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Voltage regulation by two level 48-pulse VSCs based STATCOM

Rohit[1], Dr. Kamal Sharma[2], Amandeep Kaur[3]

[1]Student, M. Tech, E-Max group of Institutions, Ambala

[2]Professor, Dept. of ECE, E-Max group of Institutions, Ambala

[3]Assistant Professor, Dept. of EEE, E-Max group of Institutions, Ambala

Abstract— **In this paper, a new configuration of STATCOM (Static Compensator) with constant DC link voltage is proposed for the voltage regulation. The proposed STATCOM consists of eight sets of two-level double way Voltage Source Converters (VSCs). Each double-way VSC consists of two six-pulse VSCs connected through an open winding transformer unit. The phase-angle difference between these two VSCs is varied for the reactive power control. The proposed STATCOM model is developed using MATLAB/Simulink, SimPowerSystems (SPS) toolboxes and dynamic performance is studied for the change in the reference reactive power, the terminal voltage reference and voltage control under switching on an inductive and a capacitive loads. Simulation results are presented to demonstrate the voltage regulation capability of the STATCOM under these conditions.**

Keywords— **Voltage Source Converters (VSCs), Static Compensator (STATCOM), Flexible Alternating Current, Transmission System (FACTS), Voltage regulation, Multi-pulse Fundamental frequency switching (FFS)**.

I. Introduction

The electrical energy consumption is increasing all over the world requiring enhanced power transmission from generating stations to load centers. This needs installation and up gradation of transmission lines or better utilization of existing lines. In the past few years, availability of Gate Turn-Off (GTO) thyristor switching devices with high-power handling capacity and the technological improvement of the other power-semiconductor devices like IGBTs have led to the development of fast controllable reactive power sources utilizing new electronic switching and converter technology. The GTO thyristor helps in the design of the solid-state shunt reactive compensation and active filtering equipment based upon switching converter technology. These Power Quality Devices (PQ Devices) are power electronic converters connected in parallel or in series with transmission lines. Flexible alternating current transmission systems (FACTS) devices are usually used for fast dynamic control of phase-angle, voltage and impedance of high-voltage ac lines.It also increase the dynamic and transient grid stability, and increased power quality for sensitive industries. As installation of new lines is not economically feasible, the existing ones have to be used in efficient manner using FACTS (flexible alternating current transmission system) devices [1–3]. Static compensator (STAT-COM) belonging to this family of FACTS devices is connected in the shunt for absorbing or generating the required reactive power.

Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability. A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; on the other hand, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage). [4–9].

The voltage source converter (VSC), a combination of the self commutating device with an anti-parallel diode is the elementary unit of the STATCOM for dynamic reactive power compensation. The gate turn off thyristor (GTO) with high power handling capability is very well suited for the VSC in high voltage and high power applications. In view of this, a reasonable literature is available on the modeling, control and simulation techniques in FACTS devices [6,7].In FACTS controllers, multi-pulse VSC topologies [8,10–13] are popularly used in transmission and industrial applications because of their low loss among all other available VSC topologies like pulse width modulation (PWM) and multi-level converters. In PWM technique the converter losses are high as the devices switch on and off several times during a cycle, and therefore is not a good choice in high power utility applications. In multi-level VSC topologies, there are several DC link capacitors and it is very difficult to regulate the DC voltages of all the capacitors. A multi-pulse VSC topology with finite pulse number produces a near sinusoidal voltage waveform with acceptable harmonic content and low switching loss. In addition to multi-pulse VSC, several multi-phase configurations [14] are available for minimizing the harmonics. In the literature available so far on the multi-pulse VSC topologies for STATCOM application, the DC link voltage is allowed to vary for the reactive power control [15,16]. In these cases, the converter is underutilized when the DC link voltage is low and converter devices are over stressed when the DC link voltage is high.

In this paper, a 48-pulse VSC configuration for the STATCOM is proposed with constant DC link voltage and low harmonic con-tent. The proposed STATCOM consists of eight sets of two-level double-way Voltage Source Converters (VSCs). Each double-way VSC consists of two six-pulse VSCs connected through an open winding transformer unit [17]. The phase-angle difference between these two VSCs is varied for the reactive power control. A decoupled current control scheme is used for the control of the STATCOM. The advantages of the proposed STATCOM are maximum utilization of the converter as the DC link voltage is always held constant.

With the ever increasing power demand, STATCOM's have a vital role to play in the operation of the power system. Moreover, the proposed STATCOM configuration has same number of devices as three-level VSC based 48-pulse STATCOM.

II. CONFIGURATION OF STATCOM

Fig. 1 shows a proposed configuration of the STATCOM. It consists of 24 single-phase transformers and 16 six-pulse three-phase VSCs. Each of 24 transformers has Y and connected primary windings as shown in this figure in order to reduce the voltage and current harmonics appearing at the utility grid and connected in open winding between two VSCs on the secondary side to form a 48-pulse VSC waveform which lowest harmonic is 47th harmonic. The leakage reactance of the and easy interface capability with energy storage devices with-out major changes in design or control of the STATCOM as in case STATCOM with variable DC link voltage. Transformer assembly is selected to be 0.2 pu [17]. The converters 1 to 8 (double-way VSC) are operated in lagging mode and converters 9 to 16 are operated in leading mode. Converters (1, 9), (2, 10) and (8, 16) have single secondary windings on their single-phase output transformers. In this configuration, each single-VSC bridge supplies one line-to-neutral voltage of star or delta connected windings

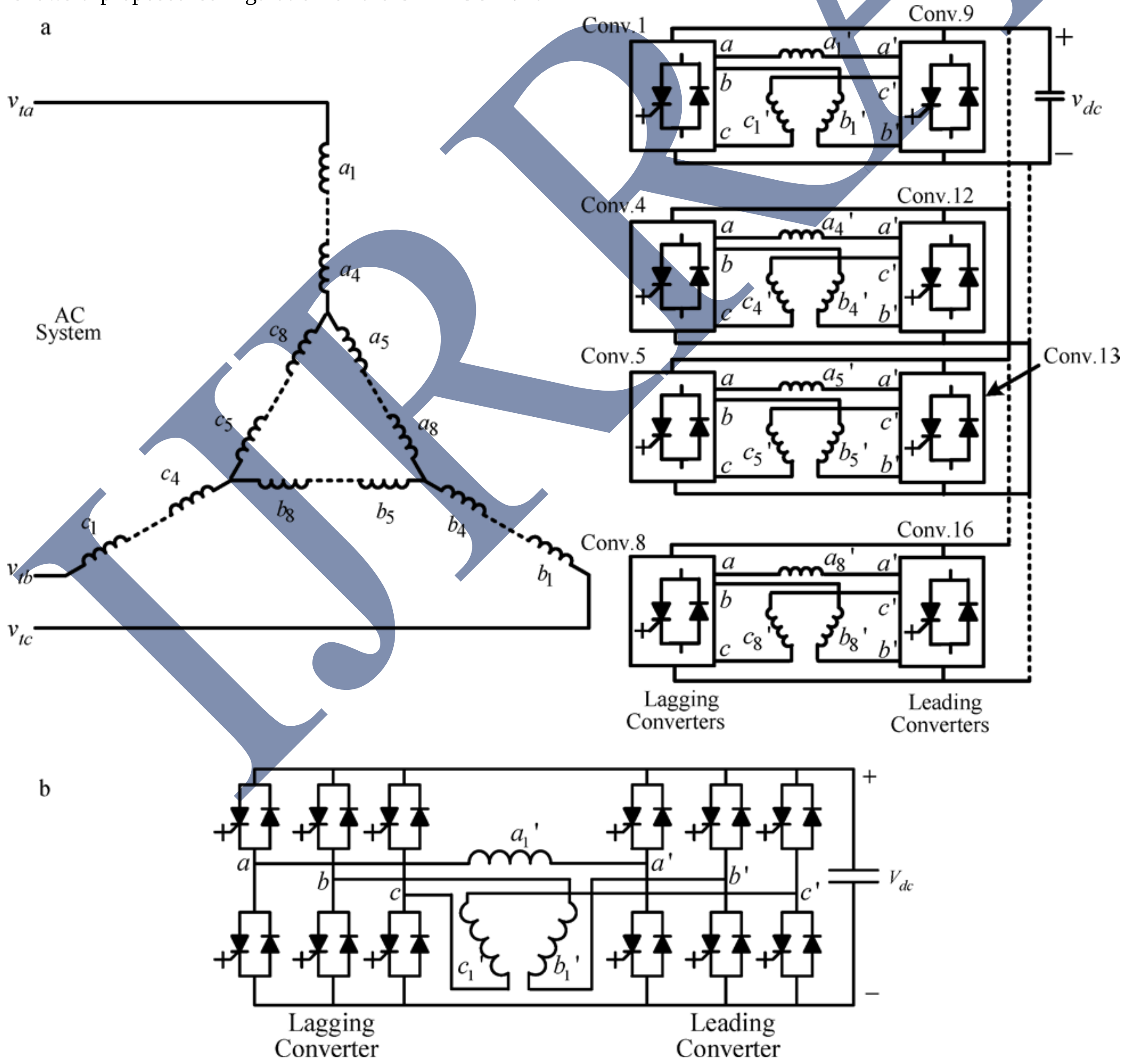

Fig. 1. (a) Configuration of the proposed STATCOM. (b) A double-way VSC

The inverter voltage is controlled by phase displacement of one half of each VSC bridge with respect to the other half. The phase- shifted phase portion of each VSC bridge is shifted the same amount, for a given output voltage, to maintain the three-phase relationship for the complete circuit. The resultant AC converter voltage waveform at one transformer primary winding is as shown in Fig. 2(a). At full output voltage the two square voltages are out of phase by 180° . Any phase difference between these two voltages produces a zero voltage period (quasi-square wave); thereby controlling the voltage magnitude. By producing eight identical quasi-square voltages which are phase shifted by 7.5° and addition of them produces a 48-pulse VSC voltage wave-form of controllable magnitude. The net effect is as controlling the phase angle between two 48-pulse VSC waveforms as shown in Fig. 2(b). Fig. 3(a) shows the AC converter output voltage waveform and its harmonic spectrum for β = 30°. Fig. 3(b) shows the variation of the %THD with the angle 'β'. For β = 0° to β = 100°, the %THD of the output voltage is always less than 4.5%. This range of β is chosen for the required reactive power control.

The basic concept of the AC output voltage control of the VSC is explained in [2], where V_s is the supply/mains voltage whereas V_t is the terminal voltage and V_{c1} is the fundamental AC converter output voltage. V_t is the terminal voltage at point of common coupling. The system configuration for the voltage regulation is shown in Fig. 4.

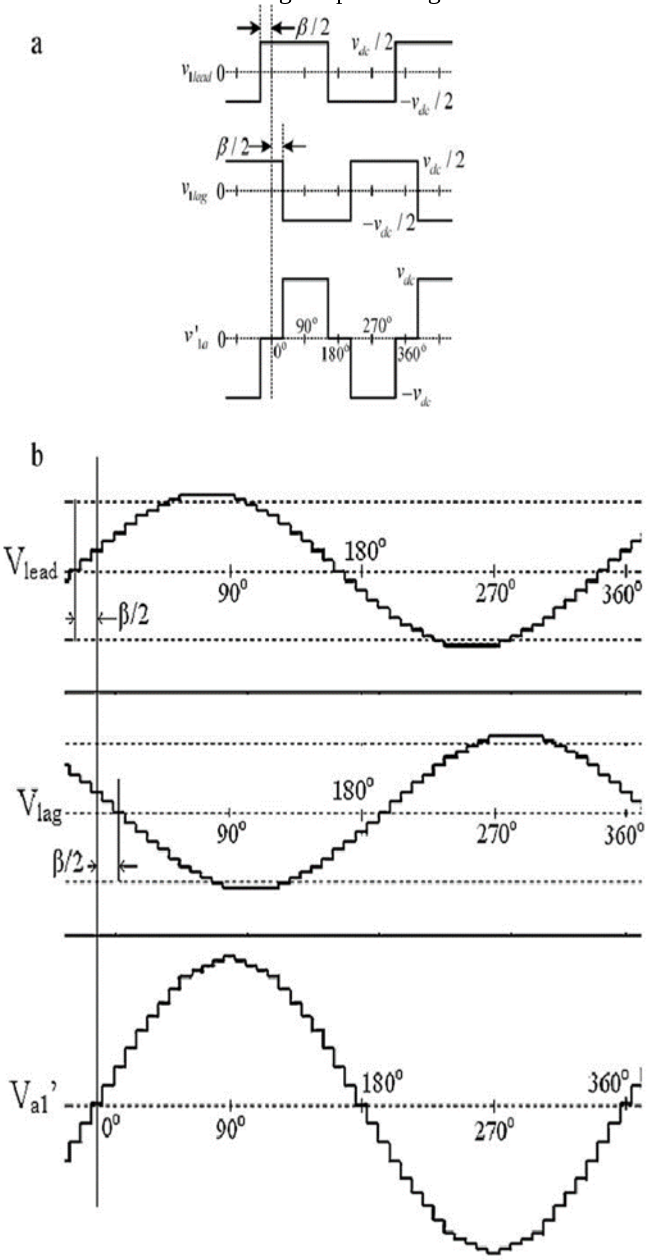

Fig. 2. (a) Operation of single double-way VSC.
(b) Voltage waveforms of lagging and leading converters and their sum.

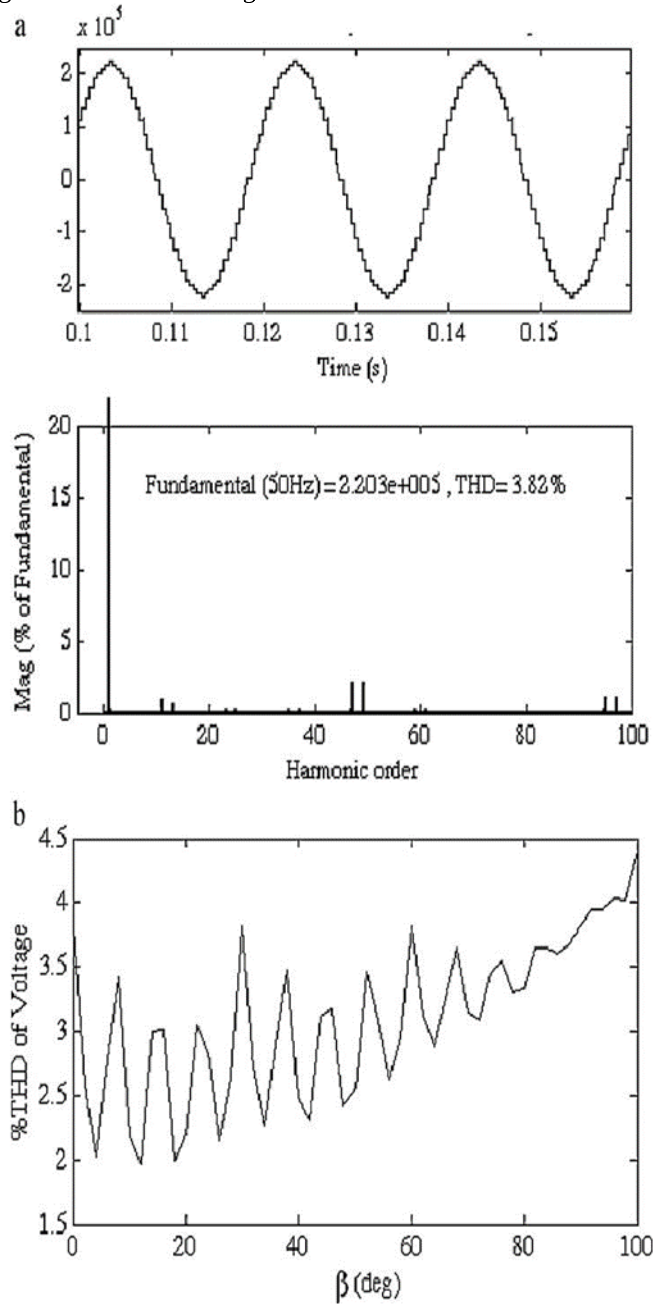

Fig. 3. (a) AC converter output voltage and its harmonic spectrum for β = 30°
(b) %THD variation of AC converter output voltage with β.

III. Control Algorithm and Results

Fig. 6 shows the block diagram of the control algorithm used in the control of STATCOM.

3.1. abc to dqo transformation

Three-phase terminal voltages 'v_{tabc}' are transformed to the 'v_{dq}' using Park's transformation.

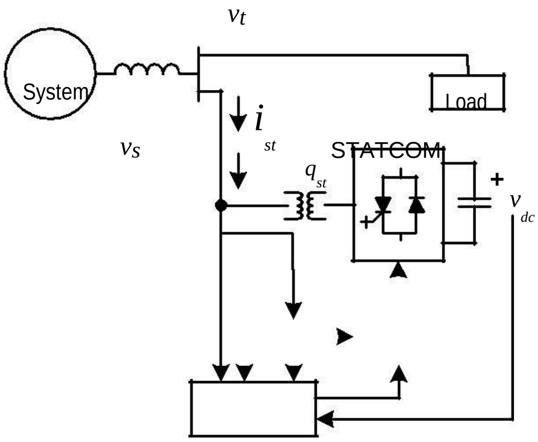

Fig. 4. System configuration for voltage regulation

In first case, the desired reactive power control is realized for a given reference reactive power Q^*, and i_q is derived from this reference reactive power Q^*. However, in the second case, required 0.2 s, the reference reactive power Q^* is set to 100MVAR, and it is brought back to zero at t = 0.4 s.

When the reference reactive power Q* is changed to −100MVAR, the phase angle ˇ* decreases as a result the AC converter voltage magnitude increases and the reactive power flows from the STATCOM to the AC system terminal voltage,

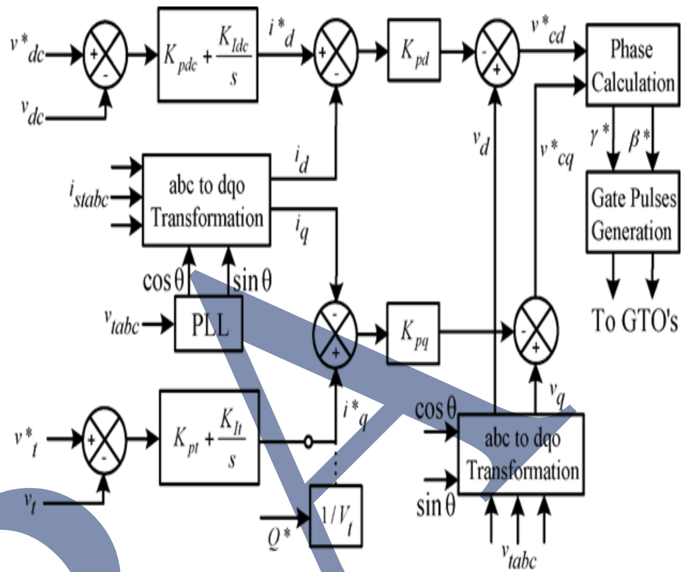

Fig. 5. Block diagram of the control algorithm

V_t * for regulating the terminal voltage under switching on an inductive and a capacitive load at different instants for data of system given in Appendix A.

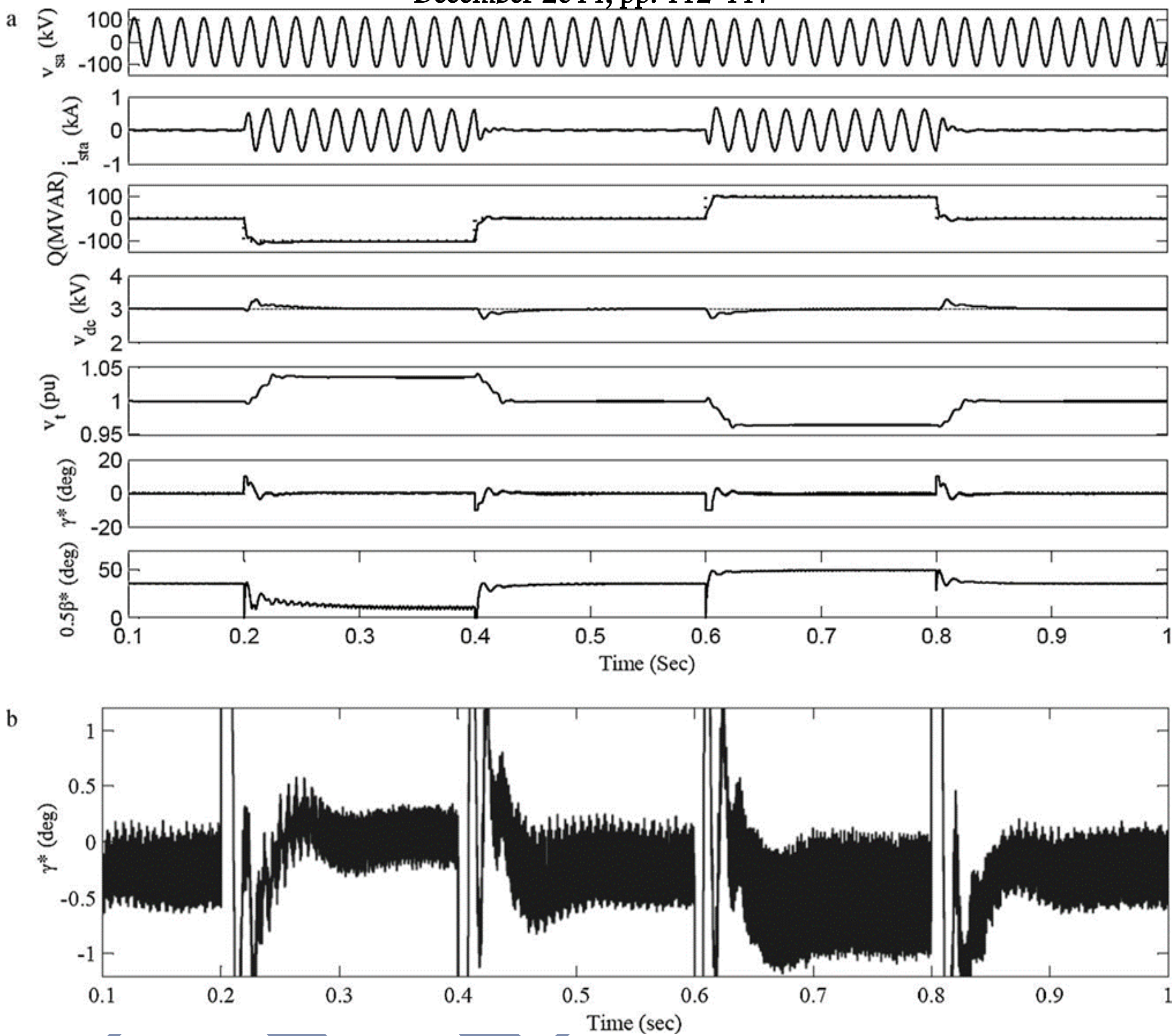

Fig 6. (a) Dynamic performance of the STATCOM for varying the reference reactive power. (b) Zoomed in waveform

Fig. 6 shows the performance of the STATCOM for varying the reference reactive power (Q^*) reactive power component of current i_q^* is computed from an AC ter-minal voltage controller for a given reference terminal AC voltage amplitude v_t^*

3.2. DC bus voltage controller

The DC voltage controller maintains the DC bus voltage at the reference value. It calculates the reference direct axis current i_d which is fed to the direct axis current controller. A proportional-integral controller is used for this purpose. In first case, the desired reactive power control is realized for a given reference reactive power Q^*, and i_q is derived from this reference reactive power Q^*. However, in the second case, required.

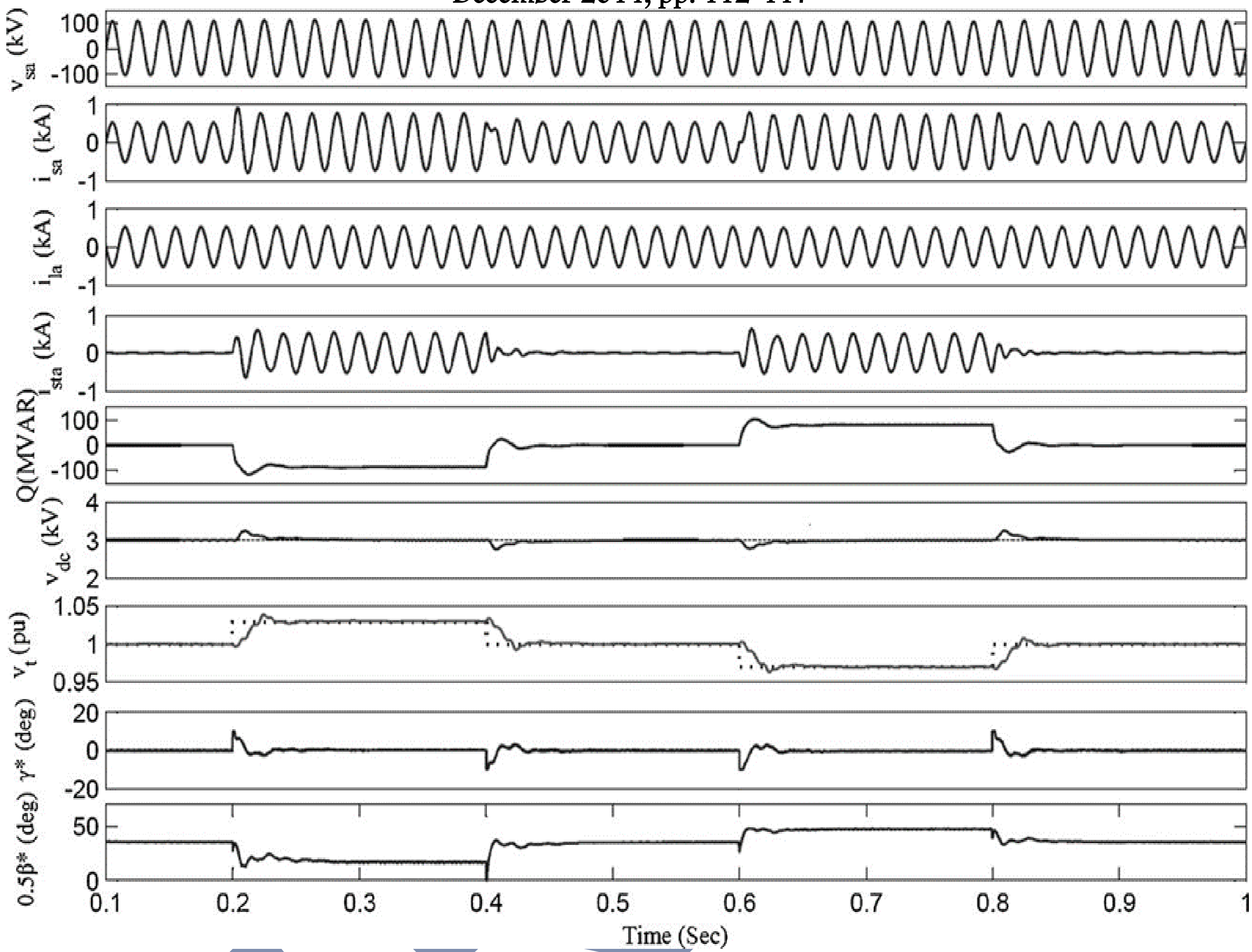

Fig. 7. Dynamic performance of the STATCOM by varying the reference terminal voltage

Where 'n' is the turn ratio (primary to secondary windings of each transformer unit) is the phase shift angle responsible for con-trolling the reactive power. The dynamic performance of the proposed STATCOM is studied for varying the reference reactive power Q^*, varying the reference 100MVAR, the phase angle increases as a result the AC converter voltage decreases and the reactive power flows from the AC sys-tem to the STATCOM shows %THD of the STATCOM current under inductive and capacitive operations, which is well below 1%

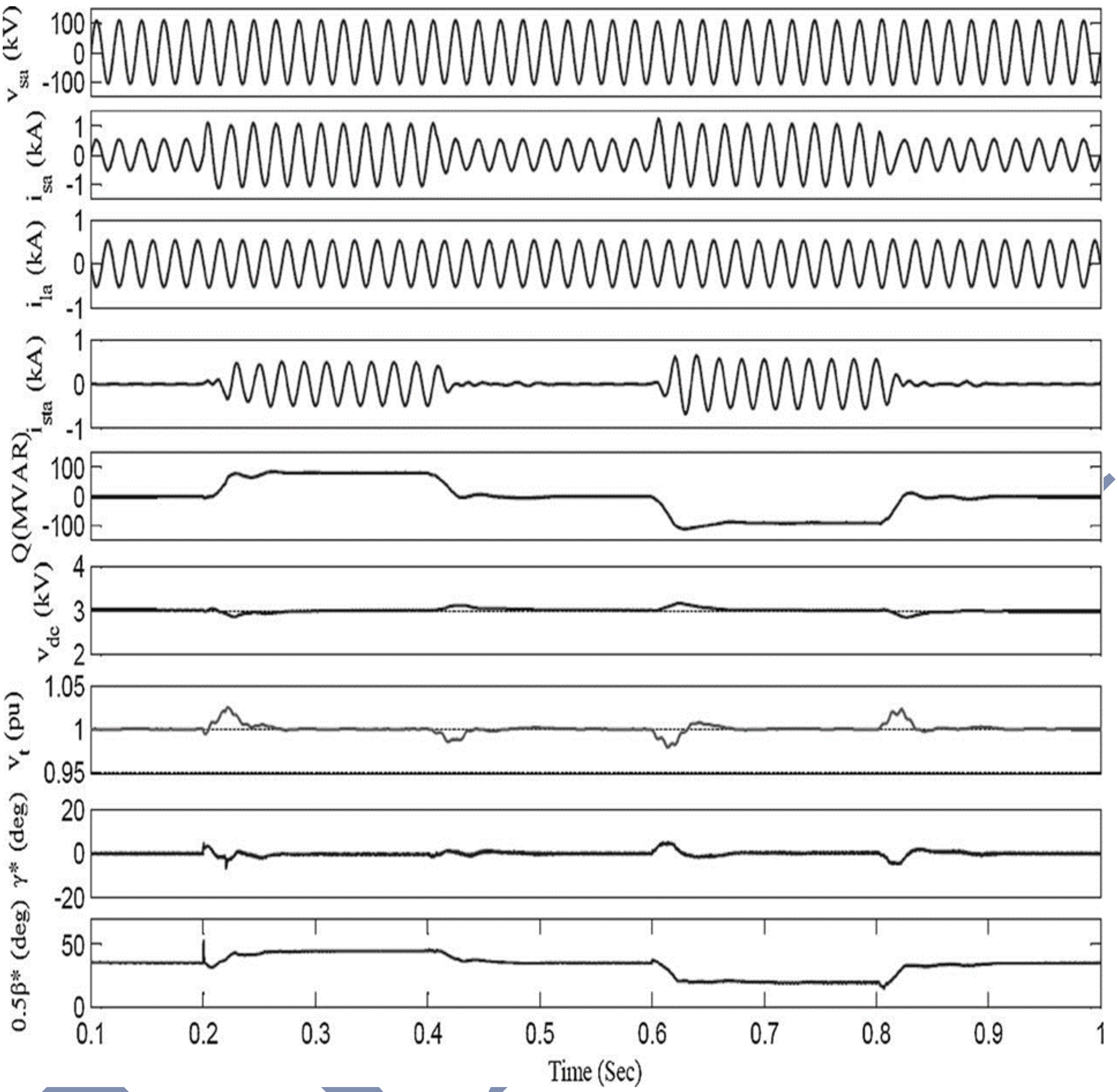

Fig. 8. Dynamic performance of the STATCOM for constant terminal voltage regulation by switching on capacitive and inductive loads.

IV. Conclusion

A new configuration of STATCOM with constant DC link voltage has been proposed and its dynamic performance has been studied under different conditions for varying reactive power, and control-ling the terminal voltage under switching on a capacitive and an inductive load at different instants. The simulation results have demonstrated the voltage regulation capability of the STATCOM. The total harmonic distortion of the system, load and STATCOM currents is observed always less than one percent which is well within the limit of an IEEE-519 standard [18]

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