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Suppression of the Capacitor Switching Transient Phenomenon using Capacitor Energizing Transient Limiter

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Abstract- Capacitors are prone to two major types of energizing transient phenomenon: transient overvoltage and inrush current (charging current). Capacitor switching transients are harmful to the capacitor and the switching device. For reducing these transient phenomena, this paper proposes a capacitor energizing transient limiter (CETL). The proposed CETL can automatically provide high impedance at the instant of capacitor energizing, thus, the switching transients can be effectively suppressed. 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. Related components are depicted. Finally, the simulation results obtained using different methods of capacitor switching verify the feasibility and performance of the proposed CETL.

Keywords- *Capacitor switching transients; distortion; Capacitor energizing transient limiter(CETL); compensation*

I. INTRODUCTION

Power-factor correction (PFC) can reduce the loss of distribution feeders, increase the capacity of transformers and lines, improve voltage drops and reduce the electric feed for utility consumers; therefore shunt capacitor banks are commonly installed in industrial plants [1, 2]. Reactive power compensation is controlled by an automatic power factor regulator (APFR) to vary the amount of PFC, generally according to the site's power factor. Since the inductive load varies with time, the capacitor will switch frequently, which will result in a high magnitude/frequency inrush current and a transient overvoltage. The capacitor's energizing transients will shorten the lifetime of the capacitor and damage the contacts of the switching device such as a circuit breaker or electromagnetic switch. Thus, some standards have been formulated to restrict the magnitude, times and duration of the energizing transients [3–4].

To date, there are several approaches for suppression of the capacitor's switch-on transients:

1. series current limiting reactor [5],
2. switch pre-insertion resistor/inductor [5,6],
3. synchronous closing control method [9, 10] and
4. power electronics control method [8].

The above approaches work in one of two ways:

1. either they increase the line impedance at the instant of switching on, or 2. they close the switch when the magnitude of the voltage across the switch is zero.

Approaches 1 and 2 belong to the way 1 and the others to 2. However, it is necessary to consider that the fixed reactor may cause system resonance and raise the rated voltage of the capacitor, in case of approach 1. Besides approach 1, the other methods need to have an additional control circuit, which will increase the cost and complexity and reduce reliability. Hence, this paper 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 [9,10] and has also seen use as an inrush current limiter to restrain the transformer inrush current [11]. The advantages of the proposed limiter are listed as follows:

- Although the DC reactor is used to suppress the energizing transients, there is no system-resonance problem, and the addition of the reactor does not necessitate an increased voltage rating of the capacitor in the steady state.
- The configuration of the circuit is simple and reliable.
- There is no need for any additional control or detection circuit, and thus the cost is low.

II. PRINCIPLE OF 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 overvoltage, as shown in Figure. 1. For the sake of simplification, the single-phase circuit is analyzed to describe the operating principle of the proposed circuit, as shown in Figure. 2. 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. Its two operation states are described as follows.

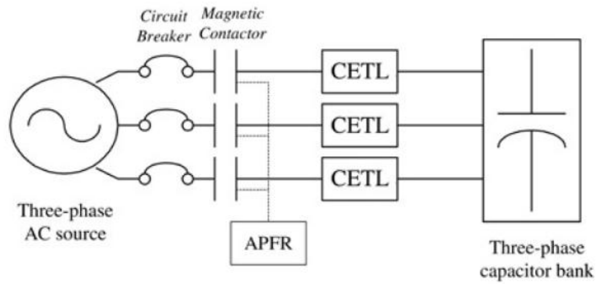

Figure 1. Installation of the CETL in a three-phase distribution system.

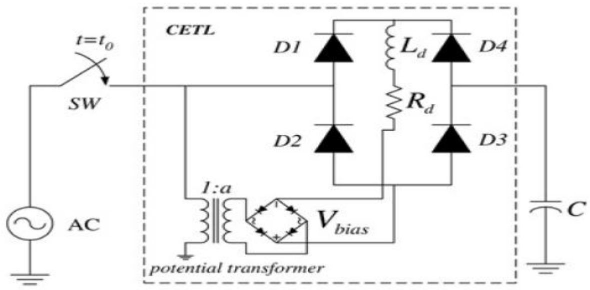

Figure 2. Single-phase circuit diagram of CETL.

The CETL with a full-wave rectifying compensating voltage system is generally installed at the customer's side, and in each phase of a three-phase power system. The system diagram is shown in Figure.3, where CH and CL stand for the capacitance of the switched utility HV capacitor bank and the customer LV PFC capacitor, respectively.

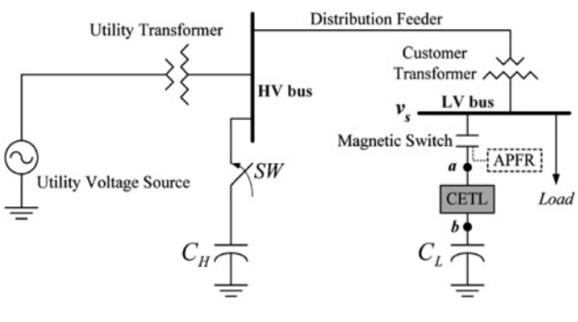

Figure 3. Location of the proposed CETL

A. *Charging suppressive mode*

When a pair of diode strings (D1 and D3 or D2 and D4) conducts at the instant of switching on, the capacitor current flows through DC reactor Ld , and the magnitudes of the inrush current and transient overvoltage will be suppressed greatly. The circuit diagram is shown in Figure. 4.

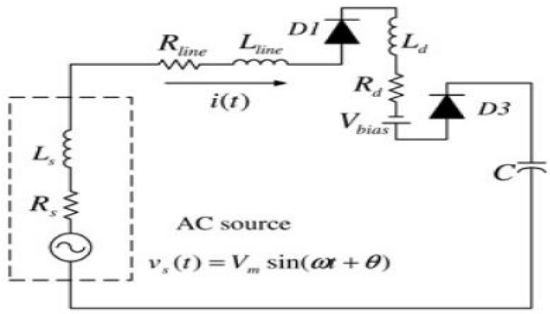

Figure 4. Circuit diagram of CETL in the charging suppressive mode.

B. *Steady state with its initial transient*

After completing the suppression of energizing transients, DC reactor Ld discharges because of the energy consumption of its coil resistance and the forward voltage drop in a pair of diode strings, and then all diodes (D1 to D4) turn on simultaneously. During this discharging period, the CETL freewheels, and the DC reactor is bypassed automatically; thus the CETL acts as a short circuit and has no effect. The capacitor current flows through the path of the turn-on diodes, as shown in Figure. 5.

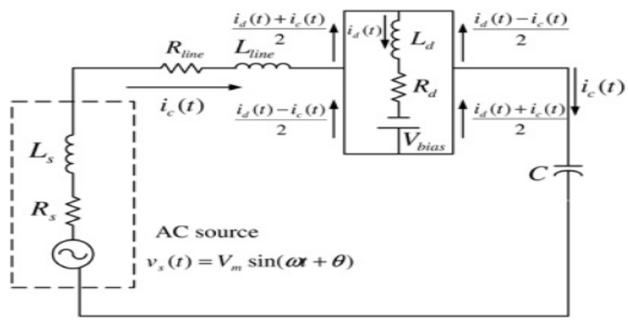

Figure 5. Circuit diagram of the CETL in the steady state with its initial transient when id is equal to or higher than the peak of ic.

After the DC reactor has been discharged, the DC reactor current reaches the capacitor current, and the DC reactor charges and discharges repeatedly in the steady state without the use of a DC-bias voltage source. As a result, the waveform of the capacitor current is distorted. For the lessening of the current distortion the DC reactor is placed in series with a DC-bias voltage source, whose supply is a full-wave rectifying voltage obtained from a step-down potential transformer; this set-up will overcome the voltage drop in the DC reactor and that in one pair of rectifier diode strings and keep the bridge diodes conducting continuously. The DC reactor current, supplied by the bias voltage source, is similar to a DC current with negligible ripple, and it leads to a short circuiting of Ld . To adjust the magnitude of the DC reactor current so that it will be equal to or slightly higher than the peak value of the capacitor current, the CETL then acts as a short circuit and has no effect in the steady state. The capacitor current waveform in the steady state will not be distorted and is similar to the wave that results from the capacitor's being directly connected to the voltage source.

III. SIMULATION AND RESULTS

In this section, the proposed transient limiter simulated using EMTP-RV software to suppress the inrush current and transient overvoltage, to be used when energizing the capacitor.

Network parameters are as follows [12].

TABLE I. SIMULATION AND EXPERIMENTAL PARAMETERS

Parameters	Contents	Value
voltage source	magnitude of rms voltage	220V
	inductance of voltage source and line	107µH
	resistance of voltage source and line	0.385Ω
capacitor	capacitance	110µF
	interior discharging resistor	125KΩ
bridge rectifier	forward voltage drop of diode	1.2V
DC reactor	inductance of DC reactor	38.87µH
	resistance of DC reactor	0.559Ω
bias voltage source	magnitude of DC current	14.1A

Case study 1: Figure 6 shows the proposed circuit is discussed in the absence of limiter, the circuit connects switch at 10ms.

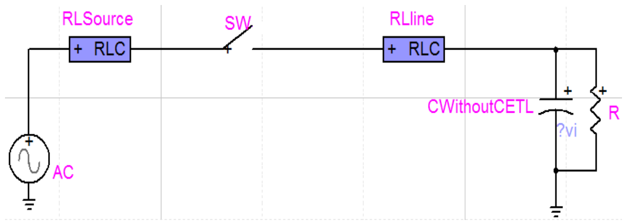

Figure 6. The circuit was simulated using EMTP-RV software without transient limiter.

Figures 7, 8 and 9 show the simulation results in Figure 6 for voltage and current waveforms of capacitor.

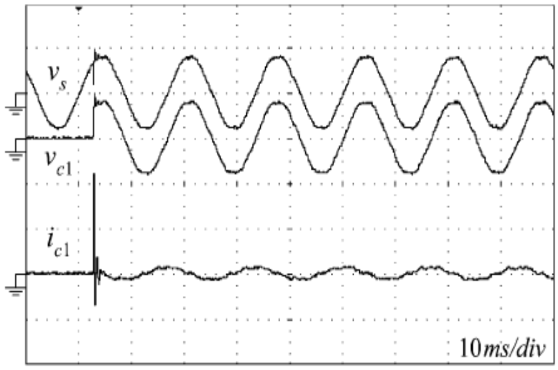

Figure 7. The voltage and current waveforms of capacitor without limiter in the laboratory [12].

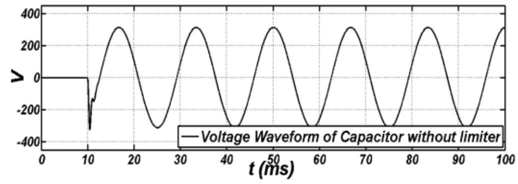

Figure 8. The voltage waveform of capacitor without transient limiter.

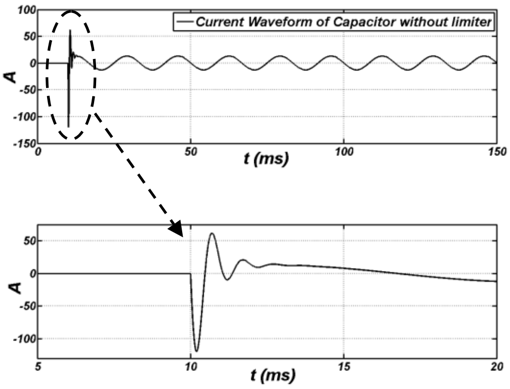

Figure 9. The current waveforms of capacitor without limiter.

As can be seen in Figure 9, Peak amplitude of the capacitor current is near -120A when connected to the switch (transient) is about 9 to 10 times the range of steady state. This amplitude will damage the contacts of the switching device.

Case Study 2: Figure.10 shows Figure.6, if the proposal limiter connects.

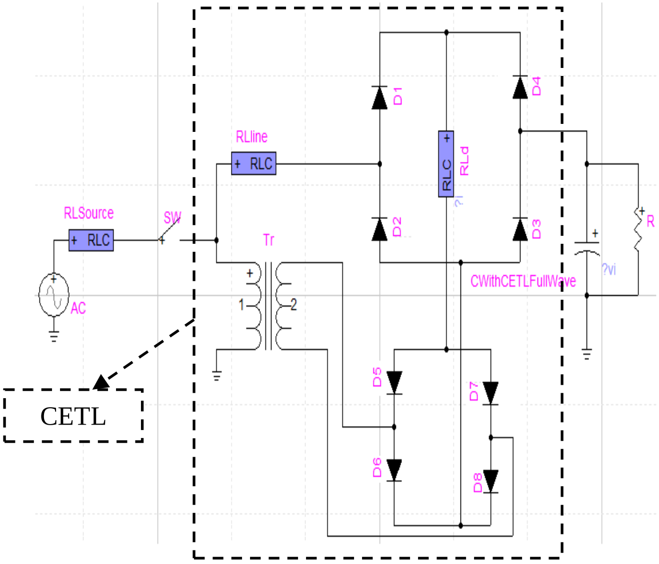

Figure 10. Circuit case study with the proposed limiter.

Figures 11-15, show the simulation results of Figure.10 when the angle is zero and 60 degree.

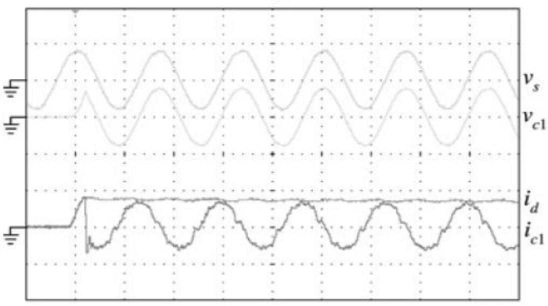

Figure 11. The voltage and current waveforms of capacitor with limiter and angle 60º at the laboratory [12].

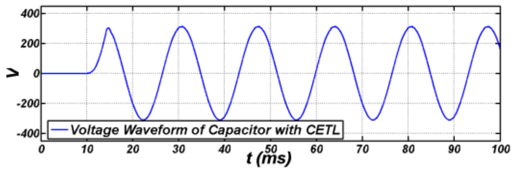

Figure 12. The voltage waveforms of capacitor with limiter and angle 60º.

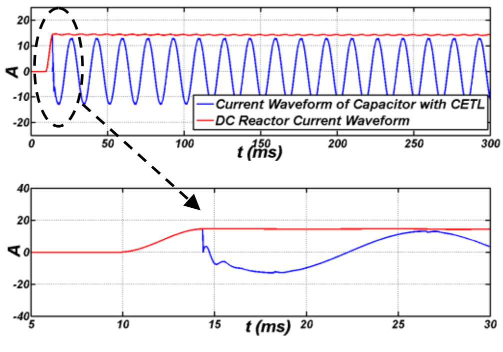

Figure 13. : The current waveforms of capacitor and reactor DC current with the proposed limiter and source angle 60°.

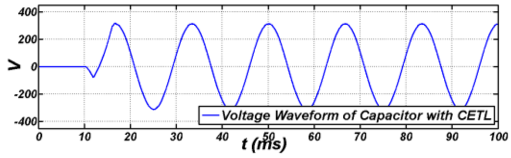

Figure 14. The voltage waveforms of capacitor with limiter and angle 0°.

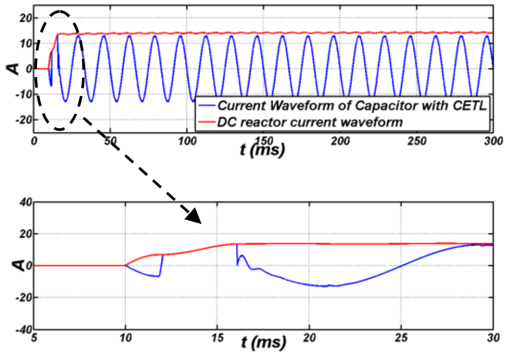

Figure 15. The current waveforms of capacitor and reactor DC current with the proposed limiter and source angle 0°.

As can be seen in Figures 13 and 15, peak amplitude of the capacitor connected to the second switch (transient) near the peak amplitude reaches a steady state. The proposed mechanism showing that the limit has been successful in suppressing capacitor having energy transients. In Table 2, the voltage and current waveforms 1 and 2 when the angle of the source is zero, are compared with each other.

TABLE II. COMPARISON OF VOLTAGE AND CURRENT OF CAPACITOR IS CONNECTED TO THE SWITCH.

Parameters	Contents	Value
Peak amplitude of the capacitor current	Without limiter	-119.79A
	With transient limiter	13.49A
Voltage of capacitor	Without limiter	The waveform of the capacitor voltage has distortion and overvoltage.
	With transient limiter	The waveform of the capacitor voltage has not distortion and overvoltage.

IV. CONCLUSION

This paper has presented the theoretical analysis and experiments for the capability of the proposed CETL to restrain the capacitor switching transients. The proposed limiter has a simple configuration and no need for any additional control circuit. The CETL can automatically insert into the circuit and provide high impedance to reduce the switching transients when the capacitor is energized. Suppression mode while charging, a pair of diodes to automatically steer the DC reactor with high impedance at the switching transients suppression capacitor provides the energy to produce. In his cursory initial steady state value, the bridge rectifier diodes conduct and restrictive mechanism to get rid of the zero impedance voltage source and the capacitor acts provides. Any increase in voltage capacitor acts installation CETL no distortion capacitors or the system will not result in any resonance phenomenon. Finally, CETL in EMTP-RV simulations have shown that having a capacitor energy transient can be suppressed effectively.

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