Harmonic and transient overvoltage due to capacitor switching

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Abstract:
This paper presents a study of equilibrium and the transient effect of the power factor correction capacitor on public service and to customers. With the presence of harmonyProduce loads, capacitors for power factor correction can cause parallel or series resonance problems tending increase the total harmonic distortion (THD) of the voltage and current waveform. The cases studied in this article review the addition of a power factor correction capacitor, in the presence of conditioning load downstream and at the conditioning load location.In both cases, the resonance is created by the addition of Capacitors cause voltage harmonic distortion and The current waveform increases. Another problem is temporary Electrical pulses are generated by switching capacitors. Increase on the client bus generated by switching capacitors harmful to sensitive electronic devices. A case study is signal where the motor operation is controlled by a semiconductor Control is performed by transient overvoltage. The first part of This article considers steady-state concerns regarding application of power factor correction capacitor when present harmonic and unbalanced loads. The last part of this article discuss transitional issues power factor correction capacitor.

1. INTRODUCTION

There are two areas that need attention. The first area of interest is harmonic distortion of voltage and current waveforms at 60 Hz. The second area of concern is power quality servicing these sensitive electronic devices. Power electronics is the most important source of harmonic distortion. However,Power electronics are not the only source of harmonic distortion, there are other sources such as arc dischargers and devices with a saturated ferromagnetic core [11-[4]. THE The harmonic distortion of the source can be amplified by application of power factor correction capacitor For many years,Capacitors are used for power factor correction and adjust the voltage. However, the use of these capacitors can create parallel or series resonance problems that increase harmonic distortion of voltage and current waveforms.The second concern concerns switching power factor correction capacitors. During capacitor switching, transient The generated overvoltage contains high frequency components. These transient overvoltages, if large enough, can damage sensitive electronic devices [5]-[6]. Short-term power surges that don't damage electronics are still possible operate the drive protection devices by disconnecting them circuit load.

2. HARMONIC AMPLIFICATION DUE TO POWER FACTOR CORRECTION CAPACITORS

Harmonics generated by the load can be modeled as a current source at harmonic frequencies. Generally speaking, harmonics circulating in the system and harmonics the current in the capacitor can be obtained from harmonics sequence components and an equivalent network model. The Sequence components for different harmonics can be obtained as described in reference [7]. system imbalance,which is common on distributed systems, is also a factor in amplifying harmonics and distortion. A simple way this example is used to illustrate how harmonic loads interact with electrical systems and capacitors. Figure 1 shows a simplified equivalent model of the electrical system and air conditioner load. The conditioning load is modeled as the conditioning load current source; The system and capacitor are modeled as impedance depends on frequency.Sequential system current and sequence capacitor .The current at each harmonic is expressed as

$$I_{Cih} = I_{aih} * \frac{Z_{SYSi}(\omega_h)}{Z_{SYSi}(\omega_h) + Z_{Ci}(\omega_h)} \qquad (1)$$

$$I_{SYSih} = I_{aih} * \frac{Z_{Ci}(\omega_h)}{Z_{SYSi}(\omega_h) + Z_{Ci}(\omega_h)} \qquad (2)$$

where

$Z_{SYSi}(\omega_h)$	is the system impedance at the harmonic frequency, $R(h) + jh\omega L$
$Z_{Ci}(\omega_h)$	is the impedance of the capacitor at the harmonic frequency, $\frac{-j}{h\omega C}$
I_{SYSih}	is the system harmonic current
I_{Cih}	is the capacitor harmonic current
h	is the harmonic order
$i = 0, 1$ or 2	zero, positive and negative sequence components

By testing (1) and (2), we see that harmonics current will have the largest amplitude when the denominator, (zSYSi(wh)+zci(Wh)), is at its minimum. This term will min when j hwL is equal to &. the value of (h) that satisfying this requirement is the resonant harmonic frequency.Sometimes there is more than one harmonic resonant due to combination of serial and parallel components.

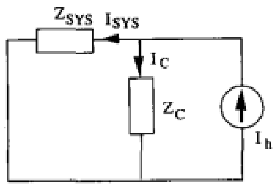

Fig. 1. Equivalent network model.

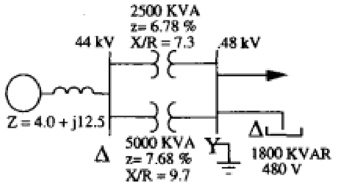

Fig. 2. One-line diagram of the industrial load.

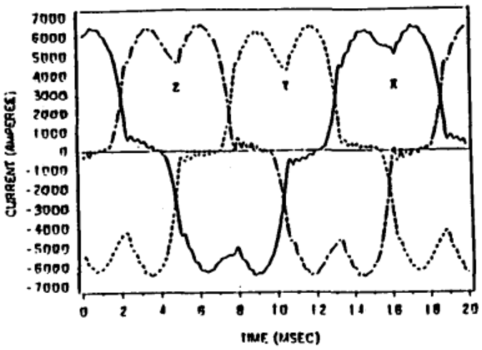

Fig. 3. Industrial load three-phase currents.

Two examples are used here to illustrate the power of the effect Factor correction capacitors can exhibit excessive harmonic distortion of voltage and current waveforms at 60 Hz [8]. IN In the first example, [7] reported that a connected delta 1,800 kVAR capacitor contributes to severe harmonics deformation at the loading site. The system diagram is shown in vestments. 2. Industrial load including 4 production lines Induction heating with two single-phase furnaces on each line. Induction furnaces operate at 8500 Hz and are used to heated 40-foot steel bars cut into railroad spikes [7].Problems created by excessive harmonics flowing through capacitor trip capacitor overheating.The increase in harmonic current also causes problems with individual 100A capacitor fuse and 3000A . main line fuse. Capacitors are connected across the load terminals to generate voltage power factor adjustment and correction; However, the result resonance in the system increases harmonic distortion and power factor is reduced. The waveform is actually recorded for The three-phase load current is shown in Fig. 3. Tables I and I1 describes the system RMS current and harmonics spectrum of the respective current.The second example illustrates air conditioning problems can happen after adding a capacitor to the circuit. In this case an ungrounded 1800 kVAR wye capacitor bank switched activated when there is a harmonic load downstream. single line The schematic diagram of the distribution system is shown in Figure 2. 4. The Adding this capacitor to the distribution circuit causes voltage increase and current harmonic distortion wave. The increase in harmonic distortion is due to amplify harmonic components. Amplification harmonic component caused by resonance condition was mentioned earlier. Another problem encountered on this circuit is the high level of unbalance. THE unbalanced conditions contribute to increased harmonics distortion of voltage and current waveforms. something interesting the occurrence in this example is asymmetric amplification harmonized composition. Spectral content of Current and voltage waveforms before and after the capacitor have been added to the circuit given in Tables I11 and IV,corresponding. THD of voltage and current waveform given in Table V. Considering these results, one can see that the effect on phase X is more pronounced than other stages. Another observation in this case is the fact than the dominant harmonic frequency for voltage and current not necessarily the same.

TABLE I

TOTAL RMS AND DISTORTION FACTORS

	Load Current		Transformer Current		Capacitor Current	
Phase	IRMS	THD	IRMS	THD	IRMS	THD
X	4552.3	20.1%	5635.3	78.3%	3398.3	129 %
Y	4394.2	26.9%	5718.6	91.6%	3494.7	135 %
Z	4532.8	24.5%	5766.7	81.9%	3406.9	129 %

TABLE II

HARMONIC ANALYSIS OF TRANSFORMER AND CAPACITOR CURRENTS

		Transformer Current		Capacitor Current	
Harmonic Order		RMS Current	Angle (Degrees)	RMS Current	Angle (Degrees)
Fund.	X	4437.1	42.9	2076.5	120.0
	Y	4215.6	163.2	2074.2	-120.3
	Z	4461.2	-75.0	2085.5	-0.2
5th .	X	77.7%	-98.4	125.6%	79.8
	Y	91.1%	139.4	132.0%	-41.5
	Z	81.5%	20.9	125.9%	-163.4
9th.	X	2.7%	-162.4	11.9%	18.9
	Y	1.7%	116.5	13.1%	-102.2
	Z	1.4%	-86.0	12.3%	133.6
11th.	X	2.7%	-162.4	11.9%	18.9
	Y	1.7%	116.5	13.1%	-102.2
	Z	1.4%	-86.0	12.3%	133.6
13th.	X	0.5%	160.8	7.5%	-106.9
	Y	1.5%	-150.8	7.0%	14.9
	Z	1.0%	-100.2	7.1%	130.8
17th.	X	0.8%	-71.4	3.2%	114.1
	Y	0.6%	-94.1	3.9%	-3.9
	Z	0.5%	-53.6	3.7%	-135.0
19th.	X	0.3%	-67.2	2.9%	-14.2
	Y	0.6%	-57.1	2.8%	108.3
	Z	0.4%	-37.2	2.7%	-136.3

3. EFFECT OF HARMONIC FILTERING

A possible solution to the steady-state conditioning problem generated using a power factor correction capacitor of one harmonic filter. A harmonic filter that matches the dominant harmonic frequency of the system can reduce harmonic distortion while Provides voltage regulation and power factor correction. One The single tuned harmonic filter is an RLC shunt element, shown in Figure. 5. The L and C elements can be tuned to the resonant harmonic frequency. Determine the L and C values used in the filter can be found from the following relationships:

$$\mathrm{jh}\omega \mathrm{L} = \frac{-\mathrm{j}}{\mathrm{h}\omega \mathrm{C}} \tag{3}$$

$$\mathrm{h}^2\omega \mathrm{L} = \frac{-1}{\omega \mathrm{C}} \tag{4}$$

$$\mathrm{h}^2|\mathrm{X_L}| = |\mathrm{X_C}| \tag{5}$$

where h is harmonic order to which the filter is tuned.

4. ASD TRANSIENT OVERVOLTAGES CREATED BY CAPACITOR SWITCHING

Momentary overvoltage of capacitor switching event frequently cause the operation of protective equipment and disconnect the customer's load. Variable speed drives (ASDs) tend to particularly sensitive to this problem because of overvoltage lower protection threshold than other customer devices to protect semiconductor devices [9]. Figure 6 shows the actual data recorded from a capacitor switching event or switching event on an a.c. system. transient overvoltage on the inverter's DC bridge has been exceeded travel setting. The drive in this case is the serving USB drive industrial loads. The drive went offline due to the capacitor. EMTP simulations were performed to illustrate the effects of ASD trigger capacitor and some parameters Implement transient overvoltage on the ASD DC bridge. THE ASD is a model in EMTP as a three-phase full-wave rectifier.Three-phase full-wave rectifier converts three-phase alternating current to DC. The converter in its simplest form consists of six diodes (see figure 7). A diode is connected to the anode (cathode) at the cathode (anode) of each phase alternates to positive (negative) DC terminal. (Current flows from anode to cathode.) For a controlled rectifier, diodes are replaced by thyristors. The The DC voltage in a controlled rectifier can be changed by controlling thyristor control pulse. The system model used for EMTP simulation is presented in Figure 8. ASD is modeled as a three-phase full wave rectifier is controlled by a capacitor on the DC terminals. The inverter or DC-AC converter has not been modeled since The main concern is the effects due to changes in the air conditioning system.Graph of simulated DC bridge voltage during capacitor use the conversion event is shown in Figure 9.EMTP is used to simulate capacitor switching operation to determine the peak voltage magnitude on the DC bridge.Switching occurs when the phase C voltage is at its maximum. For simulation purposes, the engine is modeled as Charging current remains unchanged.For PWM actuators and these simulations, a rectifier is used simply a three-phase converter. Capacitance value used in simulation is chosen to minimize voltage ripple across DC bridge. This is done to reproduce real world conditions. While operating at steady state, the current supplied to the rectifier is discontinuous because the capacitor maintains a voltage close to AC system voltage peak.

A. Effect ofLink Inductance One method that is commonly used to limit the transient overvoltage on the dc bridge during capacitor switching is to place inductance in the link connection between the rectifier and converter. The link inductance was varied with values ranging from .01 to 100 mH to determine its effect on the peak voltage at the dc bridge. A plot of peak transient dc voltage is shown vs. link inductance is shown for several values of link capacitance in Figure. 10. Generally, the addition of inductance will decrease the peak overvoltage.

B. Addition of Reactance on the AC Side Sometimes it may not be practical to vary the link inductance. Often times a reactor is placed in series with the converter ac input terminals. This solution was tested at the PWM drive serving the industrial load. A 5% line reactor was installed at the drive terminals and five capacitor switching tests were performed. The results of these tests are presented in Table VI: the dc bridge voltage as a function of per unit overvoltage as measured at the capacitor bank. In each of these tests, the dc overvoltage was less than the overvoltage threshold of the drive. Before the installation of the line reactor, overvoltages of these magnitudes would have caused the drive to trip. Simulations were performed where inductance was added in front of the drive and varied from .01 to 100 mH with a link capacitor of 1000 uF. The result is plotted in Fig. 11 along with the result obtained by varying the link inductance. For this case, the addition of inductance on the ac side has a greater effect on reducing the peak overvoltage on the dc bridge than addition of link inductance.

TABLE IV
HARMONIC ANALYSIS OF VOLTAGE WAVEFORMS

Harmonic Order		Before RMS Voltage	Angle (Degrees)	After RMS Voltage	Angle (Degrees)
Fund.	X	7344.5	-110.1	7357.6	-110.1
	Y	7333.7	130.3	7359.2	130.1
	Z	7268.8	9.8	7262.9	9.9
5th .	X	104.3	8.0	109.9	8.14
	Y	108.7	102.7	116.0	81.6
	Z	107.8	-138.2	118.2	-129.5
10th.	X	52.8	152.2	122.1	-121.4
	Y	51.2	177.9	113.1	-175.4
	Z	53.1	171.5	58.3	-108.6
11th.	X	84.8	-162.4	166.8	136.5
	Y	74.1	116.5	94.5	76.6
	Z	51.3	-86.0	71.9	119.3
12th.	X	47.2	-162.4	163.2	36.6
	Y	45.3	116.5	40.4	-11.5
	Z	53.9	-86.0	69.9	66.2
13th.	X	49.8	-71.4	127.2	-47.9
	Y	54.4	-94.1	55.9	140.4
	Z	44.3	-53.6	30.0	-32.7

TABLE V
HARMONIC DISTORTION OF VOLTAGE AND CURRENT WAVEFORMS

Phase	Before THD	After THD
I_X	7.1%	24.1%
I_Y	7.8%	13.7%
I_Z	7.2%	8.8%
V_X	2.4%	5.7%
V_Y	2.6%	3.5%
V_Z	2.1%	2.9%

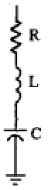

Fig. 5. Single-tuned RLC shunt filter.

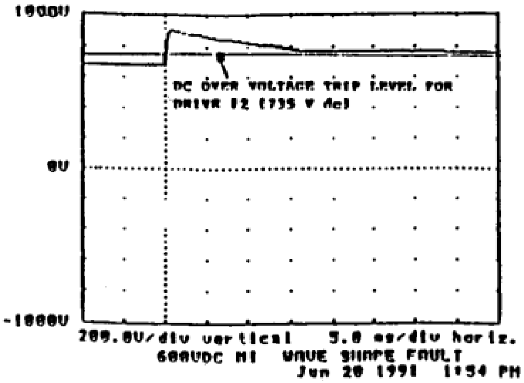

Fig. 6. Plot of actual recorded data of voltage on the dc bus of an ASD during a capacitor switching event.

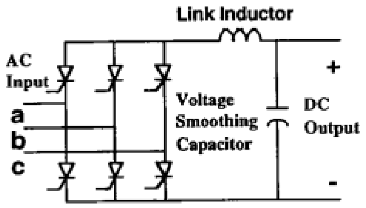

Fig. 7. Adjustable speed drive model used in EMTP.

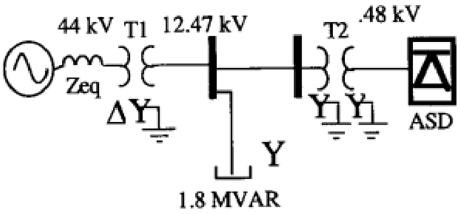

Fig. 8. System used in EMTP simulation.

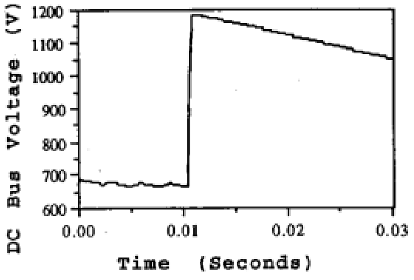

Fig. 9. Simulated capacitor switching (ASD) dc voltage.

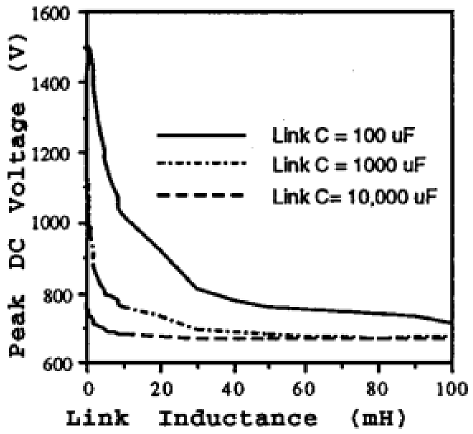

Fig. 10. DC bridge voltage vs. link inductance.

TABLE VI
DC BRIDGE VOLTAGE DURING CAPACITOR SWITCHING

Case Number	Per Unit Overvoltage	5% Reactor DC Voltage
1	1.70	727
2	1.63	732
3	1.65	727
4	1.72	732
5	1.60	692

5. CONCLUSION

Adding a capacitor for possible power factor correction Amplification of harmonics in AC power systems. It must be admitted that the gain depends on the magnitude of the power factor correction.and system impedance. In the case presented, power factor will not be improved because of the total apparent power increase. Harmonic imbalance may cause improper operation ground relay. Harmonic amplification can cause overheating of transformers and other substation equipment. One possible solution to this problem is to design filters power factor correction.The transient overvoltage on the ASD can be reduced by adding inductance on the AC system side of the inverter or on the DC side reader link. For the case of the PWM reader serving a industrial loads, a 5% flow reactor was installed and tested. THE The results show that this is an effective way to deal with annoying tripping accompanied by transient overvoltages.

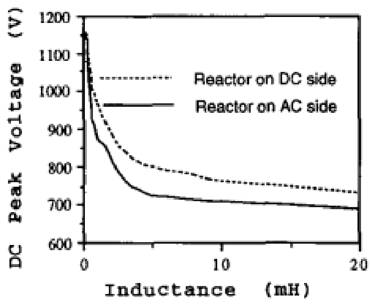

Fig. 11. Peak dc voltage as a function of reactor position.

REFERENCES

[1] IEEE Working Group on Power System Harmonics, "Power system harmonics: an overview," *IEEE Trans. Power Apparat. Syst.*, vol. PAS-102, no. 8, pp. 2455–2459, Aug. 1983.

[2] J. F. Fuller, E. F. Fuchs, and D. J. Roesler, "Influence of harmonics on power distribution system protection," *IEEE Trans. Power Delivery*, vol. 3, no. 2, pp. 549–557, Apr. 1988.

[3] J. Arrillaga, D. A. Bradley, and P. S. Bodger, *Power System Harmonics*. New York: Wiley, 1985.

[4] S. B. Davan and A. Straughen, *Power Semiconductor Devices* New York: Wiley, 1987.

[5] A. Greenwood, *Electrical Transients in Power Systems*New York: Wiley, 1991.

[6] T. Grebe, "Why power factor correction capacitors may upset adjustable speed drives," *Power Quality Mag.*, pp 14–18, May/June 1991.

[7] A. A. Girgis *et al.*, "Measurement and characterization of harmonic and high frequency distortion for a large industrial load," IEEE *Trans. Power Delivery*, vol. 4, no. 3, pp. 427–434, July 1989.

[8] M. Z. Lowenstein, "Power factor improvement for non-linear loads," presented at the 1991 Ann. Tech. Conf. Textile, Fiber, Film Ind. Committee, Greenville, S. C., May, 1991.

[9] M. F. McGranaghan, T. Grebe, G. Hensley, T. Singh, and M. Samotyj, "Impact of utility switched capacitors on customer systems: part II—adjustable speed drive concerns," *IEEE Trans. Power Delivery*, vol. 6, no. 3, pp. 1623–1628, Oct. 1991.