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Eccentric operation of STATCOM Using Predictive Controller

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ABSTRACT

The impact of multilevel converter STATCOM in transmission and distribution system is given high importance. Increment of number of switches in multi-level cascaded H-bridge converter, made it more vulnerable to open circuit and short circuit faults. To reduce the effect of faults on line voltage magnitude, in this paper an advanced improved predictive controller is used to generate PWM pulses for the power electronic devices. A Cascaded H-bridge STATCOM, interconnected to a distribution system with linear and non-linear loads. The feedback control structure of STATCOM has an advantage of reducing THD and controllable reactive power. A switch fault detection and elimination method is proposed with a bypass switch connected to each H-bridge to surpass the faulty H-bridge. The complete analysis with all control structures is designed in MATLAB/Simulink representing dynamic graphs and feasibility of proposed method is verified.

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1. INTRODUCTION

Power quality maintenance is of major problem to be solved with the increase of load demand. Many loads connected to distribution grid consume active power and also high reactive power with reduction of power factor of the main source. To maintain the power factor of source, reactive power drain from source has to be decreased with a supplement device connected to the distribution line. So, that the reactive power demand of the load can be compensated with the device and source supplies only active power, with negligible reactive power drain. This makes the active power equal to apparent power increasing the power factor of the source to unity. Voltage sags caused due to sudden change of loads can also be eliminated with increase of the total apparent power of the system, supporting the loads even in high demand conditions.

The device used to inject reactive power into the grid can be a STATCOM [1]. This FACTS device is capable for Voltage Regulation, Shunt Compensation and Powerfactor improvement. STATCOM controls line flow without disturbing thermal limits, stability margin etc. keeping losses minimum. Many research papers have been published on Multilevel converter based STATCOM with Convetional controllers like PI, carrier based techniques and Spacevector PWM. Each controller technique has it’s advantages and disadvantages. PI controllers were easy to design and compute but lack of dynamic performance in wide range with trial and error method. SVPWM is of more computational complexity and harmonic distortion, instead they had good dc-link utilization.

This paper presents a simple predictive current controller[2], proposed for multilevel converter to deliver power to the (un)balanced/(non) linear loads[6]. The paper is organized as follows: Section 2 explains the proposed predictive controller scheme. Section 3 explains in detail the fault identification and mitigation modelling. Section 4 presents simulation results after the installation of STATCOM in the Test system.

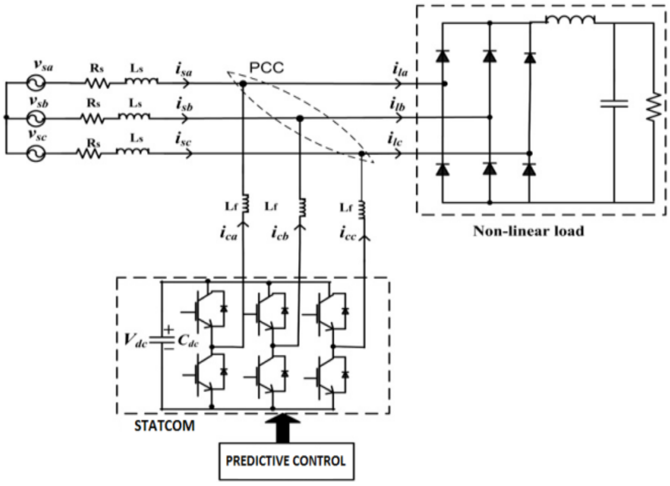

Figure 1. Block diagram of test system

A simple test system with STATCOM connected to grid shown in block diagram Figure1. The system has a three phase source with a three phase heavy linear load. The STATCOM is a combination of a VSC (Voltage Source Converter) [3] and a static capacitor. The Rs and Ls are the filter resistance and filter inductance connected to reduce the harmonic distortion caused by the STATCOM as it uses PWM control. The conventional STATCOM utilizes three levels VSC to inject reactive power into the distribution grid, along with harmonics introduced in the lines.

However the filter connected to STATCOM reduces the harmonics to a certain extent. Further harmonics introduced by the VSC can be reduced by increasing the number levels [8] of the converter. In this paper we introduce a multi-level cascaded H-bridge converter with six H-bridges [6] as the number of levels are formulated as 2n+1 where, n = number of cascaded H-bridges. The model of the multi-level cascaded H-bridge converter shown in Figure 2. Each H-bridge comprises of a DC capacitor which is considered as the reactive power compensation element. PWM [4,5] generation reference waveforms to operate the H-bridge switches are shown in Figure 3.

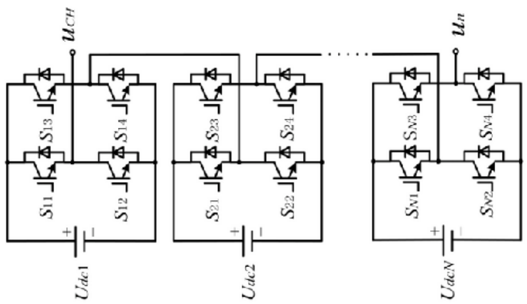

Figure 2. Multi level cascaded H-bridge converter of one phase

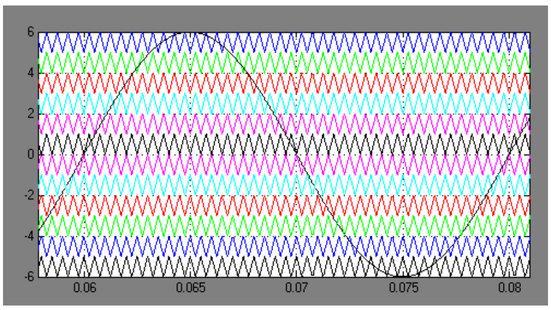

Figure 3. Reference waveforms for 13-level cascaded H-bridge converter

2. PREDICTIVE CONTROL ALGORITHM

The controller of the STATCOM predicts the output current of the converter and generate pulses for the power electronics devices. Predictive controller has cost function optimization algorithm where the system has to be operated in a discrete time domain. With respect to discrete time Ts [3] values are generated for iteration 'k+1', which is the predictive value of the iteration 'k' [6]. The discrete change in the present and next iteration can be given as

$$\frac{dy}{dt} \approx \frac{y(k+1) - y(k)}{Ts} \quad (1)$$

The ‘k+1’ predictive output current of the converter is given as

$$Io\ (k+1) = \frac{Ts}{Leq}[Vxn(k) - Vo(k)] + \left(1 - \frac{Req*Ts}{Leq}\right) * io(k) \quad (2)$$

Where, Vxn (k) is the phase voltage for the present iteration and Vo (k) is given as

$$Vo = Vxn - (Req * io) - Leq\left(\frac{dio}{dt}\right) \quad (3)$$

With the above currents prediction of all the three phases the cost function optimization is

$$g(k+1) = [i*ou(k+1) - iou(k+1)]^2 + [i*ov(k+1) - iov(k+1)]^2 + [i*ow(k+1) - iow(k+1)]^2 + [i*on(k+1) - ion(k+1)]^2 \quad (4)$$

The generated reference waveform is considered as fundamental waveform compared with triangular carrier waveforms to generate PWM signals.The block diagram of the proposed predictive controller [5] to control the reactive power output of the STATCOM is shown in Figure4.

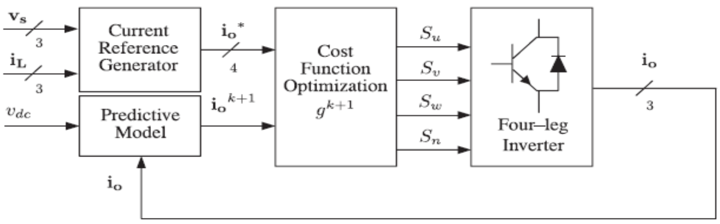

Figure 4. Proposed predictive controller scheme

The current reference (io*) generator block diagram is shown in Figure 5 with a feedback of source voltage and load current from the distribution grid. V_{dc} is the combined DC voltage of the six capacitors connected on the DC side of the H-bridges.

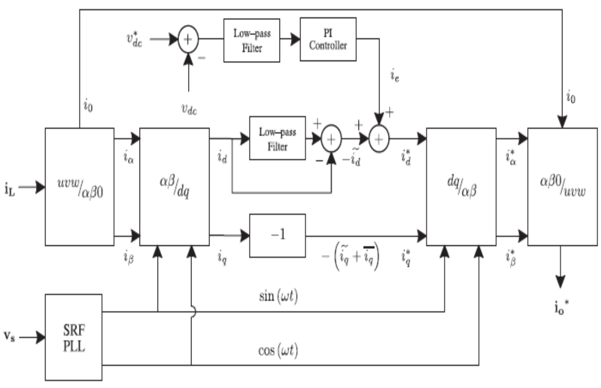

Figure 5. Current reference generator for predictive controller

3. SWITCH FAULT IDENTIFICATION AND MITIGATION MODELING

As reference to the previous section I the number of cascaded H-bridge converters are six with each converter comprising of four power electronic devices (IGBT) [9]. The four switches are labeled as S1 – S4, where S1 S4 and S2 S3 operate simultaneously ie., the same PWM signal are fed to the switches S1 S4 and S2 S3.

A single H-bridge with four IGBTs (S1-S4) can be seen below in Figure 6. Each leg contains 24 IGBTs and the total number of switches in STATCOM is 72, where the risk of fault on any switch is more. The faults on a switch can be either open circuit or short circuit, which may affect the operation of STATCOM resulting in disruptions in the grid parameters. The faulty switch has to be replaced or the entire H-bridge has to be bypassed [10,11] to eliminate the fault[12]. Rather providing alternate switch to each and every switch which increase the complexity of the device, so bypassing the H-bridge with a bypass switch is more reliable and flexible. The below Figure 7 is the diagram of the H-bridge with a bypass switch (IGBT).

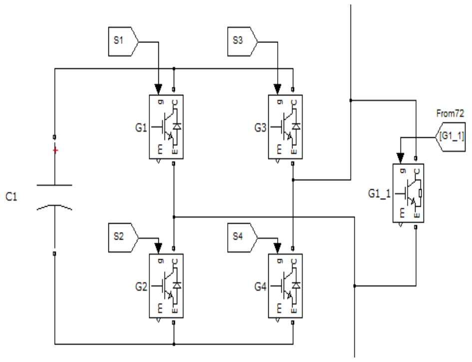

Figure 7. H-bridge with bypass IGBT switch

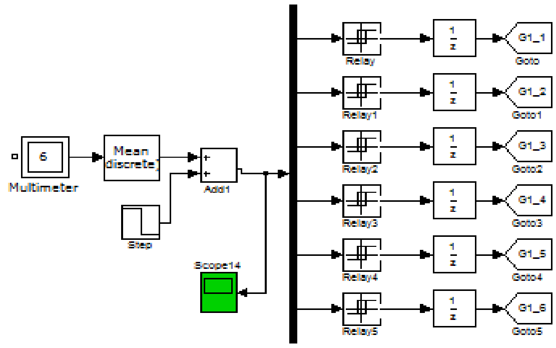

Figure 8. Controller to generate signal for the bypass switches

The signal to the bypass switch [9] is generated with feedback of H-bridge DC side capacitor voltage. A relay is set within an operating range of capacitor voltage, with the change in voltage of the capacitor during the open circuit or short circuit faults the relay operates and switches ON the bypass switch to surpass the faulty [10,11] H-bridge with elimination of fault in the STATCOM. The below Figure 8 is the feedback signal generator for the bypass switch.

4. RESULTS AND ANALYSIS

It is important to design a sophisticated control to produce a fault-tolerant STATCOM as higher level converters are used. A faulty power cell in a cascaded H-Bridge STATCOM [12] can potentially cause switch modules to explode leading to the fault conditions such as a short circuit or an overvoltage on the power system resulting in an expensive down time. Subsequently, it is crucial to identify the existence and location of the fault for it to be removed. Short circuit failure of power electronic switches in cascaded multilevel inverters is a major problem which leads to unwanted shutdown of operation, catastrophic failures in motor drives and major economical losses.

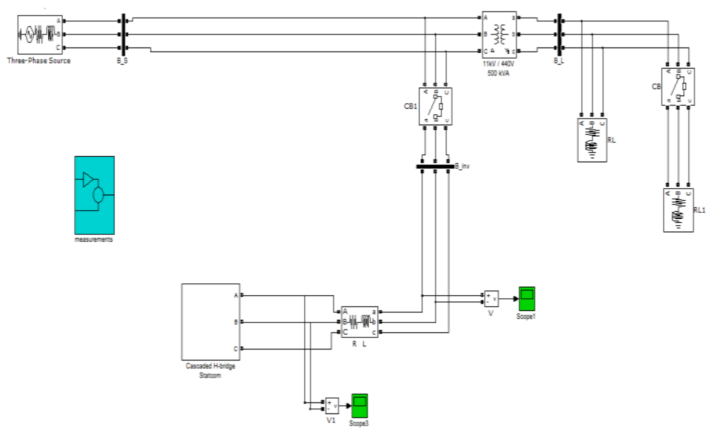

Figure 9. Simulink modeling of test system

An Overview of the system is shown in Fig: 9. Cascaded H-Bridge module is tested with both linear and non-linear loads. Converter circuit consists of IGBT switches which are controlled by predictive algorithm. The total simulation time is set to 0.7sec, where high linear load is connected to the source at 0.1sec creating voltage drop. STATCOM is connected at 0.2sec to compensate the voltage drop by injecting reactive power into the distribution grid. A fault is introduced at switches S9 and S10 of phase A at time 0.5sec and the dynamic characteristics of the distribution line are observed with and without detection and mitigation controller.

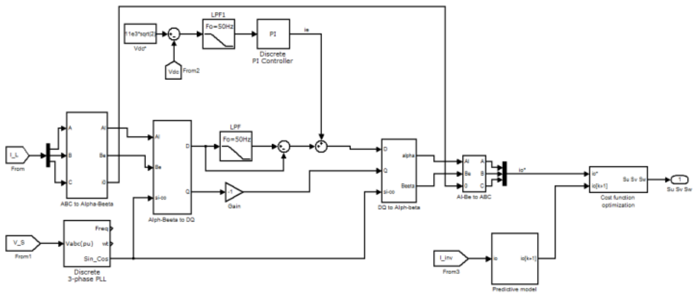

Figure 10. Predictive control modeling

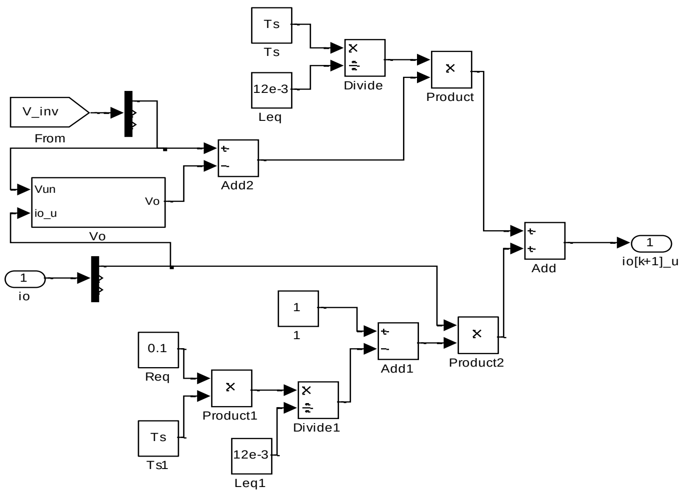

Figure 11. io[k+1] signal generator

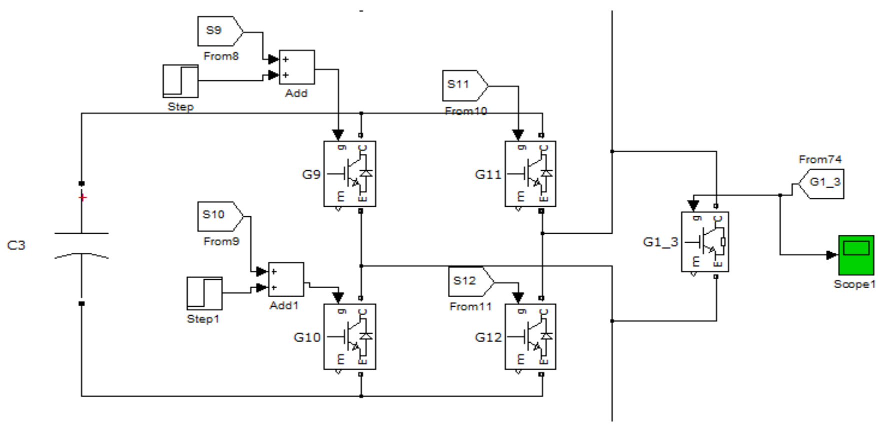

Figure 12. Bypass switch placement with switch fault in S9 and S10 switches

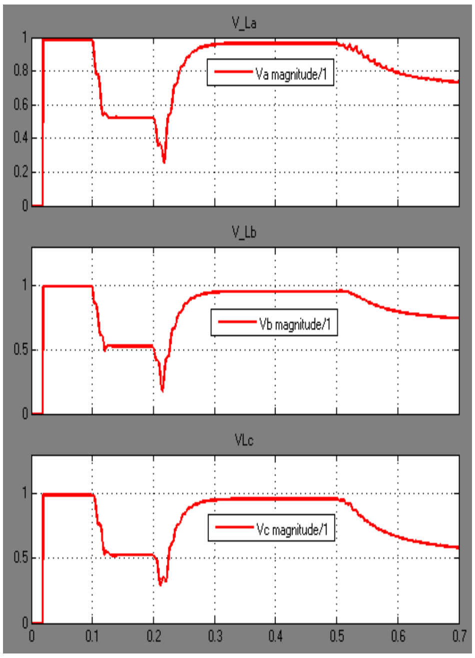

Figure 13.1. Load Voltages of Phases during open circuit fault without Controller

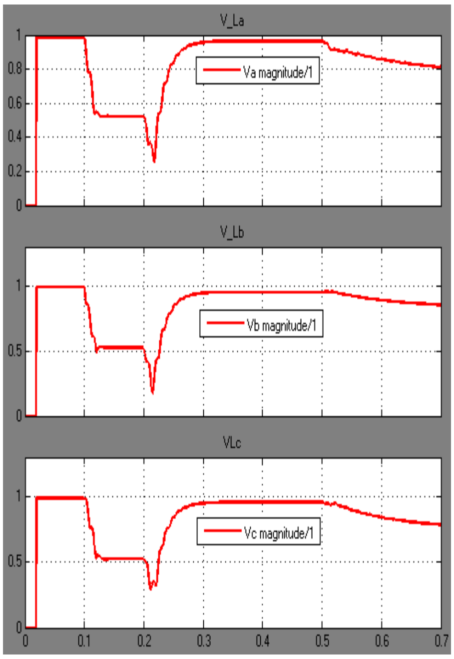

Figure 13.2. Load Voltages of phases during open circuit fault with Controller

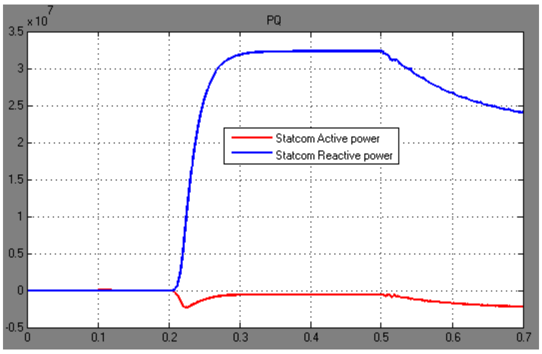

Figure 14. Active and reactive power of STATCOM

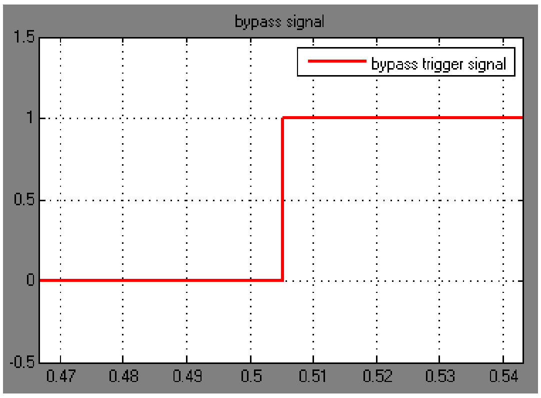

Figure 15. Relay operation signal during open circuit fault at 0.5sec

5. CONCLUSION

STATCOM operates according to voltage source converter (VSC) principles, combining unique PWM (pulse width modulation) with millisecond switching.With the above results represented, simulation of STATCOM connected distribution system with and without switch fault detection and mitigation controller, observed that the load voltages sags are improvised with bypassing the faulty H-bridge. More over the predictive controller controls the STATCOM and inject required amount of reactive power and avoid over compensation. STATCOM continuously provides variable reactive power in response to voltage variations, supporting the stability of the test system.

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