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REVIEW ON CAPACITOR SWITCHING TRANSIENTS

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Abstract: The quality of electric power has been a constant topic of study, mainly because inherent problems to it can bring great economic losses in industrial processes. Among the factors that affect power quality, those related to transients originated from capacitor bank switching in the primary distribution systems must be highlighted. In this thesis, the characteristics of the transients resulting from the switching of capacitor banks are analysed, as well as factors that influence there intensities. It presents a new application of the singled reactor-type fault current limiter to suppress the three-phase low-voltage capacitor switching transients. During the capacitor switching DC reactor provides the high impedance and at the steady state limiter free-wheels. The limiter will not cause a voltage rise at the capacitor's terminals or a distortion of the capacitor's current waveform in the steady state.

I. INTRODUCTION

Shunt capacitors are widely used in power systems to improve the voltage profile in reducing existing voltage variations or those occurring from time to time. They provide the reactive power close to where the lagging loads are connected and, in turn, help reduce network losses. Normally, they are not connected to the network all of the time and are switched on and off several times during the course of a typical day. This switching, if not specially controlled, is often by overvoltage transients that compromise the supply quality. This issue is becoming more important due to the increasing use of sensitive electronic loads that are easily disrupted or even damaged by such over-voltages[1].

Various approaches have been presented for restraining capacitor switching transients, such as the use of a series current limiting reactor, a switch pre-insertion resistor/inductor, and zero-voltage closing control. These approaches may cause problems with series resonance, voltage rises at the capacitor's terminals during the steady state, need for an additional control circuit, and complexity of the setup and control strategy [2].

In the recently developed approaches [3], a DC-reactor has been utilized to mitigate the capacitor switching transients. In [3-4], single-phase DC-reactor type capacitor transient limiters are studied. These single-phase devices must be separately installed in different phases, which in turn lead to increase in the number of the electric components and lower reliability of the system. Besides, when a single-device failure occurs, the voltage imbalance across the capacitor bank terminals has negative impacts on the operation of the system. A three-phase single-DC reactor-type limiter is proposed in [2]. In this method, a DC-reactor provides high-impedance through a three-phase coupling transformer at the energizing instants, through which the transients are suppressed.

II. LITERATURE SURVEY

A paper on Identification of Capacitor Switching Transients with Consideration of Uncertain System and Component Parameters by H. Y. Zhu and S. Chen, mentioned that capacitor switching transient is one of the most commonly encountered power quality disturbances. Measuring and identifying these transients remains a challenge as the characteristics depend on the system parameters, capacitor ratings and makeup of the connected loads. This paper describes a systematic approach to design an automated system for identifying such transients. It relies on the belief that some of the system and component parameters are either known or can be determined, and thus can be used to develop the necessary pattern for identification and discrimination. However, identification also needs to be robust against uncertainties in these parameters. The proposed method combines the techniques of wavelet transform, rank correlation and fuzzy logic to account for the uncertainties. Dynamic simulations were undertaken to verify the method and to illustrate its robustness when dealing with various uncertain transient characteristics. It is shown to be capable of identifying transients caused by switching of both isolated and back-to-back capacitors.

Analysis and Control of Large-Shunt-Capacitor-Bank Switching Transients by J C Das, it is mentioned in this paper, the Large capacitor banks at medium-voltage levels are finding applications and greater acceptability in industrial distribution systems. However, these can give rise to current and voltage transients, stress the switching devices and insulation systems, and can be detrimental to the sensitive loads, i.e., drive systems. The paper discusses the methodology of the analysis and control of the switching transients.

Transient studies for an industrial distribution system are not normally performed, and when needed, capacitor switching accounts for most of these investigations consequent to the failure of equipment or the shutdown of a process. Even in these study cases, analysis can be indirect, without rigorous calculations or computer modeling. The switching transients originate from:

a) switching of a shunt-capacitor bank, which may include switching on to a fault

b) back-to-back switching, i.e., switching of a second capacitor bank on the same bus in the presence of an already energized bank

c) Tripping or de energizing a bank under normal operation and under fault conditions

d) possible secondary resonance when the capacitors are applied at multi-voltage level(i.e., at the 13.8-kV level as well as at the 480-V level) in a distribution system; and

e) Restrikes and prestrike in the switching devices

Shunt Capacitor Bank Switching Solutions for Transient Mitigation - Design Approach and EMTP Simulations by Jayanth R. Ramamurthy and Doug Mader, this paper presents an overview of switching transients commonly encountered with single and multiple shunt capacitor bank installations and describes the evaluation of transient concerns for single and multiple shunt capacitor bank switching, followed by a step-by-step procedure for application of transient mitigation measures. Mitigation of shunt capacitor bank switching transients is an important consideration at HV/EHV level. The step by step design approach described in this paper can help in streamlining the process of choosing an appropriate solution for mitigation of capacitor bank switching transients and can easily be integrated during planning and design stage.

III. PROBLEM DESCRIPTION

For the switching of capacitor several conventional methods are being used. Fixed reactor or pre inserted reactors are creating the resonance problem. Capacitor voltage levels are also needs to increase due to series reactor. Hence the DC series reactor is proposed to avoid the above mentioned issues. DC reactor provides the high impedance through a three phase coupling transformer during energizing instants. However during the steady state operation, DC reactor charges and discharges continuously. This creates the continuous steady-state power loss. Apart from this the cost of DC reactor type limiter is high for high power applications and medium for low voltage applications. So it is required to bypass the reactor after steady state operation. And send out the better solution to reduce the cost at high power applications.

IV. BASIC CONCEPTS CONCERNING ENERGIZATION OF CAPACITORS

Switching of the capacitor bank is a delicate operation due to the nature of such particular network component. In the basic characteristic of capacitor is that the voltage cannot change instantaneously; in other words, closing on a capacitor bank is almost like closing on a short circuit initially. Therefore, when capacitor is connected to power network voltage will pull down to nearly zero for certain time interval. A high current peak, namely an inrush current, will occur while the capacitor is charging. At the same movement the capacitor voltage will start to recover from its initial state and overshoot the system voltage. The capacitor voltage then oscillate around the network voltage for few cycles. As in the case of switching where a second capacitor bank is connected in parallel to one already connected bank (back to back switching), the charged bank dumps a high frequency current peak into the uncharged capacitor bank. The inrush current resulting from back to back closing is much higher in magnitude and frequency compared to single bank closing. The primary frequency of the oscillation is generally in the range 300-1000 Hz, although higher frequency component result from the initial step change. Damping from system resistance and loading determines how long the disturbance lasts, typically between 0.25 and 0.5 cycles. The transient magnitude for normal energizing are generally in the range of 1.1 to 1.5 per unit. The higher transients are associated with larger capacitors and weaker system. There are several different type capacitor bank transient such as normal switching, back to back switching, magnification transients and restrike transients. Back to back energizing occurs when there is a capacitor already energized close to the capacitor switched. The transient frequency in the current is relatively high due to the inrush current from the energized bank to the one being energized, i.e. more than 1000 Hz. The higher frequency oscillation dies out quickly and then there is a lower frequency oscillations determined by the combination of parallel capacitor with the system source inductance. Magnification of capacitor switching transient occurs when a resonance with smaller low voltage capacitor bank.th overvoltage transients in the customer facility can exceed 2.0 per unit and disrupt equipment operation. The frequency of the magnification transients is typically less than that of a normal energizing. De-energizing a capacitor bank should not produce any noticeable transients. However, an unsuccessful de-energization can produce significant transients due to restrike during a failed capacitor opening. When initial contact opening is not successful, an arc forms between the contact and re-energizes bank. This type of energizing is not desire and is consider an abnormal switching. The transient characteristics in restrike energizing are essentially identical with normal energizing, expect that that the step change at the energizing instant is much higher and severe for restrike energization. When capacitor bank opens, there are trapped charges in the bank and when restrike occur the system voltage might be opposite polarity causing the step change to go pass zero.

Methodology

In this paper, discussion of the transient mitigation methods, full time inductor, pre-insertion inductor, zero-crossing breaker and pre-insertion resistor to mitigate current transients is presented. And the devices with resistance provide the added advantage of reducing voltage transients. Proper selection of the resistance value can significantly reduce voltage transients. Zero-crossing switching shows good transient mitigation but transients will increase if timing calibration drifts.

Capacitor energizing transient limiter for mitigating capacitor switch-on transients by Tseng, S.-T., Chen, J.-F, This study proposes a rectifier type capacitor energizing transient limiter (CETL) for mitigating the isolated capacitor and back-to-back capacitor switch-on transients. The operating condition of the proposed circuit can be divided into two states: the charging suppressive mode and the steady state with its initial transient. During the charging suppressive mode, a pair of diode strings conducts automatically and then the DC reactor provides high impedance at the instant of switching on in order to suppress the capacitor energizing transients. During the steady state with its initial transient, all diodes of the bridge rectifier conduct simultaneously and the limiter freewheels; therefore the limiter acts as a short circuit and has no effect. Thus, it is not necessary to increase the capacitor-rated voltage when the CETL is used. In this study, experiments and simulations are carried out to demonstrate the feasibility of the proposed limiter circuit.

Single-DC Reactor-Type Transient Limiter for Reducing Three-Phase Power Capacitor Switching Transients by Hsu-Ting Tseng and JiannFuh Chen, This paper presents a new application of the singled reactor-type fault current limiter to suppress the three-phase low-voltage capacitor switching transients. The proposed limiter is composed of a three-phase coupling transformer, a three-phase bridge rectifier, a dc reactor, and a dc-bias voltage source. The dc reactor is connected in the three-phase coupling transformer's secondary winding and can automatically provide high impedance at the instant of energization, thus restraining the energizing transients of the three-phase capacitor. In the steady state, the bias voltage causes all rectifier diodes to conduct simultaneously, and the limiter freewheels. Therefore, the voltage across the coupling transformer's secondary side is nearly zero, and the transformer's primary side acts as a short circuit.

The limiter will not result in a voltage rise at the capacitor's terminals or a distortion of the capacitor's current waveform in the steady state. Due to the freewheeling effect in the limiter, no transient over voltage appears across the switching device at the instant of de-energization. Analytical equations to describe the performance of the system have been developed. Finally, a 2.7-kVAR three-phase capacitor is used for demonstration, and simulation and experimental results are carried out to verify the feasibility of the proposed limiter.

Capacitor Switching Transients

The simple per-phase system is used to provide a conceptual introduction to some of the common transients involved in capacitor bank switching. $R1$ and $L1$represent the system source impedance. $CB4$ feeds two capacitor banks, represented by$C1$ and $C2$. $S1$ and $S2$ represent the circuit breakers used to switch the capacitor banks.LB is the inductance of the bus spanning between the capacitor banks. $R2$ and $L2$ are the total impedance of the feeder and distribution transformer. A distribution-level capacitor bank is attached to the transformer secondary.$CB3$ can be used to initiate and interrupt a ground fault on the bus at some distance down the feeder, depending on location of the ground. Using different portions of this system, five transients can be addressed:

1. Energization inrush
2. Back-to-back energization
3. Outrush into a nearby fault
4. Voltage magnification, and
5. Transient recovery voltage (TRV).

Novel Technique for Mitigation of Capacitor Switching Transient using Capacitor energizing transient limiter (CETL)

The mitigation methods we have seen above are mainly works on the below basic principles, [4]Either they increase the line impedance at the instant of switching on, or they close the switch when the magnitude of the voltage across the switch is zero In case of increased line Impedance, there is a possibility of system resonance, which may damage the capacitor bank. And adding a reactor in series required the higher voltage rating of capacitor. In second approach of voltage zero switching need to have an additional control circuit, which will increase the cost and complexity and reduce reliability. Hence, this it proposes a rectifier type capacitor energizing transient limiter (CETL)so as to suppress the energizing transients without adding impedance during the steady state. The configuration of the proposed limiter has been widely used as a fault current limiter to suppress the power system fault current when a fault occurs in the power transmission network [4] and has also seen use as an inrush current limiter to restrain the transformer inrush current [4].

a. Circuit operation

As for mitigating the energizing transients to avoid damage to the three-phase capacitor, the proposed CETL is inserted into each phase to suppress the inrush current and transient over voltage. A CETL is mainly composed of a DC reactor, which is made from a silicon steel iron core inductor, a bridge rectifier and a DC-bias voltage source.

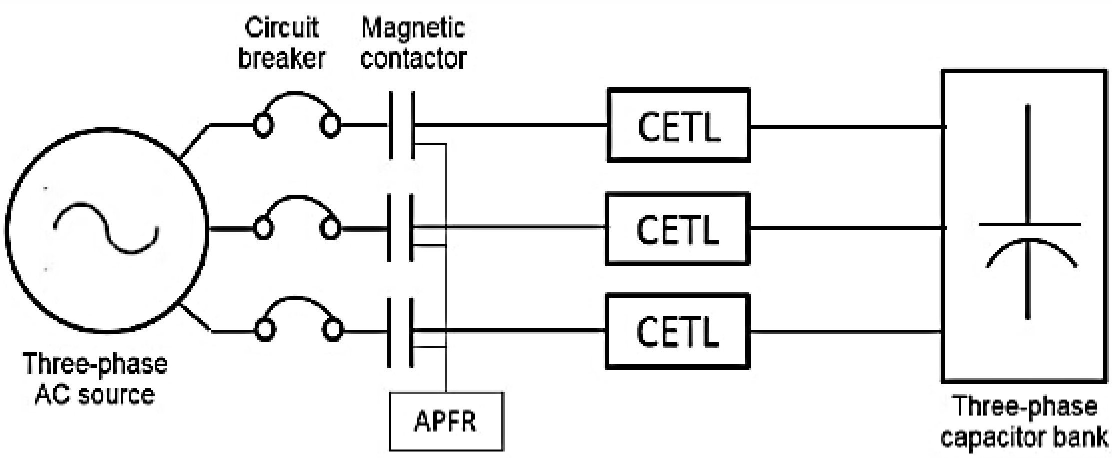

Fig.1: Installation of a CETL in three phase system

b. Single-DC Reactor-Type Transient Limiter

A three-dc reactor-type transient limiter has been proposed [4], but this limiter needs to be installed in each phase of the three-phase power system for suppressing the three-phase capacitor switching transients. Altogether, it is comprised of three dc reactors, 12 diodes for rectification, and three sets of dc-bias voltage sources. Moreover, the insulation levels and current ratings for the rectifier diodes and dc reactors must depend on the voltage level of the distribution power system, and this level cannot be adjusted arbitrarily; thus, this approach lacks flexibility. Single DC rector type transient limiter has been proposed in [2] to make the circuit more simple and reliable. This thesis is focused on this recently develop approach.

Table I: Qualitative Comparison of the approaches for reducing capacitor switching transients

Approach	Cost	Performance
Three-DC Reactor - Type Transient Limiter [2]	Moderate (for Low-Voltage Applications) High (for High-Voltage Applications)	**Advantages** 1.The effect of suppression is appreciable and viable. 2.Ready to restrain the energizing transients at any time without any control 3.No voltage rise at the capacitor's terminal in the steady state 4.No appearance of the de-energizing transients. 5.Suitable for both High- and Low voltage system **Disadvantages** 1.The ratings of bridge rectifier, dc-bias voltage source and dc reactor must depend on the system voltage level. 2.Continuous steady state power loss in the limiter
Single DC Reactor Transient Limiter [2]	Moderate (for Low-Voltage Applications) High (for High-Voltage Applications)	**Advantages** 1.The effect of suppression is appreciable and viable. 2.Ready to restrain the energizing transients at any time without any control 3.No voltage rise at the capacitor's terminal in the steady state 4.No appearance of the de-energizing transients. 5.Suitable for both High- and Low voltage system 6.The ratings of bridge rectifier, dc-bias voltage source and dc reactor can be changed by adjusting the turns ratio of the 3-PH coupling transformer **Disadvantages** 1.Continuous steady state power loss in the limiter
Zero Voltage closing control [3]	Moderate (for Low-Voltage Applications) High (for High-Voltage Applications)	**Advantages** 1.The effect of suppression is appreciable and viable. 2.Ready to restrain the energizing transients at any time without any control 3.No voltage rise at the capacitor's terminal in the steady state 4.No appearance of the de-energizing transients. 5.Suitable for both High- and Low voltage system **Disadvantages** 1. Complicated control method. 2. Need the precise detection. 3. PIV concern of power electronics-based switching devices, e.g. SCRs, for high-voltage applications. 4. For high-voltage applications each pole of the circuit breaker must be independently controlled. 5.Low reliability.

V. CONCLUSION

In this paper different mitigation techniques of capacitor bank switching is being discussed.

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