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Implementation of Cascaded Multilevel Inverter with Bidirectional Switches for STATCOM

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Abstract: Reactive power compensation and elimination of harmonics are necessary to provide high power quality for an AC system. The compensation of reactive power in an AC system using STATCOM to improve power quality is presented in this study. For the compensation of reactive power in power systems, Static Synchronous Compensator (STATCOM) is used which is a Flexible Alternating Current Transmission Systems (FACTS) device employing power electronic switches. STATCOM consists of a Voltage Source Converter (VSC). The VSC, which acts as a variable capacitive/inductive load is connected across the AC transmission line through a coupling reactor and this VSC improves the power factor by giving/consuming reactive power according to its output voltage and thus compensating the reactive power. The topology of VSC implemented here is a cascaded multilevel inverter employing bidirectional switches. By using a multilevel inverter instead of a voltage source inverter, the harmonics produced by the power electronic devices can be mitigated. The multilevel inverter topology suggested here is more advantageous than the conventional topologies. In this study, the simulation of suggested multilevel inverter for five level output and implementation of the same as STATCOM for reactive power compensation has been performed using MATLAB/Simulink and corresponding outputs obtained are reported.

Key words: Multilevel inverter, FACTS, STATCOM, power quality

INTRODUCTION

The Electric Power Research Institute (EPRI) constituted the objective of the FACTS devices. Owing to the recent advancements in power electronics, FACTS devices have been a focus of research. FACTS have replaced the existing Power System Stabilizers (PSS). FACTS devices are the power-electronics based controllers used in resolving many steady state control problems in power systems like regulation of voltage, control of power flow and transfer capability improvement (Abido, 2009). In addition, the inter-area modes damping and improving stability of power system by employing FACTS controllers are widely used, which was not possible by the existing PSS. Generally, the objective of employing FACTS in transmission routes is to improve the power quality.

There are four types of FACTS controllers, based on the connection to the transmission line, viz., series connected controllers, shunt connected controllers, combined series-series connected controllers and combined series-shunt connected controllers. STATCOM, a shunt controller is implemented in this study. STATCOM is a shunt controller type FACTS device using a DC to AC converter employed for reactive power compensation of transmission line that can internally generate/absorb reactive power without using a capacitor or reactor banks (Hingorani and Gyugyi, 1999). Therefore it has a reduced number of switches and reduced number of passive elements (Hedayati *et al*., 2010). Also, the response of STATCOM is faster than the synchronous condenser (Hassan *et al*., 2009). Of these converters, STATCOM which consists of voltage source inverter is considered. When compared to two level voltage source inverter, multilevel inverter has advantages like more efficiency and less electromagnetic interference (Rodriguez *et al*., 2002). Also, a two level inverter produces a common-mode voltage across the power semiconductor switches (Bashi *et al*., 2008). Voltage source inverter with more number of identical H bridges can be employed (Liang and Nwankpa, 1999). But this results in more cost and design complexity. To overcome this drawback, a multi level inverter with reduced number of switches is suggested.

REAL AND REACTIVE POWER

The voltage, current and power relation formula is, P = VI. In an Alternating Current (AC) circuit when impedanceelement is considered to be pureresistance, the

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current is in phase to the voltage. But when the impedance element consists of both reactance as well as resistance, the current is not in phase to the voltage. Thus the determination ofpower becomes complicated. Here the product VI is greater/smaller than the real power. The excess power is said to be reactive power, which represents the energy additionally stored/released by capacitors and/or inductors. The total power is given by the sum of the real and reactive power. It is also known as apparent power. The ratio of real power to total power is known as power factor. The power factor is mathematically given as kW/kVA. So, in order to achieve unity power factor, reactive power should be mitigated using some mitigating devices.

MULTILEVEL INVERTERS

In recent development of power electronics, the multilevel inverters have been widely used in order to minimize the harmonics generated by the power electronic devices. The multilevel inverters can be classified as (Rodriguez *et al*., 2002):

- Diode-clamped multilevel inverters
- Flying-capacitor multilevel inverters and
- Cascaded H-bridge multilevel inverters

Of these multilevel inverter topologies, the cascaded H-bridge multilevel inverter topology has been a focus of research in high voltage applications because of its advantages like minimum number of components, reliability and modularity over the other two topologies.

The cascaded five level H-bridge inverter circuit is shown in Fig. 1. Each inverter module consists of four power electronic switches and one DC source. It produces a three level output. To obtain a sinusoidal output voltage, multilevel inverters produce many voltage levels at the output by cascading several inverter modules. The increase in output voltage level results in increased number of devices. It also increases complexity and cost of the system (Khomfoi and Tolbert, 2012).

The General Circuit configuration of a cascaded five level inverter using bidirectional switches is given in Fig. 2. By using this proposed inverter topology, the power electronic switches used can further be reduced to get the same voltage at the output. The proposed inverter employs two dc input voltage sources, four power electronic switches and one bidirectional switch to make a single inverter module (to get a five level voltage at the output). Whereas in conventional cascaded multilevel inverter two H-bridge modules are needed to obtain same five level at the output (Ceglia *et al*., 2006).

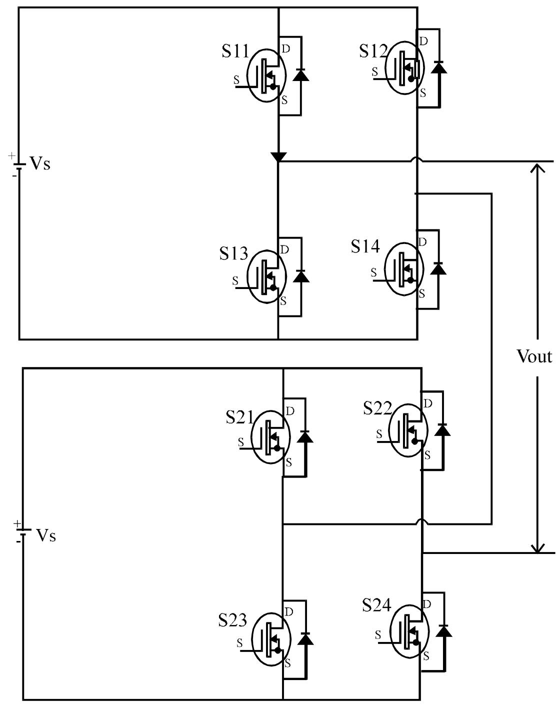

Fig. 1: Cascaded five level H-bridge inverter

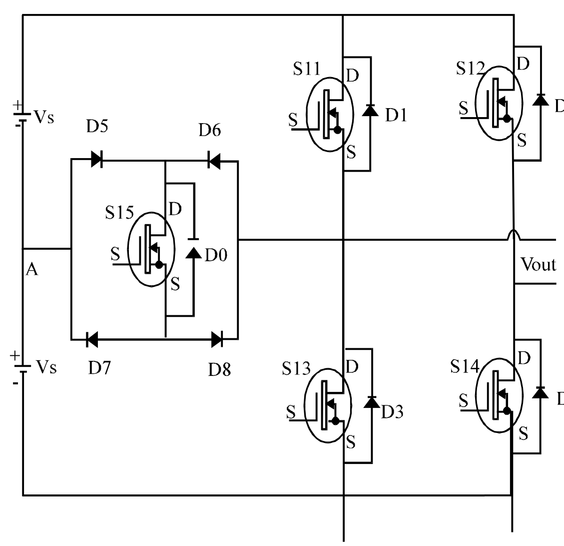

Fig. 2: Circuit configuration of a cascaded multilevel inverter with bidirectional switches

The output voltage waveform of cascaded five level inverter is given in Fig. 3.

The voltage at the output of the proposed inverter is given as:

$$V_{out} = 2K \cdot V_s$$

The No. of voltage levels at the output is given by:

$$N = 4K+1$$

Here, K means the number of inverter modules.

SYSTEM CONFIGURATION OF A STATCOM IN AN AC TRANSMISSION LINE

The one line diagram representing STATCOM with an AC transmission line is shown in Fig. 4. The STATCOM comprises of a voltage source inverter (VSI), capacitor (C) with voltage V_{dc} and a coupling reactor (X). The voltage source inverter, which acts as a variable capacitive/inductive load is connected in parallel to the AC transmission line via a coupling reactor. The reactive power transfer between STATCOM and the transmission line is done by the voltage difference across the coupling reactor. When the voltage at the output of STATCOM (V_s) is greater than the line voltage (V), reactive power is generated to the line from the STATCOM . When " V_s" is less than that of "V" reactive power is absorbed by the STATCOM from the line. This effect can be done by varying the voltage at the output of STATCOM allowing the reactive power compensation for different unit of loads, performed by varying the switching angles of power switches , by holding the voltage of the capacitor to a fixed value (Kumar *et al*., 2010).

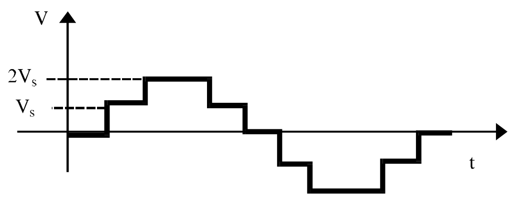

Fig. 3: Five level output voltage waveform

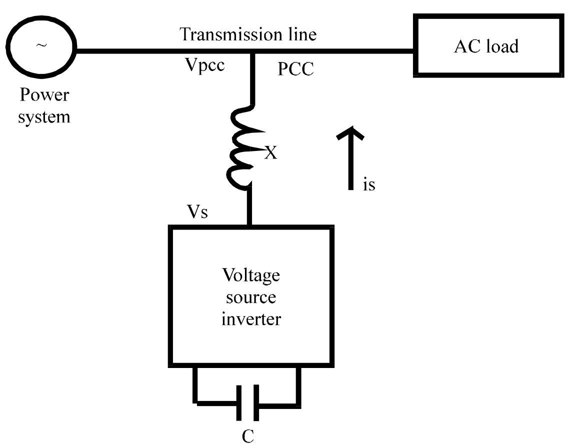

Fig. 4: One line diagram representing STATCOM

In this study, the proposed system is analyzed and simulation work has been implemented for a single phase AC transmission line using a 5-level inverter as a STATCOM. Also it can be implemented in three phase transmission lines.

SIMULATION USING MATLAB

The simulation of proposed multilevel inverter is implemented here for a five level inverter. The Fig. 5 shows the MATLAB simulated model and Fig. 6 shows the five level output voltage waveform.

Figure 7 shows the simulation of STATCOM connected in a single phase AC line using the proposed 5-level inverter implemented for two different loads. At instant 0.7 sec, load 2 is turned OFF using a breaker circuit.

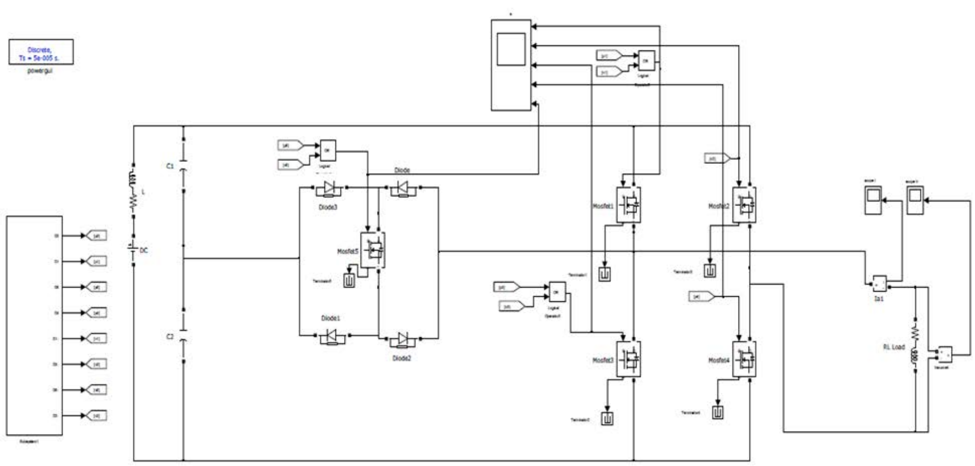

Fig. 5: MATLAB simulated model

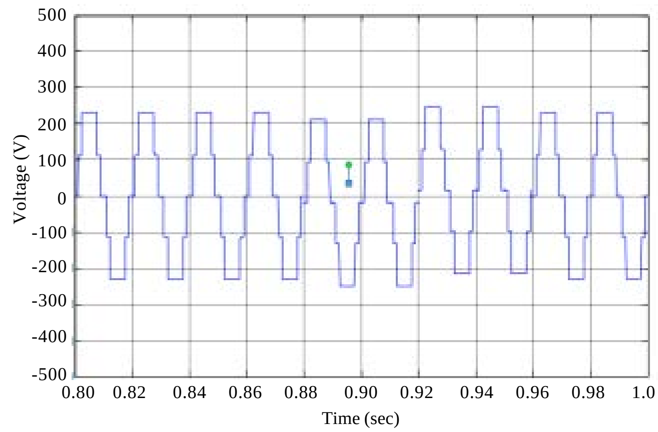

Fig. 6: Five level inverter output voltage waveform

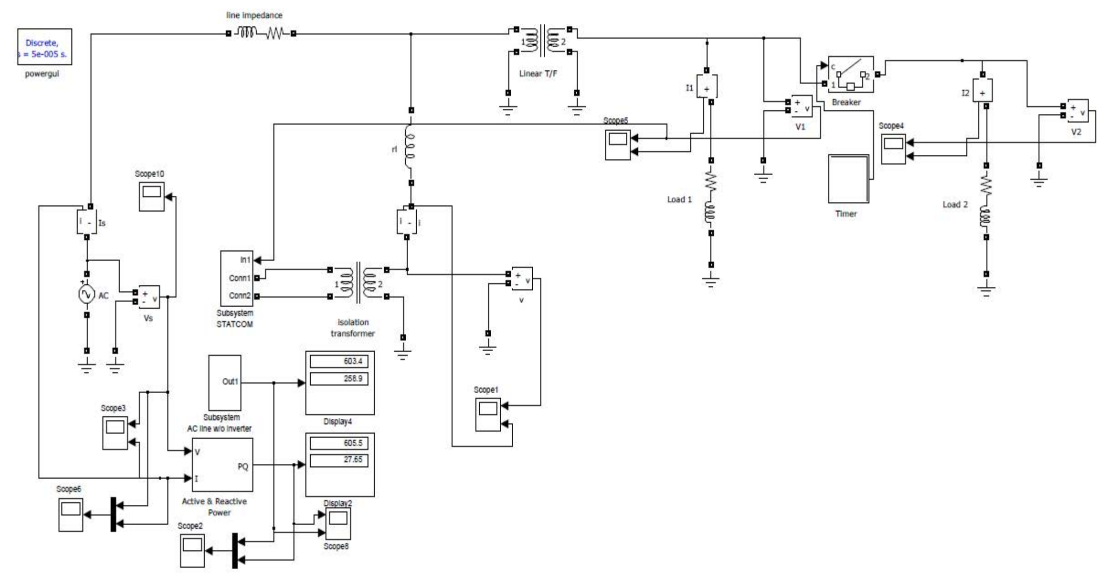

Fig. 7: STATCOM Model

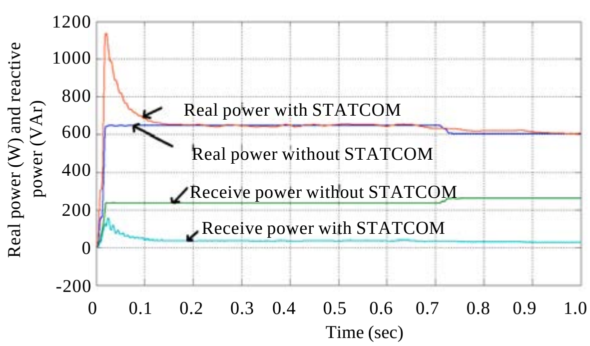

Fig. 8: Real and reactive power comparisons with and without STATCOM

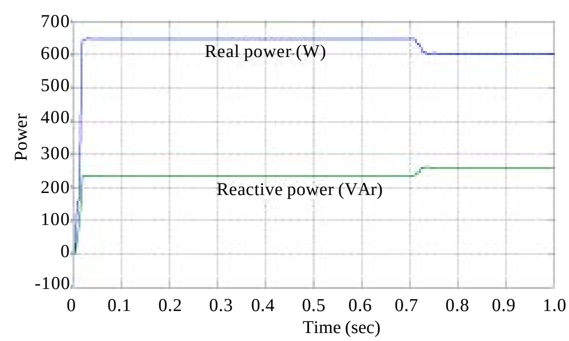

Fig. 9: Real and reactive power at the output without STATCOM

The active compensation of reactive power is achieved by using PI controller to vary the switching angles of the multilevel inverter. The K_p and K_i gain values are tuned by manual tuning method.

Figure 8 shows the waveforms of real and reactive power of power system with and without STATCOM for analysis of power. Figure 9 and 10 show the waveforms of real and reactive power individually without STATCOM

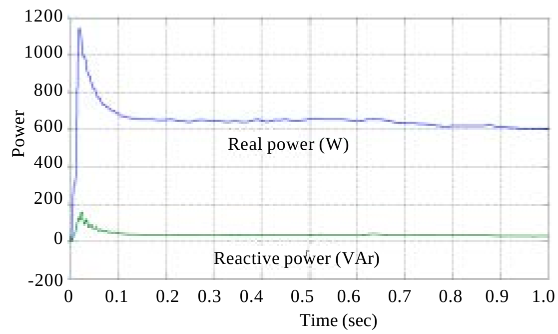

Fig. 10: Real and reactive power at the output with STATCOM

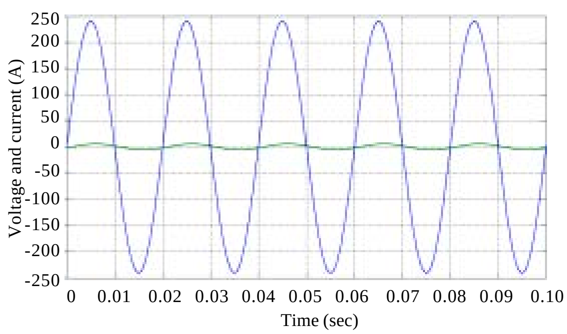

Fig. 11: Waveforms of voltage and current without STATCOM

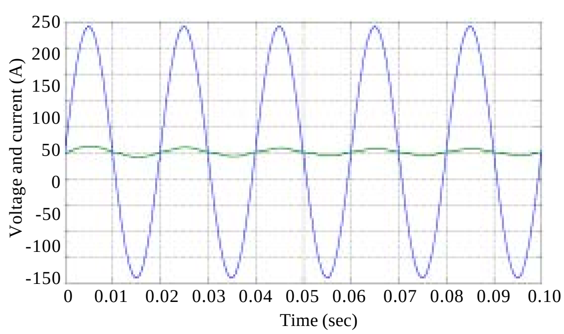

Fig. 12: Waveforms of voltage and current with STATCOM

Table 1: Real and reactive power

	Real power		Reactive power	
Transmission line	Load 1 ON (W)	Both loads ON (W)	Load 1 ON (VAR)	Both loads ON (VAR)
Without STATCOM	603.4	646.3	258.9	234.3
With STATCOM	605.5	610.6	30.9	31.3

and with STATCOM, respectively. Figure 11 and 12 show the waveforms of voltage and current individually without STATCOM and with STATCOM, respectively.

CONCLUSION

A cascaded multilevel inverter employing bidirectional switches is implemented as STATCOM in this study using a PI controller and active compensation of reactive power is achieved. The real and reactive power waveforms for different loads under open loop and PI controller are analyzed using MATLAB simulation works. Further, this work can be implemented using Fuzzy control and neuro-fuzzy control methods. Finally by implementing the proposed multilevel inverter in real-time applications, the total system cost can be minimized as the switches required are less than the conventional multilevel inverter.

SYSTEM PARAMETERS

AC supply voltage: 240 V
Supply frequency: 50 Hz
Line resistance: 20 ohms
Line inductance: 1 mH
STATCOM side DC Capacitors each: 3 mF
Coupling inductance: 1 mH
Load 1: R = 200 ohms, L = 30 mH
Load 2: R = 200 ohms, L = 30 mH

Real power and reactive power values obtained from simulation are shown in Table 1.

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