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Detection and Mitigation of Fault in Multi Level Converter STATCOMS with Three Level Converter Topologies

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ABSTRACT:

Many static synchronous compensators (STATCOMs) utilize multilevel converters due to the following: 1) lower harmonic injection into the power system; 2) decreased stress on the electronic components due to decreased voltages; and 3) lower switching losses. One disadvantage, however, is the increased likelihood of a switch failure due to the increased number of switches in a multilevel converter.

A single switch failure, however, does not necessarily force an (2n + 1)-level STATCOM offline. Even with a reduced number of switches, a STATCOM can still provide a significant range of control by removing the module of the faulted switch and continuing with (2n – 1) levels. This paper introduces an approach to detect the existence of the faulted switch, identify which switch is faulty, and reconfigure the STATCOM. This approach is illustrated on an eleven-level STATCOM and the effect on the dynamic performance and the total harmonic distortion (THD) is analyzed.

Index Terms:

Fault detection, multilevel converter, static synchronous compensator (STATCOM).

I. INTRODUCTION:

The static synchronous compensator (STATCOM) has been well accepted as a power system controller for improving voltage regulation and reactive compensation .

There are several compelling reasons to consider a multilevel converter topology for the STATCOM. These well known reasons include the following: 1) lower harmonic injection into the power system 2) decreased stress on the electronic components due to decreased voltages; and 3) lower switching losses. Various multilevel converters also readily lend themselves to a variety of PWM strategies to improve efficiency and control.

An eleven-level cascaded multilevel STATCOM is shown in Fig. 1. This converter uses several full bridges in series to synthesize staircase waveforms. Because every full bridge can have three output voltages with different switching combinations, the number of output voltage levels is 2n + 1 where n is the number of full bridges in every phase. The converter cells are identical and therefore modular. As higher level converters are used for high output rating power applications, a large number of power switching devices.

Fig. 1. Eleven-level cascaded multilevel STATCOM.

II. MULTILEVEL STATCOM:

A cascaded multilevel STATCOM contains several H-bridges in series to synthesize a staircase waveform.

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The inverter legs are identical and are therefore modular. In the eleven-level STATCOM, each leg has five H-bridges. Since each full bridge generates three different level voltages (V, 0,–V) under different switching states, the number of output voltage levels will be eleven. A multilevel configuration offers several advantages over other converter types.1) It is better suited for high-voltage, high-power applications than the conventional converters since the currents and voltages across the individual switching devices are smaller.2) It generates a multistep staircase voltage waveform approaching a more sinusoidal output voltage by increasing the number of levels.3) It has better dc voltage balancing, since each bridge has its own dc source.

To achieve a high-quality output voltage waveform, the voltages across all of the dc capacitors should maintain a constant value. Variations in load cause the dc capacitors to charge and discharge unevenly leading to different voltages in each leg of each phase. However, because of the redundancy in switching states, there is frequently more than one state that can synthesize any given voltage level.. Since there are multiple possible switching states that can be used to synthesize a given voltage level, the particular switching topology is chosen such that the capacitors with the lowest voltages are charged or conversely, the capacitors with the highest voltages are discharged. This redundant state selection approach is used to maintain the total dc link voltage to a near constant value and each individual cell capacitor within a tight bound. Different pulse width modulation (PWM) techniques have been used to obtain the multilevel converter output voltage.

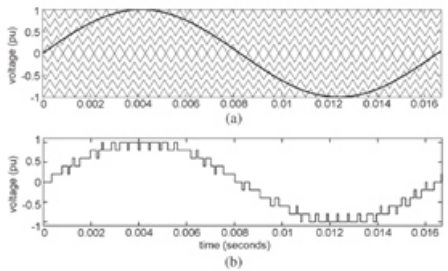

Fig. 2. (a) Carrier and reference waveform for PSPWM.
(b) Output waveform.

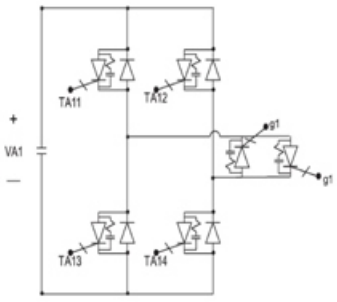

Fig. 3. Cell with fault switch.

One common PWM approach is the phase shift PWM (PSPWM) switching concept. The PSPWM strategy causes cancellation of all carrier and associated sideband harmonics up to the (N – 1)th carrier group for an N-level converter. Each carrier signal is phase shifted by

$\Delta\varphi = 2\pi/n$

where n is the number of cells in each phase. Fig. 2 illustrates the carrier and reference waveforms for a phase leg of the eleven-level STATCOM. In this figure, the carrier frequency has been decreased for better clarity. Normally, the carrier frequency for PWM is in the range of 1–10 kHz.

III. FAULT ANALYSIS FOR THE MULTILEVEL STATCOM:

A converter cell block, as shown in Fig. 3, can experience several types of faults. Each switch in the cell can fail in an open or closed state. The closed state is the most severe failure since it may lead to shoot through and short circuit the entire cell. An open circuit can be avoided by using a proper gate circuit to control the gate current of the switch during the failure. If a short circuit failure occurs, the capacitors will rapidly discharge through the conducting switch pair if no protective action is taken. Hence, the counterpart switch to the failed switch must be quickly turned off to avoid system collapse due to a sharp current surge.

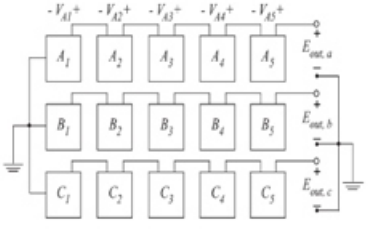

Fig. 4. Simplified eleven-level cascaded multilevel STATCOM.

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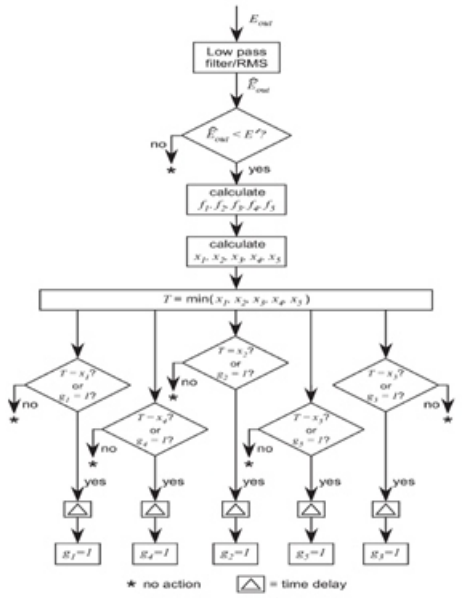

Fig. 5. Flowchart for eleven-level converter.

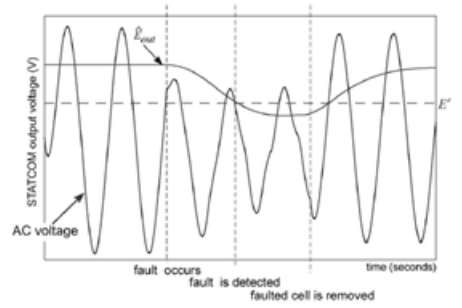

Fig. 6. STATCOM-filtered output voltage and threshold value.

Consider the simplified eleven-level converter shown in Fig. 4. The process for identifying and removing the faulty cell block is summarized in Fig. 5. The input to the detection algorithm is ˆEout for each phase, where ˆEout is the STATCOM filtered RMS output voltage. If the STATCOM RMS output voltage drops below a preset threshold value (E_), then, a fault is known to have occurred (see Fig. 6).

IV. SIMULATION RESULTS:

The single line diagram of the electrical distribution system feeding an arc furnace is shown in Fig. 8. The STATCOM has been shown to be an efficient controller to mitigate arc furnace flicker. The electrical network consists of a 115-kV generator and impedance that is equivalent to that of a large network at the point of common coupling (PCC).

The STATCOM is connected to the system through a Y-Delta transformer. The system was simulated using PSCAD/EMDTC. The electrical arc furnace load is non sinusoidal, unbalanced, and randomly fluctuating. Electric arc furnaces are typically used to melt steel and will produce current harmonics that are random. In addition to the integer harmonics, arc furnace currents are rich in inter harmonics. The flicker waveform has sub synchronous variations in the 5–35-Hz range. Fig. 9 shows the active power drawn by the arc furnace. Note that the STATCOM is able to improve the line active power such that active power variations caused by the arc furnace do not propagate throughout the system as shown in Fig. 10. The simulation model and control scheme is described in detail in. The dc capacitor voltages normally vary and are kept in relative balance through redundant state selection .

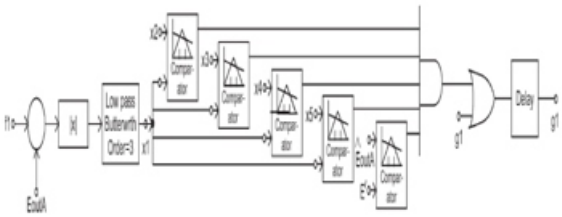

Fig. 7. Proposed fault detection and remediation control for cell 1.

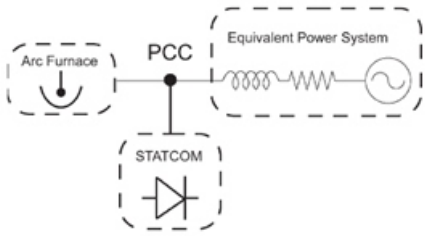

Fig. 8. Test system.

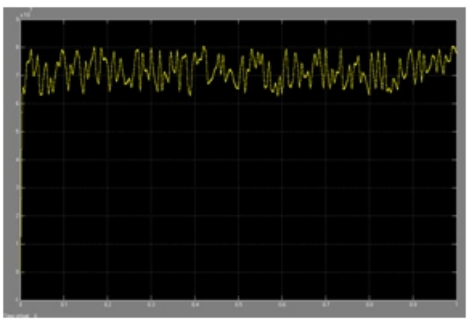

Fig. 9. Active power drawn by the arc furnace load.

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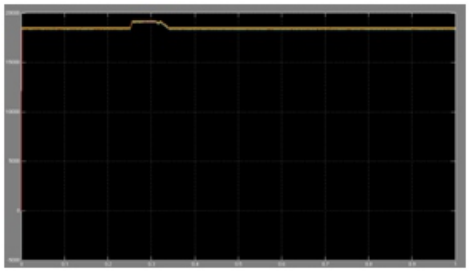


Fig.10 Dc voltages across fault levels.

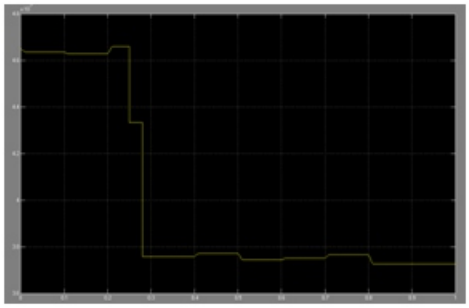
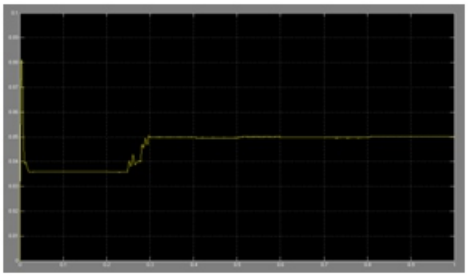
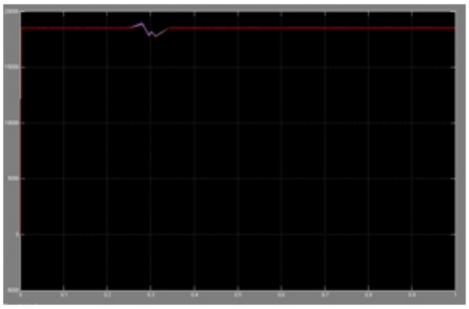


Fig.5.11 Dc output Voltage





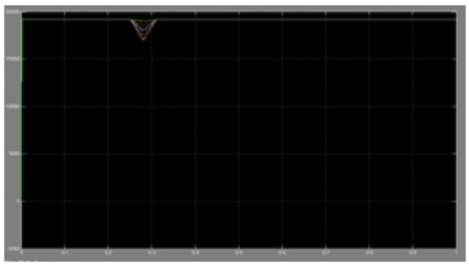


Fig. 12. Individual module capacitor voltages before, during, and after fault.

CONCLUSION:

A fault detection and mitigation strategy for a multi-level cascaded converter has been proposed in this paper. This approach requires no extra sensors and only one additional bypass switch per module per phase. The approach has been validated on a 115-kV system with a STATCOM compensating an electric arc furnace load. This application was chosen since the arc furnace provides a severe application with its non sinusoidal, unbalanced, and randomly fluctuating load. The proposed approach was able to accurately identify and remove the faulted module. In addition, the STATCOM was able to remain in service and continue to provide compensation without exceeding the total harmonic distortion allowances.

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