MODELLING OF FLEXIBLE COMPENSATING DEVICES USING FUZZY CONTROLLERS

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Abstract- The Flexible ac transmission system (FACTS) technology is the application of power electronics in transmission systems. To understand and control the interactions between the FACTS devices based on VSCs and the utility system, there is a need for appropriate models to obtain fast and accurate results. There are several models of the FACTS devices based on ideal VSCs. The main purpose of this technology is to control and regulate the electric variables in the power systems. This is achieved by using converters as a controllable interface between two power system terminals. Two VSC models are proposed for the fast and efficient simulation of FACTS devices containing hard switched sinusoidal pulse width modulation (SPWM) VSCs. The power electronic circuit is modeled as a time-varying-topology network. This is a very useful approach at power system level., power switching devices are modeled as ideal switches. In this paper, modeling of UPFC is performed based on sinusoidal pulse width modulation (SPWM) voltage source converters (VSC) and modeling of UPFC is performed based on Fuzzy Controller VSC. The UPFC is the most versatile device of the family of FACTS devices since it is able to control the active & reactive power respectively, as well as the voltage at the connection node. These models can be used to compute both the transient and the periodic steady-state solution of a power network containing VSC-based FACTS. The proposed Fuzzy logic based UPFC models have been implemented in MATLAB/Simulink software.

Index Terms- Distribution Generation, power quality (PQ), Active type SFCL.

I. INTRODUCTION

Today's power systems are highly complex and require careful design of new devices taking into consideration the already equipment, especially for transmission systems in new deregulated electricity markets. This is not an easy task considering that power engineers are severely limited by economic and environmental issues. Thus, this requires a review of traditional methods and the creation of new concepts that emphasize a more efficient use of already existing power system resources without reduction in system stability and security. On the other hand, new transmission systems are expensive and take considerable amount of time to build. Hence, in order to meet increasing power demands, utilities must rely on power export/import arrangements through existing transmission systems. In the late 1980s, the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems; the proposed concept is known as Flexible AC Transmission Systems (FACTS).

The two main objectives of FACTS are to increase the transmission capacity of ac lines and control power flow over designated transmission lines. The improvements in field of power electronics have had major impact on the development of concept itself. The use of FACTS controllers can potentially overcome disadvantages if electromechanically controlled transmission systems. The analysis of a power electronic system is complex, due to its switching behaviour. Therefore there is need for simpler, approximate models. One common approach to the modelling of power converters is averaging.

The three phases Voltage Source Converter (VSC) is the basic building block of most new FACTS and custom power equipment. The converter may be employed as a shunt compensator, series compensator or a hybrid compensator, as is the case with the Unified Power Flow Controller (UPFC) and the Interline Power Flow Controller (IPFC). Independent of the specific application, modeling is typically performed using an approximate continuous time representation of the converter in the synchronous reference frame.

FACTS has come a long way since the early 1970s, when the concept was developed for generating controllable reactive power through switching power converters. The first FACTS device was the Static VAR Compensator (SVC), which was brought to the market by, the Electric Power Research Institute (EPRI) two decades ago. This compensator consists of a fast thyristor switch controlling a shunt capacitor bank and/or a reactor, to provide dynamic shunt compensation. Dynamic shunt compensation automatically and instantaneously adjusts the reactive power output smoothly thus maintaining the voltage at required level. Conventional Thyristor and silicon controlled rectifiers formed the technological foundation for this device. More than 800 SVCs are being installed worldwide both for utility and industrial (especially in electric arc furnace and rolling mills) purposes.

The first generation of facts devices are:

- Static VAR Compensator (SVC)
- Thyristor-Controlled Series Capacitor (TCSC)
- Thyristor-Controlled Phase Shifter (TCPS)

The second generation of facts devices are:

- Static Compensator (STATCOM)
- Static Synchronous Series Compensator (SSSC)
- Unified Power Flow Controller (UPFC)

II. MODELING ANDSIMULATION OF VSCs

The modeling of VSCs using switching functions is not a new issue; in [10]–[12] models have been reported based on the switching function approach. Under this approach, the powerelectronic circuit is modeled as a time-varying-topology network. This is a very useful approach at power system level.

Usually, power switching devices are modeled as ideal switches; e.g., infinite resistance when the switch is open, and a zero resistance when the switch is closed. Unfortunately, some problems during the solution process can appear, such as numerical oscillations, necessity of very short integration steps to achieve a high precision, and inconsistent initial conditions [7].

The models presented in our paper are an enhancement of the six-pulse VSC based on a conventional switching function approach, since we preserve all the advantages of the ideal switch model and eliminate its disadvantages.

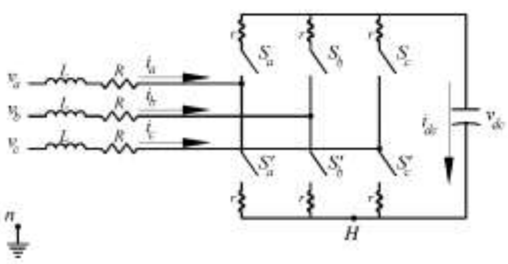


Fig. 2. Six-pulse converter.

Basically, the conventional switching function approach is a special case when the maximum harmonic order in the Fourier model is infinite and when the cutoff frequency is infinite in the hyperbolic tangent model. The models proposed in this paper can be easily incorporated in existing FACTS models, such as those proposed in [12], since multipulse arrangements in [12] are achieved by combining several six-pulse VSCs.

A. VSC State Space Representation

The circuit representation of a six-pulse converter is shown in Fig. 2. The bidirectional switching function is identified by and for each phase , which can be on or off, is the switch-on state resistance, is 1 or 0, corresponding to the on and off states of the switch, respectively. In addition, and are complementary, e.g., .

The state-space model of this converter is

$$L\frac{dx}{dt} = f(t, x) \qquad \ldots\ldots\ldots\ldots 1$$

Where

$$x = [i_a \quad i_b \quad i_c]^T \qquad \ldots\ldots\ldots\ldots 2$$

$$f(t,x)=\begin{pmatrix} -(R+r)i_a - \left(S_a - \frac{1}{3}\sum_{i=a,b,c} S_i\right)v_{dc} + v_a \\ -(R+r)i_a - \left(S_b - \frac{1}{3}\sum_{i=a,b,c} S_i\right)v_{dc} + v_b \\ -(R+r)i_c - \left(S_c - \frac{1}{3}\sum_{i=a,b,c} S_i\right)v_{dc} + v_c \end{pmatrix} \qquad \ldots\ldots\ldots\ldots 3$$

According to (3), (1) is a discontinuous time-varying system since the switching function has only two states and it instantaneously changes from one state to another. Under these conditions, the conventional numerical integration does not give numerical solutions to a high precision.

To alleviate these problems, in this contribution two models for the representation of the VSC are proposed; one is based on a Fourier series expansion and the other is based on a hyperbolic tangent function of the switching function. It will be shown that with the proposed approaches, the numerical integration process can use larger integration steps, as the discontinuities produced by the commutation process no longer exist.

B. Sinusoidal Pulse Width Modulation (SPWM)

Consider one arm of a converter as illustrated in Fig. 3. The desired signal (reference signal) is , and the dc voltage across the capacitor is . The purpose is to transform the continuous into a series of pulses having a fixed amplitude .To

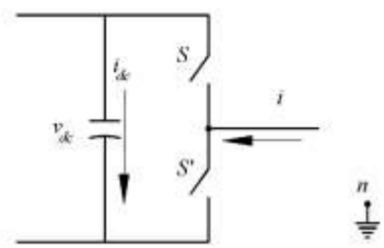


Fig. 3. Single-phase equivalent circuit.

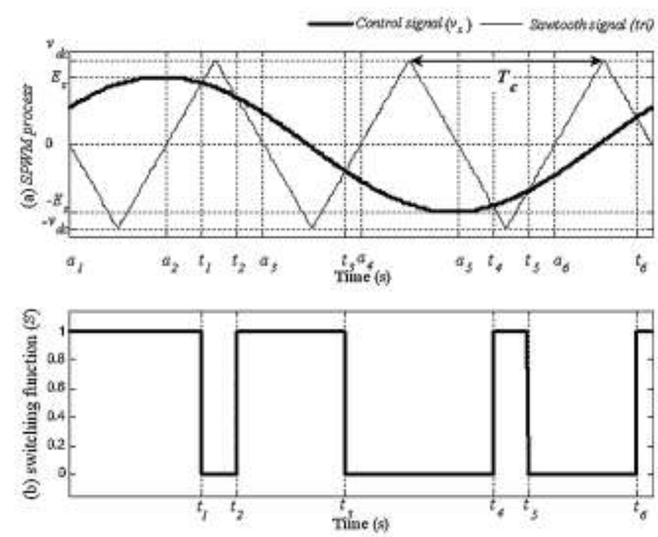


Fig. 4. Transforming a desired continuous signal v_s into a SPWM signal. (a) SPWM process. (b) Switching function (S).

achieve this result, a sawtooth wave (tri) is drawn. Now, conduction takes place whenever lies above the triangular waveform(tri), and conduction ceases whenever it lies below. The resulting pulse train contains the signal . The SPWM process is illustrated by Fig. 4(a). The corresponding switching function is shown in Fig. 4(b). This switching function corresponds only to one phase; however, it can be extended to the other two phases. In practice, is much shorter than that shown in Fig. 4(a). Consequently, the change in during one carrier period is considerably less than the indicated in Fig. 4(a). In other words, a higher carrier frequency directly improves the reproduction of the original signal ; the carrier frequency is defined as

.

The frequency-modulation radio is defined as , where is the frequency of . Higher implies a high switching frequency. As we have mentioned before, there are several simulation problems related to the switching process. In addition, the numerical error increases with the increase in the switching frequency.

III. SIMULATION RESULTS

The proposed distribution system with DGs with and without active SFCL is simulated using MATLAB/SIMULINK. First the distribution system is studied under no fault conditions and then it is studied under single line to ground fault from unsymmetrical nature and triple line to ground fault from symmetrical nature with and without active SFCL. The fault currents at different buses are reduced with the use of active type SFCL in the distribution generation systems.

MODELING OF SPWM VSC for UPFC

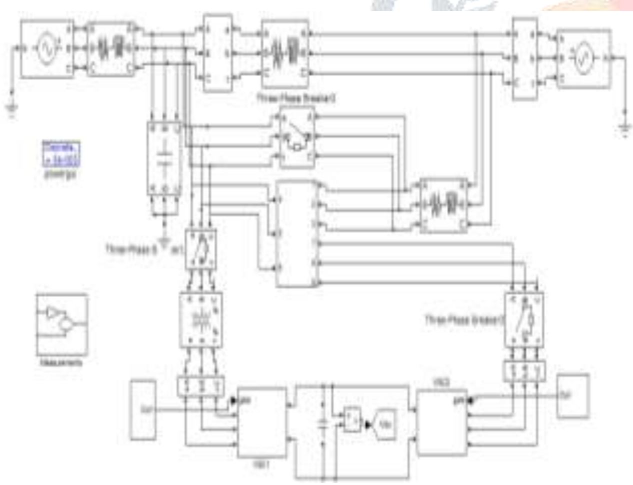


Fig 5 Sinusoidal PWM VSC using UPFC

MODELING OF UPFC BASED ON FUZZY CONTROLLER

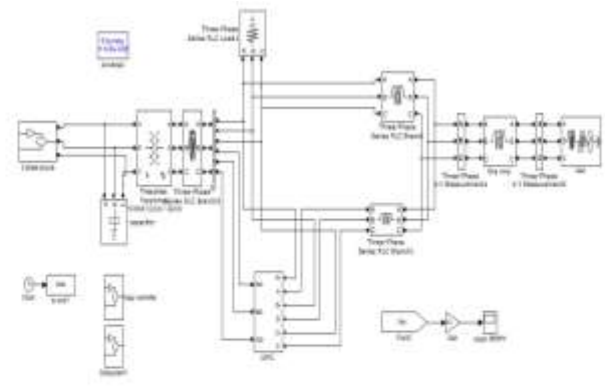


Fig 6 UPFC using FUZZY CONTROLLER

MODELING OF SPWM VSC for SSSC

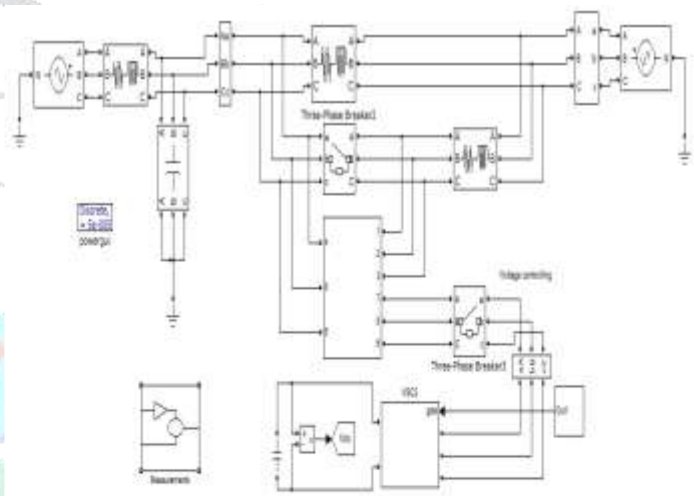


Fig 7 SPWM VSC using SSSC

MODELING OF SSSC BASED ON FUZZY CONTROLLER

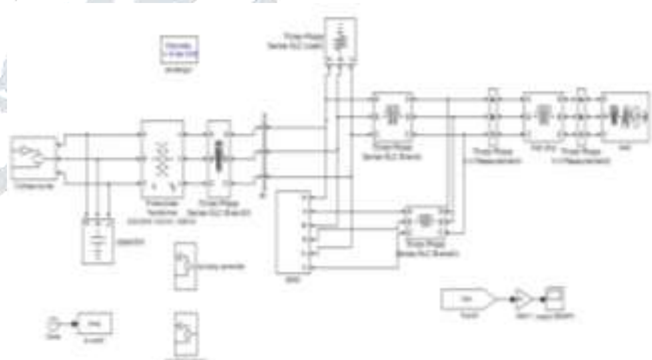


Fig 8 SSSC using FUZZY CONTROLLER

MODELING OF SPWM VSC for STATCOM

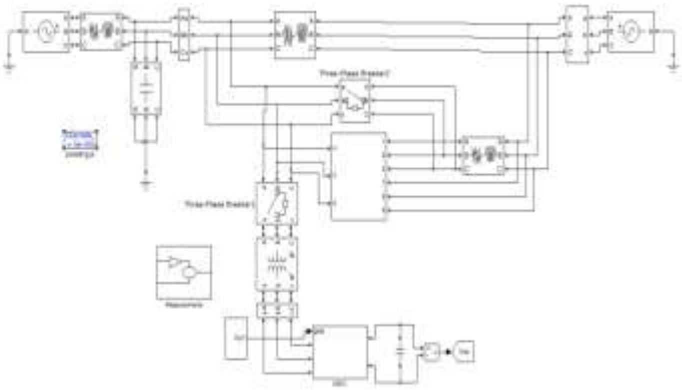
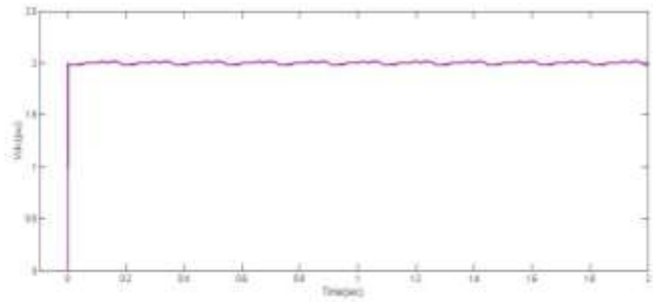


Fig 9 SPWM VSC using STATCOM



Vdc(PU)

MODELING OF STATCOM BASED ON FUZZY CONTROLLER

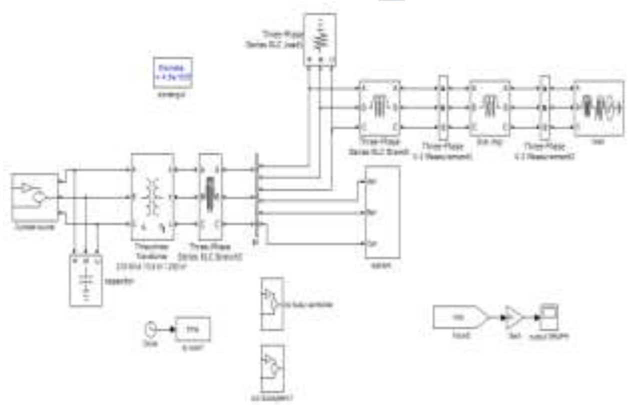
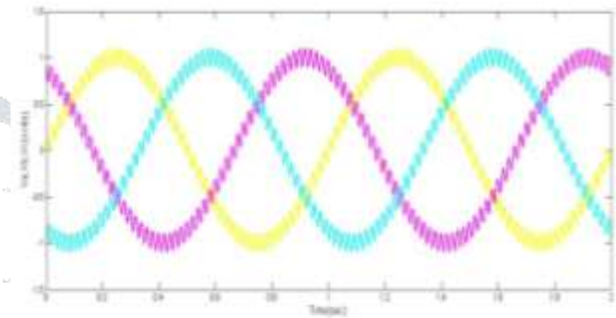
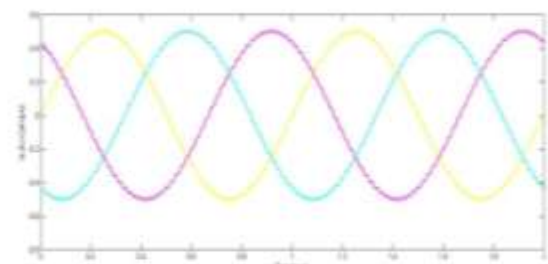


Fig 10 STATCOM using FUZZY CONTROLLER



Vabc(PU)



Iabc(PU)

Fig 12. Corresponding Capacitor voltage (Vdc), Phase voltages (Va,Vb,Vc), series currents (ia,ib,ic)

FUZZY CONTROLLER BLOCK

Fig 11. Internal fuzzy controller block

SIMULATION RESULTS

STEADY STATE RESULTS FOR UPFC BASED ON SPWM VSC

TRANSIENT STATE RESULTS FOR UPFC BASED ON SPWM VSC

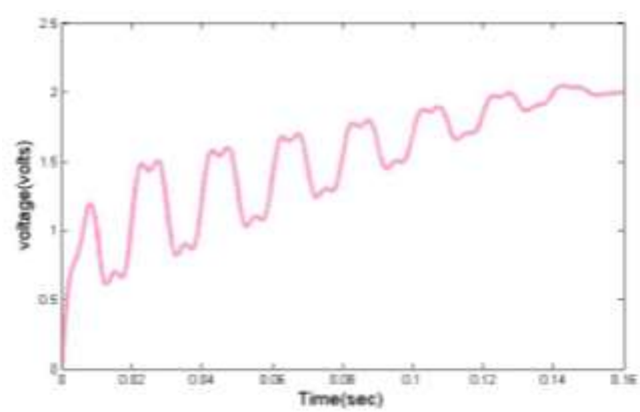
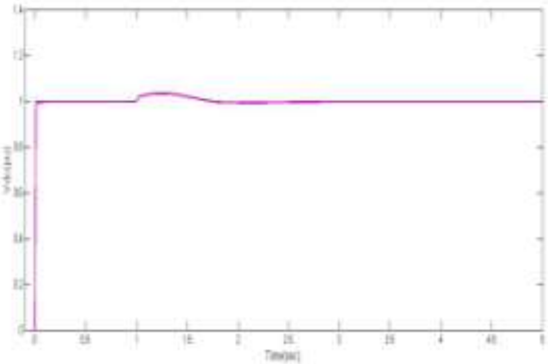
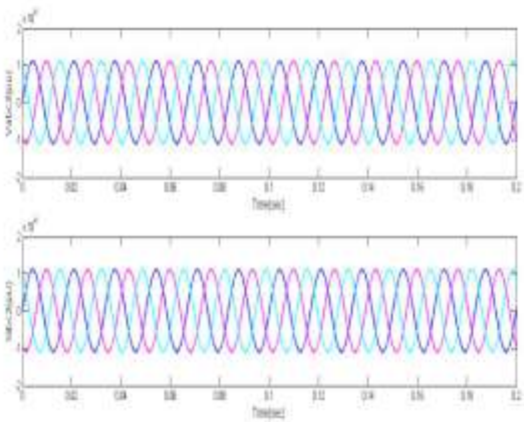


Fig 13. Transient state (Vdc) for UPFC

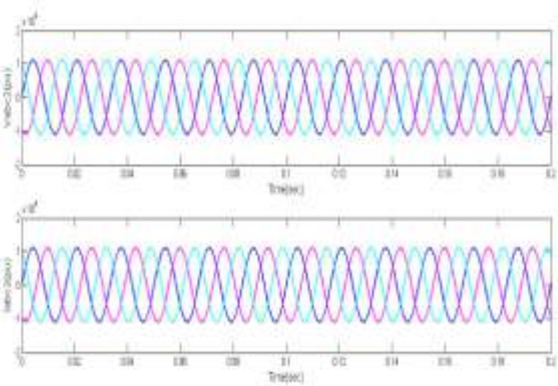
STEADY STATE RESULT FOR UPFC BASED ON FUZZY CONTROLLER



Vdc(PU)



Shunt voltage Vabc3 (PU), current Iabc3 (PU)



Series voltage Vabc2 (PU) ,current Iabc2 (PU)

Fig 14. Corresponding dc capacitor link voltage (Vdc), series & shunt Voltages Vabc2, Vabc3 and currents Iabc2, Iabc3

TRANSIENT STATE RESULTS FOR UPFC BASED ON UPFC FUZZY CONTROLLER

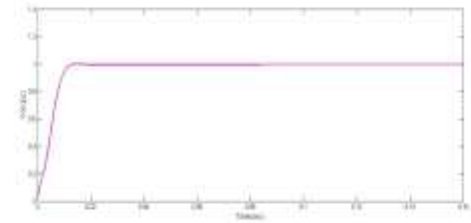
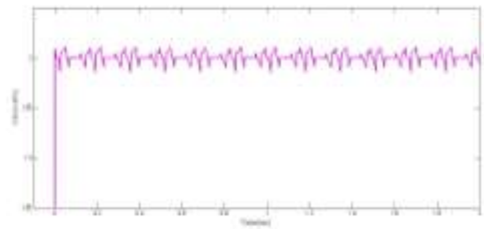
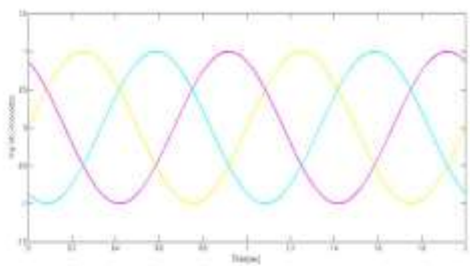


Fig 15. Transient state Vdc (PU) for UPFC

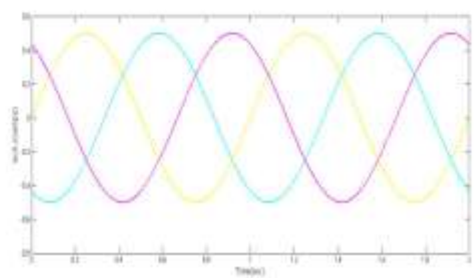
STEADY STATE RESULTS FOR SSSC BASED ON SPWM VSC



Vdc(PU)



Vabc(PU)



Iabc(PU)

Fig 16 Corresponding Capacitor voltage (Vdc), Phase voltages (Va,Vb,Vc), series currents (ia,ib,ic)

TRANSIENT STATE RESULTS FOR SSSC BASED ON SPWM VSC

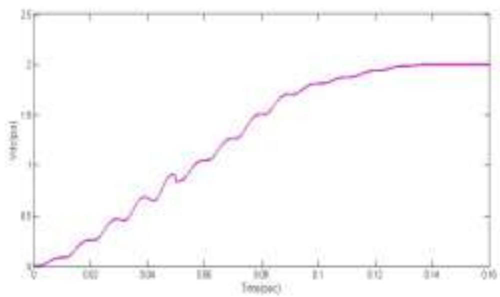
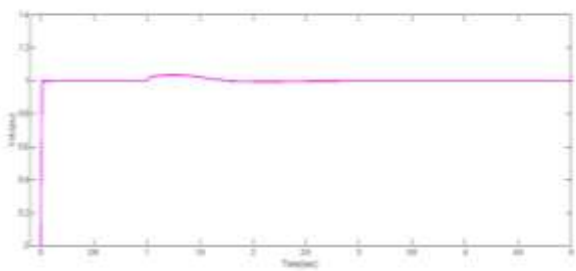
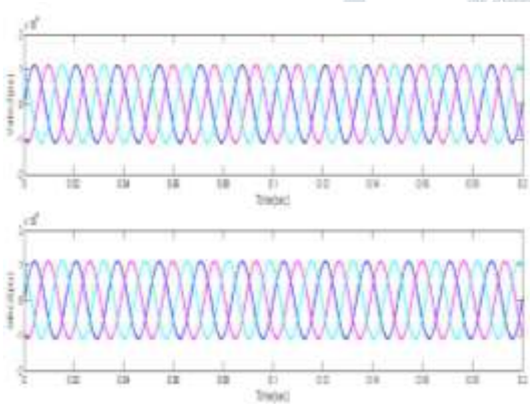


Fig 17 Transient state Vdc (PU) for SSSC

RESULT FOR SSSC BASED ON FUZZY CONTROLLER



Vdc (PU)



Vabc2 (PU), Iabc2 (PU)

Fig 18 Corresponding capacitor voltage (Vdc), Series Voltage Vabc2, & Current Iabc2

RESULT FOR TRANSIENT STATE SSSC BASED ON FUZZY CONTROLLER

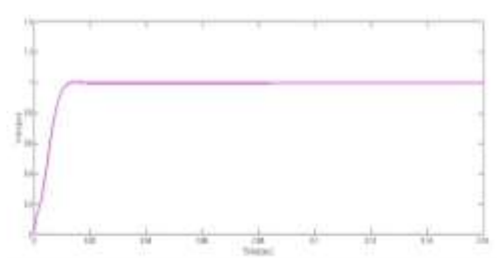
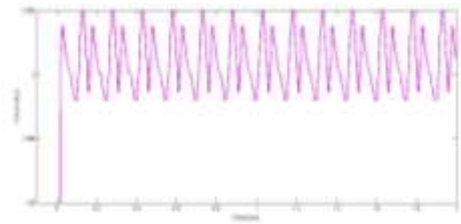
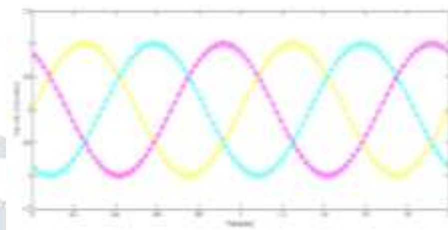


Fig 19 Transient state Vdc (PU)

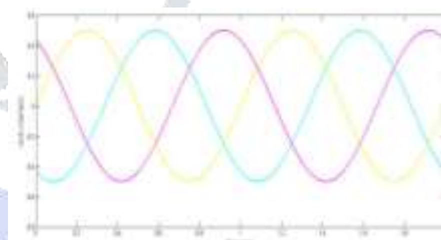
STEADY STATE RESULTS FOR STATCOM BASED ON SPWM VSC



Vdc (pu)



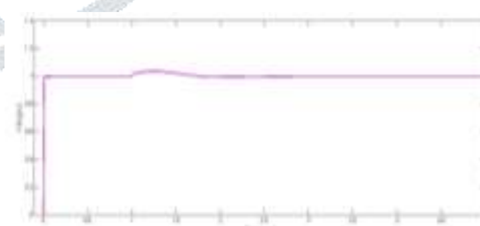
Vabc(pu)



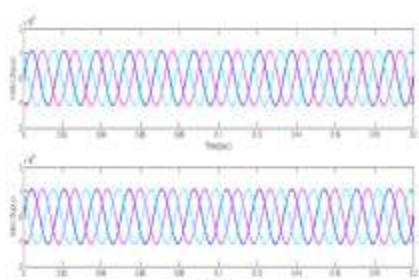
Iabc(pu)

Fig 20 Corresponding Capacitor voltage (Vdc), Phase voltages (Va,Vb,Vc), series currents (ia,ib,ic)

STEADY STATE RESULT FOR STATCOM BASED ON FUZZY CONTROLLER



Vdc(PU)



Vabc3 (PU), Iabc3 (PU)

Fig .21 Corresponding capacitor voltage (Vdc), Shunt Voltage Vabc3 & current Iabc3

IV. CONCLUSION

The proposed models have been used for the computation of the solution of FACTS devices connected to a power network. It has been shown that the proposed models can be used to compute both the transient and the periodic steady-state solution of a power network containing VSC-based FACTS. In this project SPWM VSC based UPFC is implemented in MATLAB/Simulink and it can be observed that the ripple content is reduced in Vdc by using fuzzy logic controller. UPFC model is faster & accurate compared to STATCOM and SSSC. The proposed VSCs models have been only implemented in a network including FACTS devices; however, these models can be used in any power-electronic device based on SPWM six pulse converters, or even for multilevel converters based on arrangement of six-pulse converters. The suppression in fault level is verified MATLAB/SIMULINK software.

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