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Voltage Controlled DSTATCOM Using Fuzzy Controller for Power Quality Improvement

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Abstract

The proposed schemes show voltage controlled distribution STATCOM compensator advantages over the traditional voltage controlled DSTATCOM. The scheme generates a new algorithm for voltage controlled mode operation of distribution STATCOM compensator to generate reference voltage. The proposed schemes ensure the unity power factor (1.0 p.u) to be achieved at the load terminal during nominal operation which can't be done in traditional method. The DSTATCOM injects lower current and reduces loses in voltage source inverter and feeder, further the capacity of compensator to mitigate the voltage sag is increased. The DSTATCOM can switch between current control mode (CCM) and voltage control mode (VCM) mode any time needed using fuzzy which is not possible in the traditional method. The system also apt in tackling power quality problems by providing power factor correction, voltage regulation and can free the system from harmonics by eliminating them and maintain load balance. The experimental results along with simulations are demonstrated the system is efficient enough.

Key Words: current control mode, power quality (PQ), voltage-control mode, voltage-source inverter.

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1. INTRODUCTION

Distribution system plays a very important role between bulk power source or sources and the consumer service switches and is an inseparable part of electric system. A Distribution system suffers from current as well as voltage-related power-quality (PQ) problems via low power factor, distorted source current, and voltage disturbances, harmonic distortion due to harmonic current and also heating in the electrical equipments. A DSTATCOM (STATCOM connected in the distribution section hence DSTATCOM) connected at the point of common coupling (PCC), has been utilized to mitigate both types of PQ problems. The DSTATCOM can operate in VCM and CCM mode but one at time the DSTATCOM when operating in current control mode (CCM), it injects reactive and harmonic components of load currents to make source currents balanced, sinusoidal, and in phase with the PCC voltages. In voltage control mode (VCM), the DSTATCOM regulates PCC voltage at a reference value to protect critical loads from voltage disturbances, such as sag, swell and unbalances. However, the advantages of CCM and VCM cannot be achieved simultaneously with one active filter device, since two modes are independent of each other.

In CCM operation mode, the DSTATCOM cannot compensate for voltage disturbances. Hence CCM operation of DSTATCOM is not useful under voltage disturbances, which is major disadvantage of this mode of operation. Traditionally, in VCM operation, the DSTATCOM regulates the PCC voltage at 1.0 p.u. However, a load works satisfactorily for a permissible voltage range. Hence it is not necessary to regulate PCC voltage at 1.0 p.u. For maintain the 1.0.p.u voltages the DSTATCOM compensates for the voltage drop in feeder. To compensate the voltage drop in feeder the DSTATCOM has to provide additional reactive currents which increase the source current which in turn increases the losses in the voltage-source inverter (VSI) and feeder. Due this increased current injection the VSI is de-rated in steady – state condition. As a result of the above condition its capability to mitigate deep voltage sag decreases**.** One more hurdle is that UPF cannot be achieved when the PCC voltage is 1 p.u. In the literature, so far, the operation of DTATCOM is not reported where the advantages of both modes are achieved depending on load requirements while overcoming their demerits.

This paper considers the operation of DSTATCOM in VCM and proposes a control algorithm to obtain the reference load terminal voltage. This algorithm provides the combined advantages CCM and VCM**.** The UPF operation at the PCC is achieved at nominal load, whereas fast voltage regulation is provided during voltage disturbances. Also, the reactive and harmonic component of load current is supplied by the compensator at any time of operation. The discrete PWM controller is used to generate switching pulses.

In this project, it uses a fuel cell, universal bridge of three-level, neutral-point-clamped VSI is proposed which is different from all other existing topologies. This structure allows independent control to each leg of the VSI.

2. PROPOSED CONTROL SCHEME

Circuit diagram of DSTSTCOM-compensated distribution system shows the proposed fuel cell, universal bridge of three-level, neutral-point-clamped VSI topology. This structure allows independent control to each leg of the VSI [7]. Fig. 2 Shows the single-phase equivalent representation of fig.1.filter inductance and resistance are L_f and R_f respectively and the shunt capacitor C_{fc} eliminates high-switching frequency components.

Using discrete modeling of the system a discrete voltage control law is obtained and it is also shown that the PCC voltage can be regulated to the desired value with properly chosen parameters of VSI. Then a procedure to design VSI parameters is show cased. The DC capacitor voltage is maintained at reference value using a proportional integral (PI) controller [7].

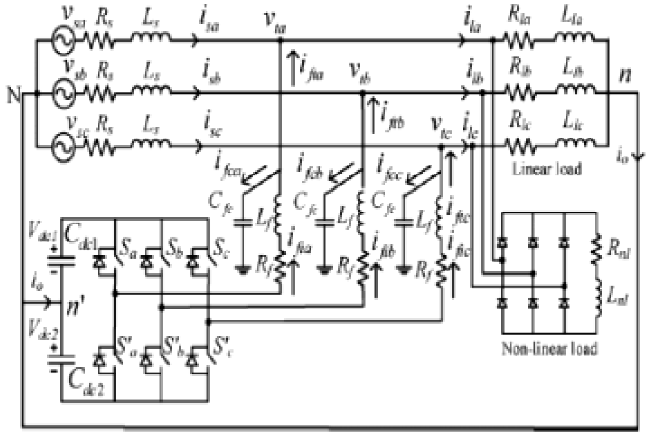

Fig. 1 Diagram for D-STATCOM compensated distribution system

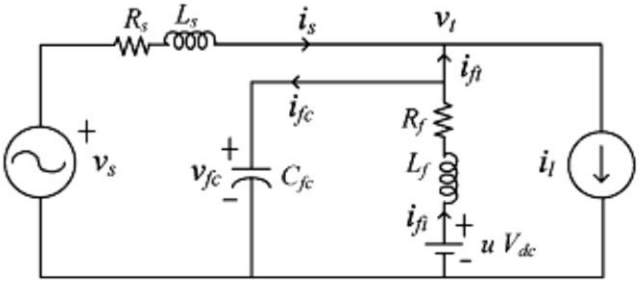

Fig. 2 Single-phase equivalent circuit of DSTATCOM

The state-space equations for the circuit shown in fig are given by

$$\dot{x} = Ax + Bz \qquad (1)$$

$$A = \begin{bmatrix} 0 & \frac{1}{C_{fc}} & 0 \\ \frac{-1}{L_f} & \frac{-R_f}{L_f} & 0 \\ \frac{-1}{L_s} & 0 & \frac{-R_s}{L_s} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & -\frac{1}{C_{fc}} & 0 \\ \frac{V_{dc}}{L_f} & 0 & 0 \\ 0 & 0 & \frac{1}{L_s} \end{bmatrix}$$

$x = [\, v_{fc} \quad i_{fi} \quad i_s]^t$ $\qquad$ $z = [u \quad i_{fi} \quad v_s \,]^t$

$$v_{fc}\,(k+1) = G_{11} v_{fc}\,(k) + G_{12} i_{fi}\,(k) + H_{11}\,u(k) + H_{12} i_{ft}(k) \qquad (2)$$

Where,

$G_{11} = 1 - T_d^2/2L_f\,C_{fc}$

$G_{12} = T_d/C_{fc} - T_d^2 R_f/2L_f\,C_{fc}$

$G_{13} = 0$

$H_{11} = T_d^2 V_{dc}/2L_f C_{fc}$

$H_{12} = -T_d/C_{fc}$

$H_{13} = 0$

From (2) its seen that the terminal voltage can be maintained at reference value depending upon the VSI parameters V_{dc}, C_{fc}, L_f, R_f and the sampling time.VSI parameters must be chosen carefully .let v_t^* be the reference load terminal voltage. A cost function J is chosen as follows [8]

$$J = \left[v_{fc}(k+1) - v_t^*(k+1)\right]^2 \qquad (3)$$

The dead beat control law form equation (2) can be given as

$$u^*(k) = \frac{v_t^*(k+1) - G_{11}v_{fc}(k) - G_{12}i_{fi}(k) - H_{12}i_{ft}(k)}{H_{11}} \qquad (4)$$

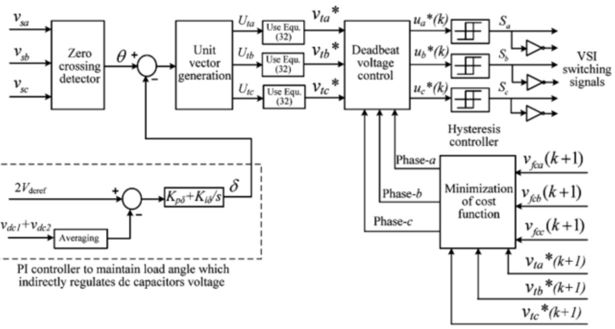

Fig. 3 Overall control block diagram of the controller to control DSTATCOM in distribution system

The future reference voltage which is unknown is predicted one-step-ahead by using a second -order Lagrange extrapolation formula as

$$v_t^*(k+1) = 3v_t^*(k) - 3v_t^*(k-1) + v_t^*(k-2) \qquad (5)$$

2.2 Design of VSI Parameters

DSTATCOM regulates terminal voltage satisfactorily, depending upon the properly chosen VSI parameters. The design procedure of these parameters is presented as follows.

2.2.1 Voltage Across DC Bus (V_{dc}): The dc bus voltage is taken twice the peak of the phase voltage of the source for satisfactory performance. Therefore, for a line voltage of 400 V, the dc bus voltage is maintained at 650 V.

2.2.2 *DC Capacitance (Cdc):* Values of dc capacitors are chosen based on a period of sag/swell and change in dc bus voltage during transients.

$$C_{dc} = \frac{2pST}{V_{dcref}^2 - V_{dc}^2} \qquad (6)$$

Here, S=10 kVA, V_{dcref} =650 V, p=1, and $V_{dc} =$ 0.8 V_{dcref} or 1.2 V_{dcref}. Using (6), capacitor values are found to be 2630 uf and 2152 uf. The capacitor value 2600 uf is chosen to achieve satisfactory performance during all operating conditions.

2.2.3 *Filter Inductance (Lf):* Filter inductance (L_f)should provide reasonably high switching frequency and a sufficient rate of change of current such that VSI currents follow desired currents.

$$L_f = \frac{2V_m}{(2h_c)(2f_{max})} = \frac{0.5V_m}{h_c f_{max}} \qquad (7)$$

Where, $2h_c$ is the ripple in current. With f_{max}=10 kHz and hc=0.75 A (5% of rated current), the value of $L_f$using (7) is found to be 21.8 mH, and 22 mH is used in realizing the filter.

2.2.4 *Shunt Capacitor(Cfc):* The shunt capacitor should not resonate with feeder inductance at the fundamental frequency(ω_o). Capacitance, at which resonance will occur, is given as

$$C_{fcr} = \frac{1}{\omega_0^2 L_s} \qquad (8)$$

For proper operation, C_{fc} must be chosen very small compared to C_{fcr} (8) i.e $C_{fc} << C_{fcr}$.

Here, a value of 5 uF is chosen which provides an Z=637ohm at ω_o.This does not allow the capacitor to draw significant fundamental reactive current. In the traditional method, the reference voltage is 1.0 p.u., whereas in the proposed method, equation (9) is used to find the reference voltage.

$$V_t^* = \sqrt{V^2 - \left(\left|\bar{I}_{la1}^+\right| X_s\right)^2} - \left|\bar{I}_{la1}^+\right| R_s. \qquad (9)$$

3. INTRODUCTION TO FUZZY LOGIC CONTROLLER

Fuzzy logic is originated as logic of ambiguous concepts. Fuzzy set theory has been widely used in the area of industrial controls; particularly in situations where conventional control design techniques have been difficult to apply. The fuzzy controller is used because of its advantages like it is very robust, can be easily modified and cheaper to implement. Simple fuzzy logic can be built up by group of rules based on human knowledge of system behavior. A simulation model can be built by using MATLAB/ simulink to study the behavior and performance of the proposed controllers. Fuzzy logic controller can also provide desirable control for both small and large signal same time, which is not possible with linear control technique. The fuzzy logic controller performs its operation in four stages:

i. Fuzzification: it converts input data into suitable linguistic values
ii. Knowledge base: it consists of a data base with necessary linguistic definitions and the set of control rules.
iii. Decision Making: this is a logic which simulates a human decision process and infers the control action using definitions of knowledge base
iv. Defuzzification : it is an interface which gives non fuzzy control action from the output of decision making logic [9]

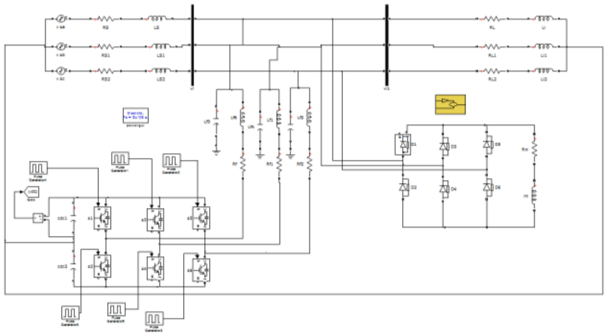

Fig. 4 Proposed circuit with fuzzy controller

3.1. FUZZY LOGIC MEMBERSHIP FUNCTIONS

Membership function can have multiple different types, such as triangular wave-form, trapezoidal, Guassian waveform, bell-shaped waveform, sigmoidal waveform and S-curve wave. The exact type depends on actual application. For those systems that need significant dynamic variation in short period of time, a triangular or trapezoidal waveform should be used. For system that need very high control accuracy, Gaussian or s-cure waveform should be selected.

3.2 Rule Base Design

Fuzzy rules are conditional statement that specifies the relationship among fuzzy variables. With the knowledge of previous system behavior fuzzy rule are developed. The objective of this paper is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs to the fuzzy logic controller. The values of membership function are assigned to the linguistic variables using five fuzzy subsets which are derived from these 2 inputs as; “NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big “[10]. Triangular membership functions are selected for all these singletons. Rule base table formed based on human knowledge. Table 1 shows the rule base of fuzzy logic controller, where all the entries of the matrix are fuzzy sets of error (e), change in error (De) and output change in values. These fuzzy control rules for error and change of error can be referred in Table 1.

Table 1: Rule Base Design for Fuzzy Logic Controller

(e) (de)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

3.3 DEFUZZFICATION

The output of the inference mechanism is a fuzzy value, so it is necessary to convert this fuzzy value into a real value, since the physical process cannot deal with fuzzy value. This operation that is the inverse of fuzzification is known as defuzzification. The well-known center of gravity defuzzification method has been used because of its simplicity.

3.3 NORMALIZATION

Generally, the universes of discourse of input and output variables of FLC are the real line. In practice, each universe is restricted to an interval that is related to the maximal and minimal possible values of the respective variable, that is, to the operating range of the variable. The rules will not be properly framed if the operating range is not suitably selected. For simplification and unification of the design of the FLC and its computer implementation, however, it is more convenient to operate with normalized universe of discourse of the input/output variables of the FLC [10].

3.4 DENORMALIZATION

In denormalization process the output values of fuzzy controller are converted to a value depending on the terminal control element. In the denormalization procedure the defuzzified normalized controller output u_N is denormalized with the help of an off-line predetermined scalar denormalization N_u^{-1} which is the inverse of the normalization factor N_u.

Let the normalization of the controller output be performed as:

$$u_{N=} N_u.u \qquad (10)$$

Then, the denormalization of u_N is simply:

$$u = N_u^{-1}.\ u_N \qquad (11)$$

The choice of the N_u essentially determines, together with the rest of the scaling factors, the stability of the system to be controlled.[11] Obtaining the normalization and denormalization parameters of fuzzy controller is important for system stability.

4. SIMULATION RESULTS

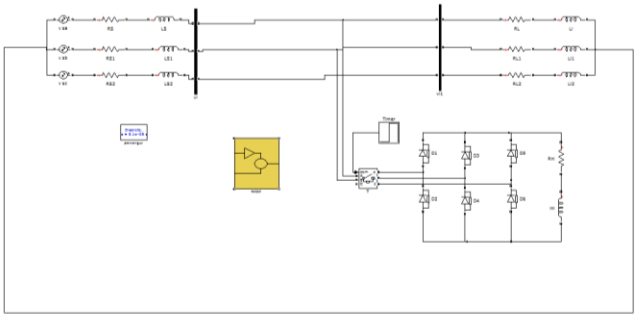

Fig. 5 Simulation circuit before compensation (Terminal Voltages and Source Currents)

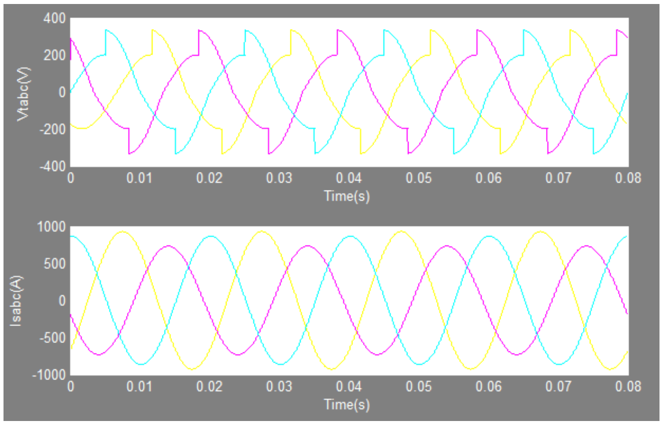

Fig. 6 Simulation wave form of terminal voltages and source currents

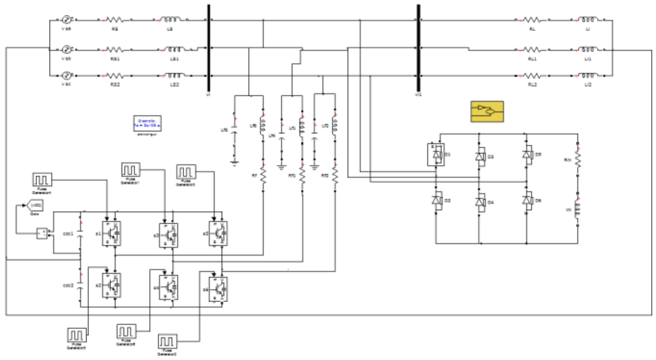

Fig. 7 Simulation circuit for phase voltages, powers, source and compensator rms currents

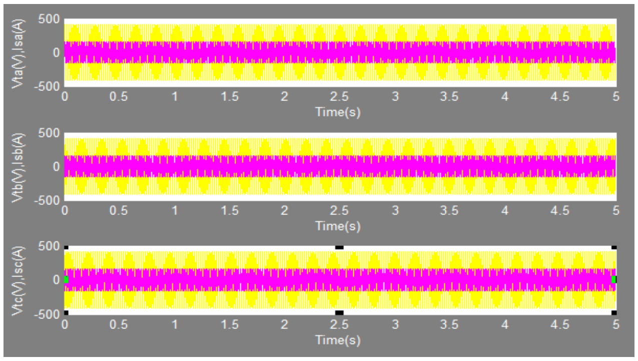

Fig. 8 The simulation wave form of terminal voltages and source currents

a) Phase-a b) phase-b c) phase-c

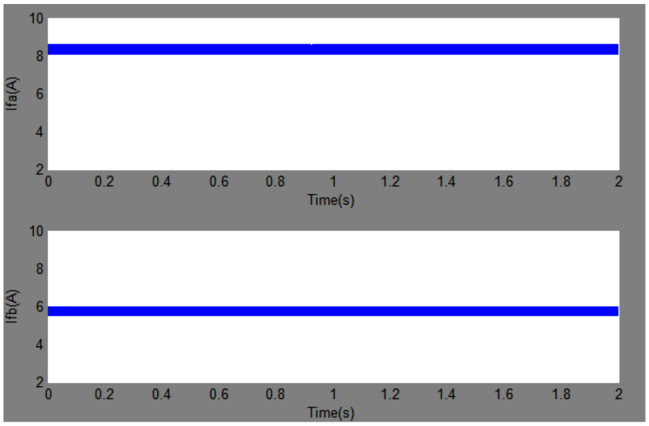

Fig. 9 Simulation wave form of phase-a compensator rms currents (a) Old method (b) new method

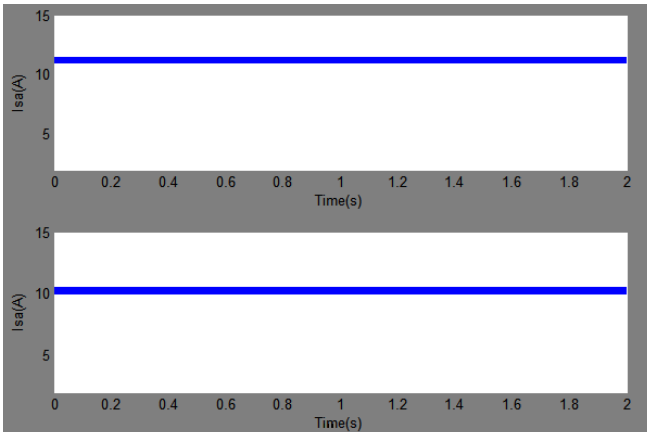

Fig. 10 Simulation wave form of phase-a source rms currents (a) Old method (b) new method

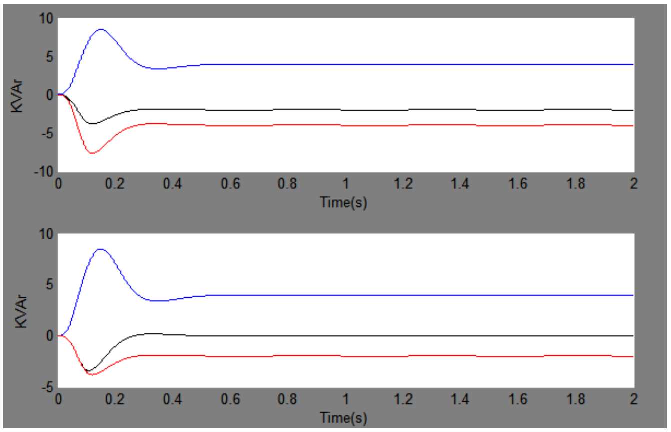

Fig. 11 The simulation wave form of load(QL), compensator (Qvsi) and PCC(Qpcc) reactive powers (a) Old method (b) new method

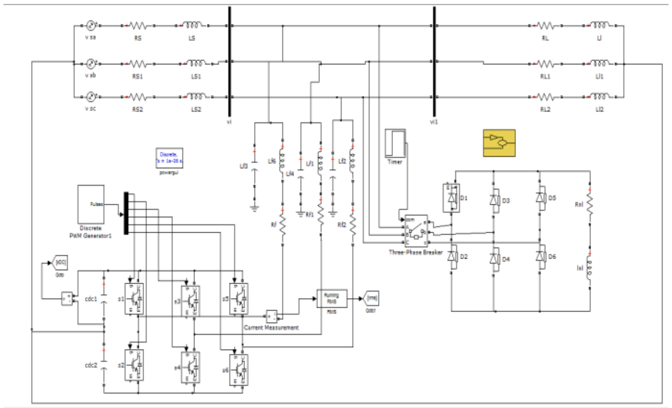

Fig. 12 Simulation circuit for sag operation

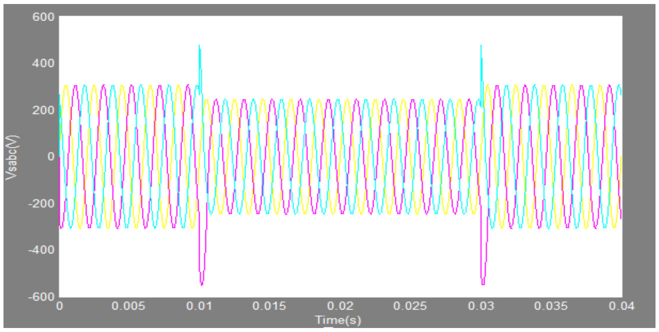

Fig. 13 Simulation wave form of source voltage during sag

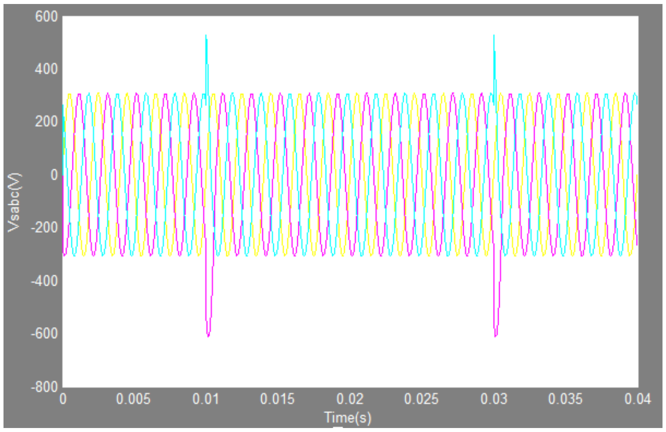

Fig. 14 Simulation wave form of terminal voltage after sag

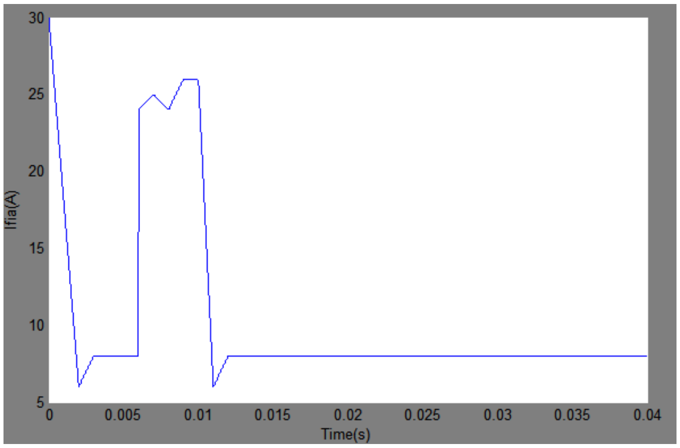

Fig. 15 Simulation wave form of compensator rms current

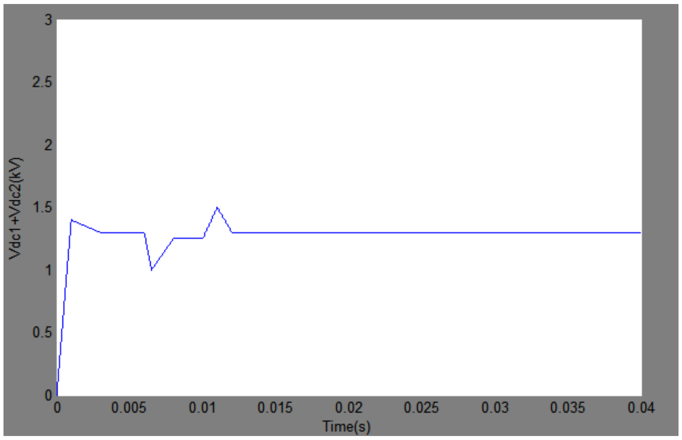

Fig. 16 The simulation wave form of voltage at DC bus

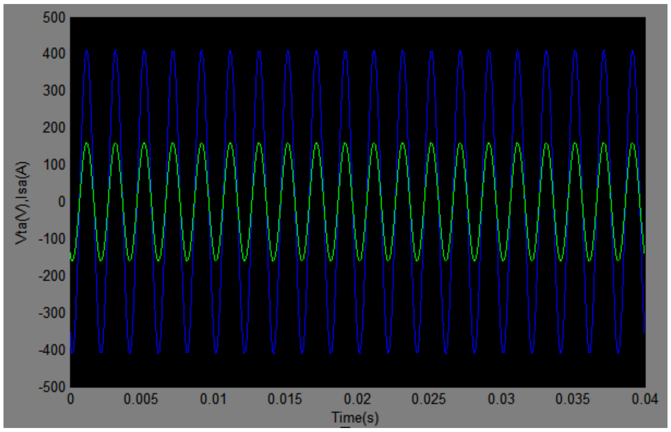

Fig. 17 Simulation wave form of source and terminal voltage during load change

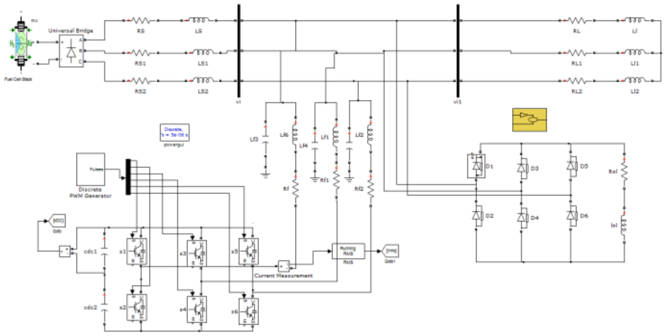

Fig.18 Simulation waveform for RES fed improved load angle

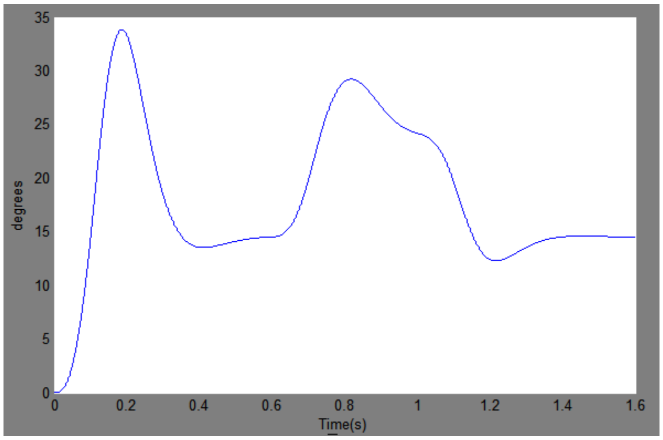

Fig. 19 Simulation wave form of RES fed improved load angle

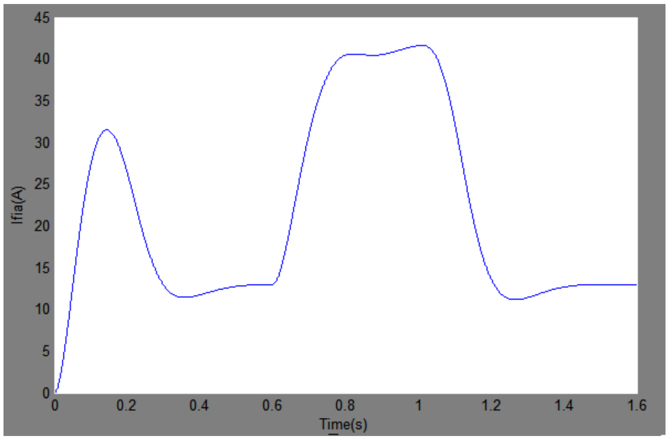

Fig. 20 Simulation waveform of RES fed compensator rms current

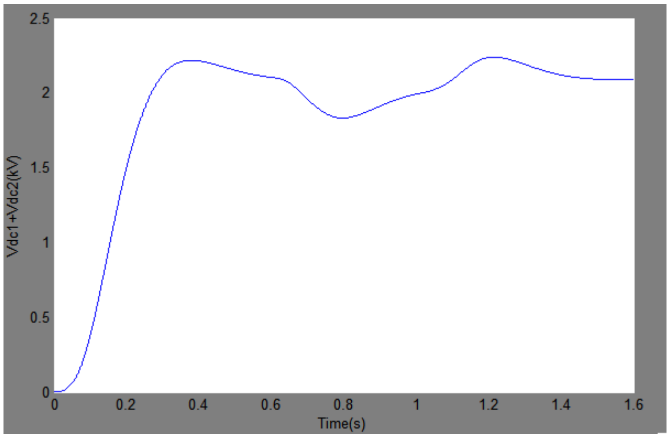

Fig. 21 Simulation wave form of RES fed DC voltage

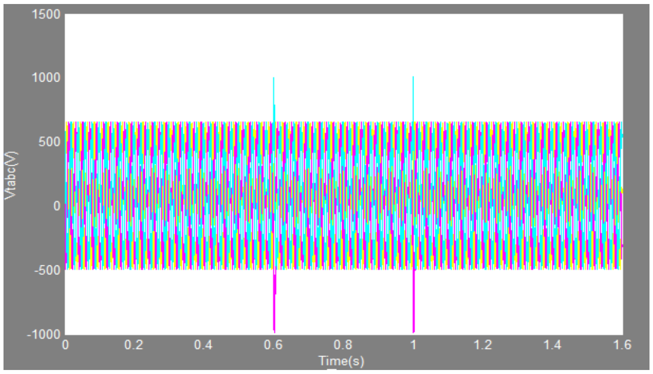

Fig. 22 Simulation wave form of RES fed terminal voltage

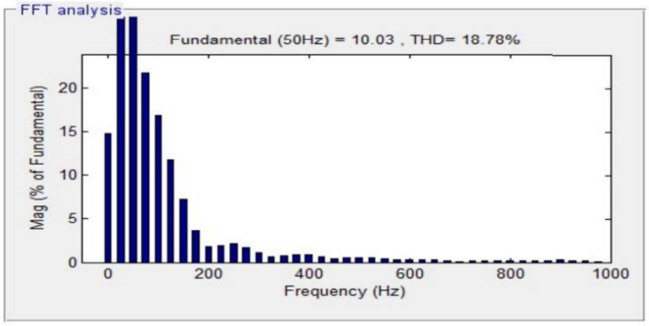

Fig. 23 THD spectrums with fuzzy controller

5. CONCLUSION

The simulation results show that the proposed scheme provides DSTATCOM, a capability to reduce several PQ problems (related to voltage and current). In future, we can use this type of topology to fulfill our requirements, as this model gives more load current, more rms current, more dc voltage, more terminal voltage compared to the existing topology. The advantages of using the system are :

i) nearly UPF is maintained for a load change;

ii) fast voltage regulation has been achieved during voltage disturbances; and

iii) losses in the VSI and feeder are reduced considerably, and have higher sag

In future, we can use this type of topology to fulfill our requirements, as this model gives more load current, more rms current, more dc voltage, more terminal voltage compared to the existing topology.

Since the renewable energy sources are available in more quantity, they can replenish at any time and they are free of cost in some situations. Even though if there are any financial expenses if we spend one time the sources will last long time when compared to non-renewable energy sources.

So, this project can serve any human being in future to meet their continuous power supply without any disturbances and they can lead a successful life.

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