Low Cost Transient Free Thyristor Switching Capacitor for Power Factor Correction Panels

Mahmoud Gaballah, Mohammed El-Bardini

Abstract— The paper discusses the operating principles and control characteristics of a thyristor switching capacitor (TSC) that used to improve the transient response of capacitor switching. Since the capacitor draws too much current from the main supply at the instant of turn-on. In this paper, the TSC is implemented in such a way that need a minimum number of thyristors with low cost logical control circuit which introduces an economical way to replace the contactor based power factor correction panels. The proposed TSC operations verified through experimental results.

Index Terms— Capacitor banks, Power factor, Thyristor switching capacitor.

I. INTRODUCTION

Industrial plants which contain electrical loads (e.g. induction motors, welding equipment, arc furnaces and fluorescent lighting) draw not only active power from the supply, but also the inductive reactive power (KVAR). This reactive power is necessary for the equipment to operate correctly but could be interpreted as an undesirable burden on the supply. These plants are faced with stringent requirements by the utility to maintain a near unity power factor. These plants have traditionally utilized switched capacitor banks as a cost-effective means for power factor correction (PFC).The capacitor banks are controlled by a microprocessor based relay which continuously monitors the reactive power demand on the supply. The relay connects or disconnects the delta connected capacitors to compensate for the actual reactive power of the total load and to reduce the overall demand on the supply.

When switching capacitors, whether they are low, medium or high voltage, precautions must be taken to ensure that the inrush current is limited to a non-destructive value. The right capacitor switching device is key to reliable and trouble free capacitor bank performance.

Energizing and de-energizing shunt capacitor banks from the system presents some unique challenges since the voltage across the capacitor cannot change instantaneously. Energizing capacitor banks cause unwanted, high frequency, steep front, voltage and current transients that may cause nuisance tripping of adjustable-speed drives, computer network problems, and customer equipment damage or failure [1], [2].The steep front over voltage at equipment and cable insulation, shortening their life. Several techniques have been developed to mitigate these transients including application of arrestors, inrush reactors, controlled voltage switching devices, thyristor switched capacitor, pre-insertion resistors, and pre-insertion inductors. This paper aims to present a solution for capacitor switching based on controlled voltage semiconductor switches which have a large number of operations, and capable of reducing voltage transients and inrush current. This solution improves the performance and reliability of capacitor switching over general purpose devices (such as vacuum switches, circuit switchers, and circuit breakers) while maintaining a competitive cost.

II. CONVENTIONAL CAPACITOR SWITCHING METHODS

Capacitors operate at full power immediately after every switching. No-load or low-load periods do not exist. When a capacitor is switched to an AC voltage through a traditional contactor, the result is a resonant circuit damped to a greater or lesser degree as shown in figure 1. The switching of capacitors causes high inrush peak which puts a lot of stress on the switchgear and finally damages the normal contactors.

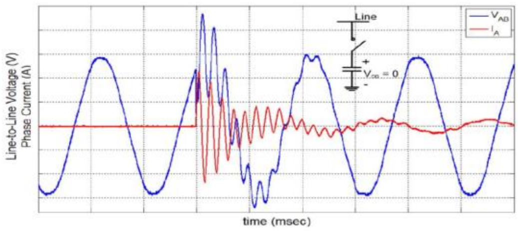

Figure 1.Capacitor turn-on transient with contactor

To prevent this capacitor switching contactors are fitted with early make contact fitted with resistors or inductors to reduce the capacitive inrush current during the first quarter cycle. After approx 6 msec, the early make contacts open, and the main contacts then carry the capacitor current. When two or more capacitor banks are paralleled within close proximity to each other,

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the peak transient inrush current to the uncharged bank may exceed the normal peek steady state capacitor current by several orders of magnitude. This high frequency explosive release of energy can cause damage to the switching device capacitors, if it is not limited. This phenomenon is caused by the contactor contacts not being open far enough at the first current zero on switch off. It is crucial to have the contacts moving fast in opening, such that at the first zero crossing, the contacts are far enough apart and the dielectric strength good enough to prevent a discharge from the energized capacitor. Vacuum contactors are particularly good at this type of performance because the environment is pure and constant in life; therefore the only consideration is speed or velocity of contact movement.

III. THYRISTOR SWITCHED CAPACITOR

Thyristor Switched Capacitor (TSC) System is a type of Static VAR Compensator (SVC) shunt to the line. Single phase TSC consists of a number of back-to-back connected thyristor pair in series to a capacitor and a reactor as can be seen from Figure 2. The number of branches in one phase depends on the required precision of the reactive power [3]. Due to its countless benefits including simple design and installation, TSC is preferred in many application areas. The most common one is the reactive power compensation [4].
TSC has been used since early 70s [3], [4], [5]. It was the only tool to improve the transient stability of capacitor switching. Some of the research tried to obtain this concept with GTO-Thyristor pairs as in [6]. However, GTO brought more complicated control mechanism and increased the cost. For the same reason, some other control techniques that support to charge the capacitors before switching on for a better transient response were improved [7], [8] and new zero-crossing detectors were utilized with the improvement of technology [9].

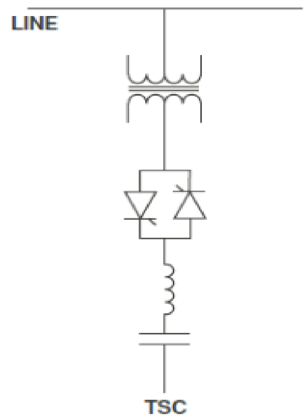

Figure 2.General structure of TSC.

IV. THE PROPOSED METHOD

The basic key point in the proposed method is to have transient-free capacitor switching. From the practical point of view, the less the transient passes the more the lifetime of the components is. The method was applied to switch a three phase delta connected capacitor to provide capacitive reactive power to the main electricity so that it reduces or cancels the reactive power demand of the large industrial loads.

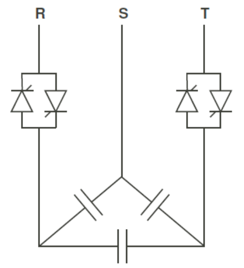

Figure 3. Structure of TSC Delta Connected Capacitor Bank.

The proposed method uses two groups of back to back thyristors instead of three groups used in standard TCR as shown if figure 3. The thyristor switches the capacitor immediately when the difference between capacitor voltage and system voltage equals zero as shown in figure 4, the current starts to flow through the capacitor and increases from zero to its peak value without any inrush current. The switch off is produced naturally when the control signal is off and the direct current flowing through thyristor extinguishes.

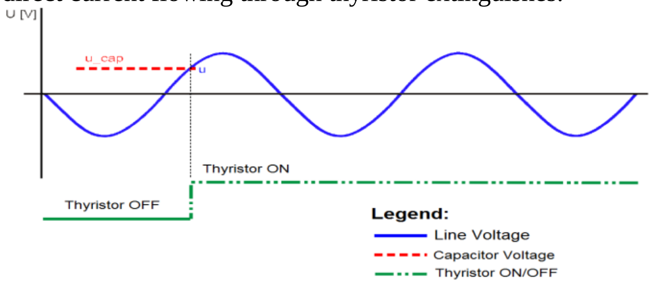

Figure 4.Principle of TSC switching at zero crossing Bank

The connection of capacitor banks in the zero-cross voltage minimizes the initial current peak which causes the variation of voltage across the capacitor, extending its life and preventing voltage drops occur in the network due to wiring inductances. This method uses a minimum number of thyristors and provides fast capacitor switching without any disturbances to the network.

V. PRACTICAL RESULTS:

The operating principles and the design rules described in the previous section are verified by conducting an intensive experimental work. The block diagram of the experiment is shown in figure 5.

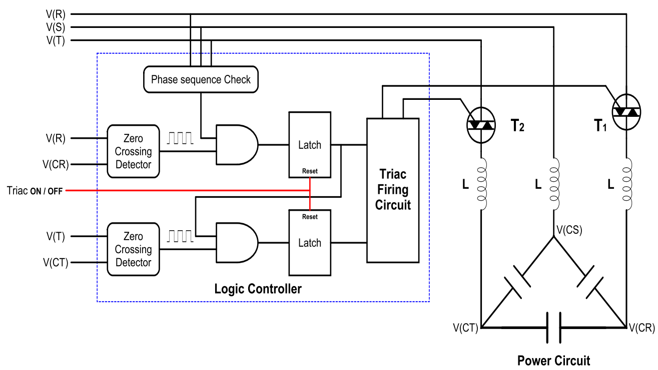

Figure 5.Schematic of the experimental work Bank.

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The experiment uses a delta connected capacitor unit having a capacitance of 210 µf for each capacitor. Therefore each capacitor can produce 8.4 KVAR at rated voltage and frequency (400V,50 Hz).As a minimum protection for the thyristors against current peaks (di/dt) a coil with inductance 0.1µHis mounted in series with the thyristor module. The switching occurs when the voltage across the thyristor switch is zero. Therefore the capacitor does not draw high amounts of current as it is exposed to zero voltage difference at the instant of a turn-on.

For the switching transient when the capacitors are initially discharged (Figure 6) there are negligible distortions on the capacitor voltage and line-to-neutral voltage waveforms (Figure 6 (a) and Figure 6 (b) respectively).

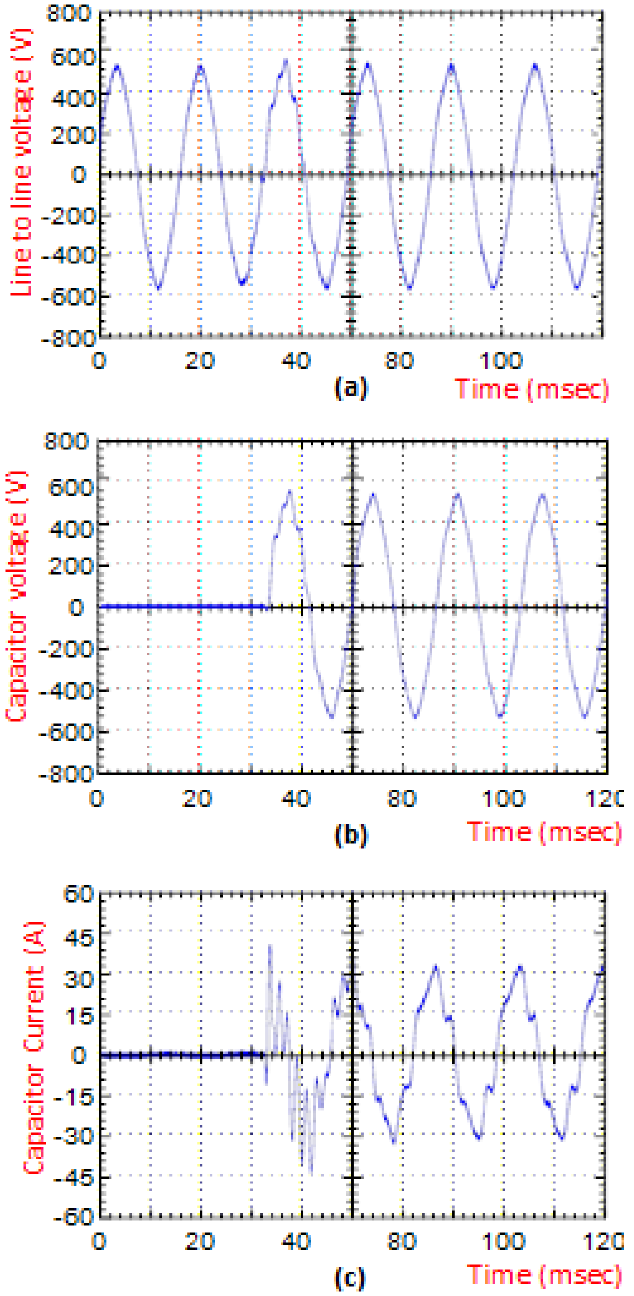

Figure 6.Resultant waveforms of TCR switching when the capacitor is initially discharged

The amplitude of transient current (Figure 6 (c)) only rises up to 45 A "nominal peak current = 32A" which means that it still has a decent transient response compared to the contactor switched capacitor's performance. The same conclusion is obtained in case of switching a charged capacitor. The waveforms shown in Figure 7 are obtained when the capacitors are initially charged to almost the peak value of the line-to-neutral voltage.

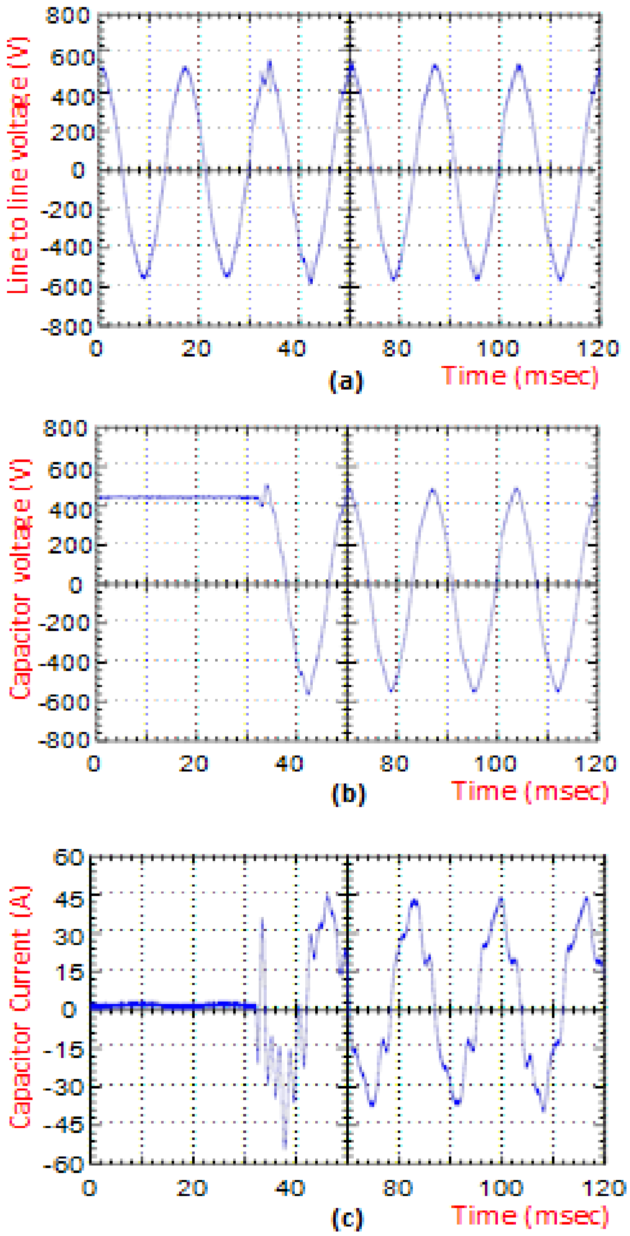

Figure 6.Resultant waveforms of TCR switching when the capacitor is initially charged

VI. CONCLUSION:

The work in this paper deals with the analysis, design and implementation of thyristor switched capacitor banks. It introduces a low cost implementation of thyristor switching capacitor which is suitable for power factor correction panels. The experimental results prove that there is a great decent in inrush current transient response compared to the contactor switched capacitor with negligible distortions on the capacitor voltage and line-to-neutral voltage waveforms.

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