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A Method for Reducing Three-Phase Power Capacitor Switching Transients

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ABSTRACT: This paper proposes a single-dc reactor type transient limiter to reduce the three-phase low-voltage capacitor switching transients, and the concept of the proposed limiter has been used to restrain the fault current in a high voltage power system.This limiter can be also applied for suppressing the three-phase transformer inrush current and the three-phase motor-starting current in distribution power systems.

KEYWORDS: DC reactor, three phase power capacitor, Transformer

I.INTRODUCTION

Power-factor correction can provide many benefits, including increasing the capacity of distribution transformers and lines, reducing the power loss of distribution feeders, improving voltage drops, reducing electric bills for power consumers, etc. Hence, shunt capacitor banks are commonly installed in industrial plants to provide reactive power. When the capacitor is energized, the result is an inrush current and transient overvoltage. Such transient phenomena will shorten the lifetime of the capacitor and damage the contacts of the circuit breaker or electromagnetic switch. Moreover, the transients may lead the sensitive equipment to operate abnormally and could also bring about problems with power quality.

Various approaches have been presented for restraining capacitor switching transients, such as the use of a series current limiting reactor, a switch preinsertion resistor/inductor, and zero-voltage closing control, but resonance occurs in this method. Moreover a three-dc reactor-type transient limiter has been proposed here, this limiter needs to be installed in each phase of the three-phase power system for suppressing the three-phase capacitor switching transients. Moreover, this approach lacks flexibility.

II.CAPACITOR SWITCHING TRANSIENT

One to four banks of switched capacitors are typically consist in Capacitor banks applied within distribution. They are designed to be on and off automatically based on power factor and/or voltage. Due to load variations a number of switching operations will occurs. Each of the events is followed by a low-frequency decaying ring wave transient that can result in power quality problems for nearby industrial and commercial loads.When a capacitor bank is energized, the bank and the network are subject to transient voltage and current. The severity of the effect is determined by the size of the capacitor and the network impedance. The worst case occurs when the capacitor bank is energized close to a bank that is already connected.

III.INRUSH CURRENT

Inrush current input surge current or switch-on surge refers to the maximum, instantaneous input current drawn by an electrical device when first turned on (Fig 1). Power converters also often have inrush currents much higher than their steady state currents, due to the charging current of the input capacitance. The selection of over current protection devices such as fuses and circuit breakers is made more complicated when high inrush currents must be tolerated. The

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over current protection must react quickly to overload or short circuit but must not interrupt the circuit when the (usually harmless) inrush current flows. The inrush current into the newly connected bank is determined by the size of the capacitor bank and the inductance between the two banks. The larger the banks, and the smaller the inductance between banks, the higher will be the inrush current.The frequency of the inrush current is determined by the ratio of capacitor bank reactance and the impedance between the banks. The smaller the impedance, the higher will be the frequency.Power-factor correction can provide many benefits

- Increasing the capacity of distribution transformers and lines.
- Reducing the power loss of distribution feeders.
- Improving voltage drops.
- Reducing electric bills for power consumers.

Hence shunt capacitor banks are commonly installed in industrial plants to provide reactive power. Then the capacitor is energized, the result is an inrush current and transient overvoltage.Such transient phenomena will

- Shorten the lifetime of the capacitor
- Damage the contacts of the circuit breaker or electromagnetic switch
- The transients may lead the sensitive equipment to operate abnormally
- Bring about problems with power quality

Devices currently available for transient over-voltage control either attempt to minimize the transient over-voltage (or over-current) at the point of application or limit the overvoltage at remote locations.Various methods for restraining capacitor switching transients are

- The use of a series current limiting reactor.
- A switch pre-insertion resistor/inductor.
- Zero-voltage closing control.
- A three-dc reactor-type transient limiter
- Fixed inductors,
- MOV arresters,
- Dividing the capacitor bank into smaller size banks,
- Avoiding the application of capacitors at multi-voltage levels to eliminate the possibilities of secondary resonance.
- Time the switching device to close at the best possible time (when voltage across the switch is zero) rather than altering the circuit parameters.

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
- Complexity of the setup and control strategy.

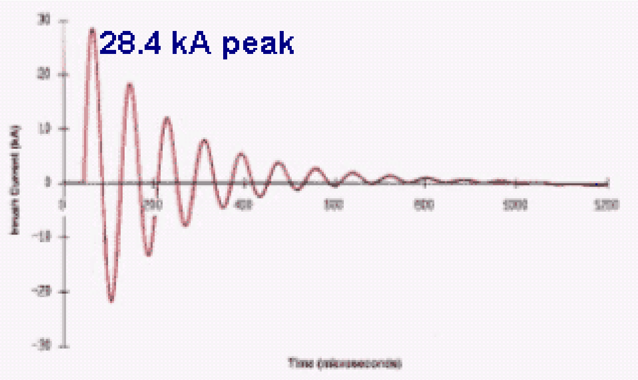

Figure1. An example of inrush current transients during capacitor bank energization.

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IV.THREE DC REACTOR TYPE LIMITER

Three DC reactor type 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 .In order to overcome the shortcomings of the three-dc reactor type transient limiter, this paper proposes a single-dc reactor type transient limiter to reduce the three-phase low-voltage capacitor transients, and the concept of the proposed limiter has been used to restrain the fault current in a high voltage power system.

It uses only one dc reactor to restrain the three-phase capacitor switching transients,which enables

- Simpler operation.
- Less power loss in the steady state.
- The consistency of transient suppression.

Even though the dc reactor is inserted between the voltage source and the capacitor, it will not cause problems with

- Series resonance, and
- It is not necessary to increase the capacitor's voltage rating during the steady state.

Therefore, the reactor's insertion will not affect the steady stateperformance of the capacitor.

- The configuration of the circuit is simple and reliable.
- There is no need for any additional control or detection circuit.
- It can restrain the switching transients that result from the energization of the three-phase grounded-wye, ungrounded-wye, or delta connected capacitor.
- As long as the amplitude of the dc reactor current is greater than that of the line current, the proposed limiter still keeps the original performance under unbalanced three-phase voltage supply conditions.

The proposed limiter not only restrains the capacitor switching transients but also limits the fault current when a fault occurs at the three-phase capacitor. Thus, it can also reduce the interrupting rating in the circuit breaker.

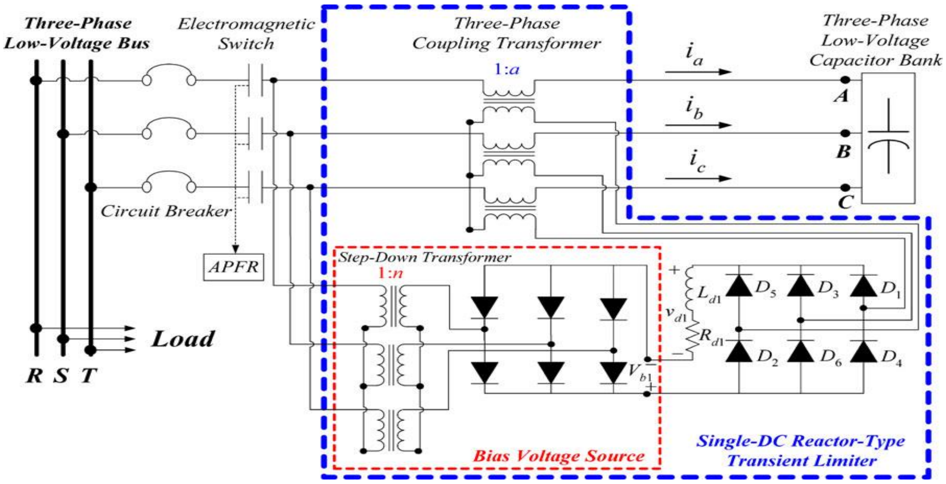

Figure2. Circuit configuration of the proposed single-dc reactor-type transient limiter

V. CIRCUIT CONFIGURATION

The circuit configuration of the proposed single-dc reactor type transient limiter (Fig 2) consisting of

- A dc reactor.
- A three-phase bridge rectifier.
- A dc-bias voltage source.
- A three-phase coupling transformer.

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The three-phase coupling transformer is inserted in series between the voltage source and the capacitor bank, and its main function is to reflect the impedance of the dc reactor into the primary circuit at the instant of energization. The insulation levels and current ratings for the three-phase bridge rectifier and the dc reactor can be changed by adjusting the turn's ratio of the three-phase coupling transformer.It provides electrical isolation between the transformer's primary and secondary sides as well.

The dc reactor is made from a silicon steel iron-core inductor with an air gap that prevents core saturation and reduces the remnant flux in the iron core. It is connected at the dc output terminal of the three-phase rectifier, and is connected in series with a bias voltage source, supplied by a single-phase or three-phase full wave rectifying voltage from a step-down potential transformer or a switching-mode power supply. For reducing the power loss before switching on, the bias voltage source is synchronously supplied at the instant of energization.

VI. OPERATION PRINCIPLE

The proposed single-dc reactor-type transientlimiter can be simplified as a single-phase circuit. Simplified single dc type transient limiter is shown in figure 3.

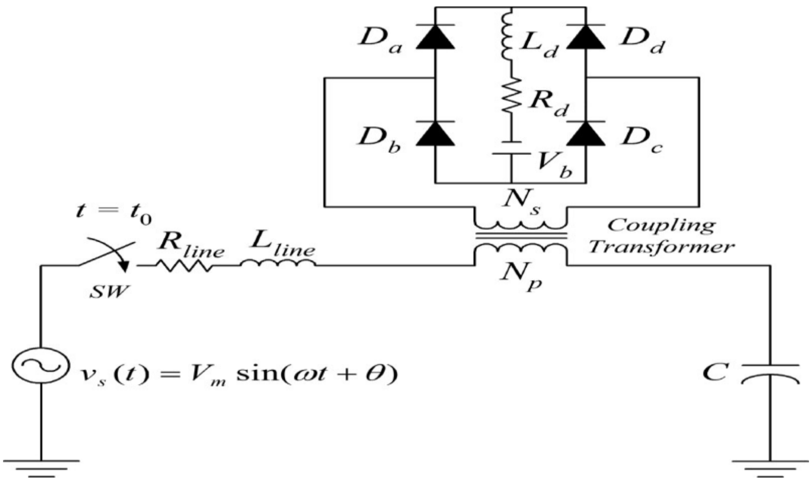

Figure3. Simplified single dc type transient limiter

According to the charging and discharging behaviour of the dc reactor, its operation states are described as follows

A. Transient State:

This state can be divided into two modes as follows.

a) Limiting Mode:

When a pair of diode strings (Da and Dc or Db and Dd) conducts at the instant of switching on, the capacitor current referred to the coupling transformer's secondary side flows through the dc reactor. Due to the reactance of the dc reactor, the magnitude of inrush current will be suppressed below the expected value and the transient overvoltage will be below the peak value of rated voltage.

b) Freewheeling Mode:

After suppressing the energizing transients, the dc reactor discharges due to the resistance of the dc reactor's coil and the forward voltage drop across the rectifier diode; then, all diodes (Da to Dd) turn on simultaneously .During this period, the limiter freewheels and acts as a short circuit. The capacitor appears to connect directly to the voltage source, and the current of the transformer secondary side flows through the path of those turn-on diodes

B. Steady State:

Because of the resistance of the dc reactor and the forward voltage drop across the rectifier diode, the dc reactor charges and discharges every half cycle during then steady-state period, and the capacitor current waveform is distorted.To address this problem, the dc reactor is in series with a dc-bias voltage source to overcome the voltage drop of one pair of the diode strings, and this setup also keeps the bridge diodes continuously conducting. The bias voltage

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source acts as a key component for allowing the dc reactor to be bypassed, and the circuit characteristic is similar to the freewheeling mode of the transient state. The magnitude of dc reactor current is adjusted so that it will be equal to or higher than the peak value of Ic, which is referred to the transformer's secondary side; then, secondary current does not flow to the dc reactor and the limiter acts as a short circuit. Thus, the voltage across the transformer's secondary side is close to zero and the primary side acts as if it is short circuited. Furthermore, the waveform of the capacitor current is not distorted, and it appears that the capacitor is connected directly to the voltage source.

C. De-Energization State:

When the capacitor is de-energized, the contacts of the switching device are opened and the capacitor current will soon become zero. Meanwhile, the dc-bias voltage is equal to zero, and thus, it is equivalent to a short circuit. Because the dc reactor releases its energy stored in the steady state, its voltage polarity is reversed, and all diodes keep conducting. The dc reactor current still circulates and the limiter keeps freewheeling. Therefore, even though the dc reactor is used between the voltage source and the capacitor, no transient overvoltage appears across the contacts of the switching device at the instant of de-energization. When the energy stored in the dc reactor is exhausted, all diodes will stop conducting, and the dc reactor current will become zero.

VII. CONCLUSION

This paper has presented a new application of the singled reactor-type fault current limiter to reduce the three-phase capacitor inrush current and transient overvoltage. Unlike other approaches, the proposed limiter has

- No need for any additional control circuit
- The circuit topology is simple.
- It can reduce complexity
- Increase reliability.

A point that is especially to be noted is that fewer components are required for the proposed single-dc reactor-type transient limiter as compared with the three-dc reactor type. Since the transient limiter provides high impedance during the transient period, the energizing transients can be effectively suppressed. During the steady-state period, the limiter freewheels without adding any impedance between the voltage source and the capacitor. Thus, the terminal voltage of the capacitor will not rise, and thus, it is not necessary to increase the capacitor's voltage rating. The installation of the limiter almost will not result in voltage and current distortions in the capacitor or system series resonance. According to simulated and experimental results, it has been proved that the proposed single-dc reactor-type transient limiter is effective for suppressing the three-phase capacitor switching transients, Will not affect the steady-state performance of the capacitor, the proposed limiter can restrain the back-to-back capacitor switching transients as well.

For high-voltage applications, the insulation levels of three-phase bridge rectifiers, three-phase coupling and step down transformers and a dc reactor need to be properly taken into account. In practice, VAR compensation is required when a fault occurs somewhere upstream in the system. Most faults will result in unbalanced voltage sags, and thus, the future work is recommended to investigate the performance and feasibility of the proposed limiter under these unbalanced conditions .In addition, given different design considerations, the proposed limiter can be also applied for suppressing the three-phase transformer inrush current and the three-phase motor-starting current in distribution power systems.

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