vol. 16, no. 6, pp. 821-827, Nov. 2001.

[4] P. Jintakosonwit, S. Srianthumrong, P. Jintakosonwit, "Implementation and Performance of an Anti-Resonance Hybrid Delta-Connected Capacitor Bank for Power Factor Correction*," IEEE Trans. Power Del.,* vol.22, no. 6,pp. 2543-2551, Nov. 2007.

[5] IEEE Guide for Application of Shunt Power Capacitors, IEEE Std. 1036-1992.

[6] N.D. Rao, S.I. Sporea, A. Sawma, "Analysis of resonance problems and harmonic filter design in power factor correction capacitor applications, *"IEEE Canadian Conference on Electrical and Computer Engineering,* vol. 1, pp. 293-296, May. 1998.

[7] Pichai Jintakosonwit, Sunt Srianthumrong, "Control of an Anti-Resonance Hybrid Capacitor System for Power Factor Correction,*" Power System Technology, 2004. Power Conf 2004. 2004 International,* ***,*** *Conference,* vol. 2, pp. 1133-1138, Nov. 2004.