Fuzzy Logic based Power Quality Improvement and PV Power Injection by DSTATCOM with Variable DC Link Voltage Control from RSC-MLC

M. Pavani
PG Student

N. Karthik
Associate professor

Dept of EEE,
Bapatla Engineering College

***Abstract* — The study proposes a method to optimize dc-link voltage of Distribution Static Compensator (DSTATCOM) based on load compensation requirement using Reduced Switch Count Multi-Level Converter (RSC-MLC)integrated with Photo-Voltaic (PV) system. The proposed method is capable of compensating reactive power, unbalance and harmonics demanded by three phase unbalanced and non-linear loads connected to the distribution side, leading to improvement of power quality. It is also capable of providing real power support to the load and thus prevents source from getting over loaded whenever required. the maximum power point tracking (MPPT) of PV panels is achieved by using Perturb and Observe (P & O) algorithm. In this project, the THD of the system is observed with a D-STATCOM with PI controller and without any compensators. The effect of replacing DC link by a Photo voltaic (PV) system is to be observed. In this project, conventional PI controller is replaced by a fuzzy logic controller and the THD of the system is observed with and without PV system. The performance of these controllers is compared, and suitable controller is proposed to increase power quality of system when renewable energy sources are introduced into the system. The whole work is to be performed in MATLAB/SIMULINK.**

Keywords*— *DC-link voltage, DSTATCOM, Power Quality,PV system, Reduced Switch Count Multi Level Converter (RSCMLC), Switching Losses

I.INTRODUCTION

The quality of available supply power has a direct economic impact on industrial and domestic sectors which affects the growth of any nation [1]. This issue is more serious in electronic based systems. The level of harmonics and reactive power Demand are popular parameters that specify the degree of distortion and reactive power demand at a particular bus of the utility [2].

The harmonic resonance is one of the most common problems reported in low- and medium-level distribution systems. It is due to capacitors which are used for power factor correction (PFC) and source impedance [3]. Power converter based custom power devices (CPDs) are useful for the reduction of power quality problems such as PFC, harmonic compensation, voltage sag/swell compensation, resonance due to distortion, and voltage flicker reduction within specified international standards [4]–[6]. These CPDs include the distribution static compensator (DSTATCOM), dynamic voltage restorer, and unified power quality conditioner in different configurations [7]–[9]. Some of their new topologies are also reported in the literature such as the indirect matrix converter based active compensator where the dc-link capacitor can be removed [10]. In the proposed method, the dc-link voltage regulation is achieved using Reduced Switch Count Multi Level Converter (RSC-MLC). The gate pulses of inverter switches are controlled using Hysteresis Controller which is faster and simpler [9]. The gate pulses are derived using Instantaneous Symmetrical Component Theory (ISCT) to get the reference harmonic currents based on load demand [10]. These harmonic currents are used to find the required reference dc-link voltage. The RSC-MLC is operated using Pulse Width Modulation (PWM)technique to obtain the desired level of dc-link voltage. The specialty of this RSC-MLC topology is reduced voltage stress at any operating condition across switches, which leads to reduction in switching losses.

Due to growing consumption of conventional sources of energy, there is a huge need to employ non-conventional resources in as many applications possible because they are freely available as well as non-polluting [11]. The solar energy is viewed as one of the popular and potential energy source for meeting the demands. The solar energy is converted into electrical energy by using Photo Voltaic (PV) cells. Several analysis upon the stability and performance of the PV integrated systems for various applications have been performed [12], [13], [14]. In the proposed method, the PV panels are used to charge the batteries of RSC-MLC.

The Maximum Power Point Tracking (MPPT) is achieved using Perturb & Observe (P & O) algorithm and the output voltage of PV panel is stepped up using High Gain Boost Converter (HGBC) [15]. During day time, PV panels produce maximum real power. Therefore, the batteries can be charged and real power support can also be provided. At night, PV panels cannot deliver real power due to insufficient irradiation. In this case, the batteries will support the dc-link voltage for reactive power and harmonic compensation. The real power can be shared intelligently based upon the availability of irradiation and demand. The complete details of dc-link voltage variation using proposed RSC-MLC for achieving power quality improvement and injection of real power is discussed below extensively.

The PI controller generates the error signal to drive the error to zero. PI controller is a closed loop controller which is leaden sum of error and integrate that value. Conventional controller has the gain of steady state error to be zero for step input. The transient response of the PI controller in DC-link voltage will be very slow. To overcome this problem a better fuzzy logic controller is proposed to improve the transient response of the dc-link voltage. The DC link capacitor voltage is maintained using a fuzzy logic controller. Fuzzy controller is its robustness in system parameters and speed of operation is more. PI and Fuzzy both controllers are operated under steady state and transient state conditions. Now we are calculating the THD compared with and without using controllers.

II.SOLAR CELL CHARACTERISTICS

The solar cell is mainly made of PV wafers, converts the light energy of solar irradiation into voltage and current directly for load, and conducts electricity without electrolytic effect. The electric energy is obtained from the PN interface of semiconductor directly; therefore, the solar cell is also known as PV cell .The equivalent circuit of solar cell as shown in Figure1

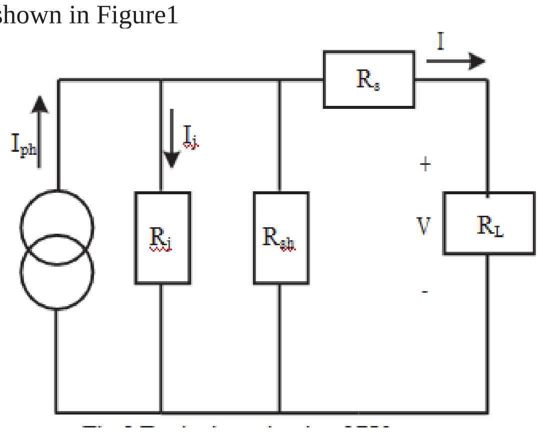


Fig.1 Equivalent circuit of PV array

The current source Iph represents the cell photovoltaic current, Rj is used to represent the nonlinear resistance of the p-n junction, Rsh and Rs are used to represent the intrinsic shunt and series resistance respectively. Normally value of Rsh is very large and Rs is very small. Hence both of them can be neglected to simplify the analysis. PV cells are grouped in larger units to form PV modules. They are further interconnected in series-parallel combination to form PV arrays. The mathematical model used to simplify the PV array is represented by the equation $I = n_p I_{ph} - n_p I_{rs}\left[e^{\left(\frac{q}{kTA}*\frac{V}{n_s}\right)} - 1\right]$

Where I is the PV array output current, V is the PV array output voltage, ns is the number of series cells, np is the number of parallel cells, q is the charge of an electron, k is the Boltzman constant, A is the p-n junction ideality factor, T is the cell temperature, and Irs is the cell reverse saturation current. The factor A decides the deviation of solar cell from the ideal p-n junction characteristics. Its value ranges from one to five. The photo current Iph depends on the solar irradiance and cell temperature as below

Where Iscr is the cell short circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient and S is the solar irradiance in mW/cm2. The Simulink model of PV array is shown in Fig. 4. The model includes three subsystems. One subsystem to model PV module and two more subsystems to model Iph and Irs

III.PROPOSED OPERATION OF DSTATCOM USING RSC-MLC INTEGRATED WITH PV-PANELS

The schematic diagram of DSTATCOM for power quality improvement and PV power injection with RSC-MLC on dcside of VSI is shown in Fig. 1. In most of the existing topologies of VSI, the dc-link voltage is maintained constant (i.e., twice the peak of Vpcc) for all load conditions [7]. But, in reality the dc-link voltage required is low when system is operated at off-peak load conditions. Therefore, constant rated dc-link voltage leads to unwanted switching losses during reduced load conditions. The dc-link voltage can be reduced at off-peak loads without compromising the compensation. This reduces the voltage stress across switches of VSI and minimizes the switching losses at reduced loads.

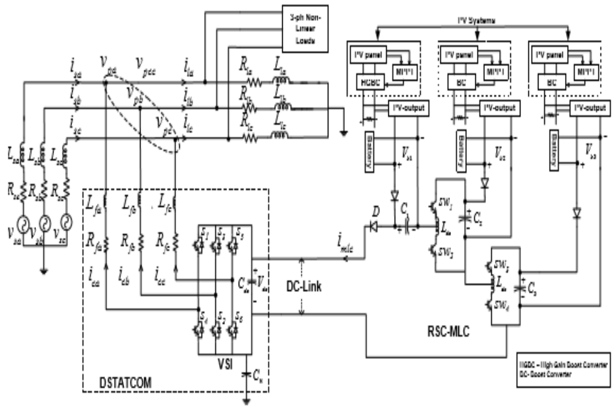


Fig. 1: RSC-MLC controlled DSTATCOM for PQ improvement and real power injection from PV in distribution system

In the proposed method, RSC-MLC is used for regulating the dc-link voltage of DSTATCOM. At reduced loads, it reduces the dc-link voltage which leads to minimization of switching losses. The operation of RSC-MLC and selection of dc-link voltage based on various load requirements is explained here in detail. The dc-voltage sources used for RSC-MLC are PV-Panels which is a source of real power. Hence, the real power sharing can also be achieved based on availability of sunlight and the load demand. The reference dc-link voltage for the proposed method is estimated as shown

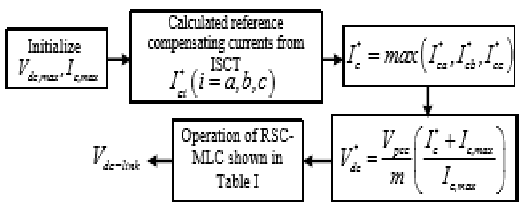


Fig. 2: Flow-c $I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{100}$ age calculation

B. Generation of Gate Pulses for DSTATCOM.

The control algorithm of gate pulses generation for DSTATCOM is shown in Fig. 4. The reference compensating currents are derived using ISCT [16]. These reference compensating currents are compared with actual compensating currents supplied by DSTATCOM and error is given to hysteresis controller. It generates gate pulses, which will operate the DSTATCOM in such a way that it injects exactly the same compensating current required by the load.

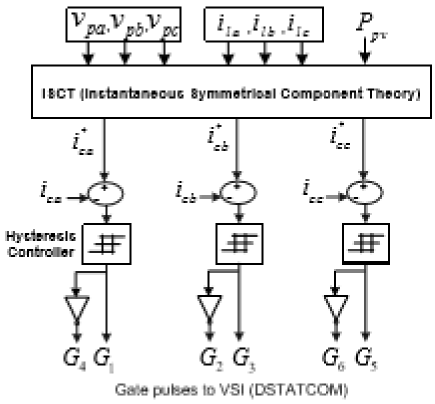


Fig. 4: Control algorithm of gate pulse generation for DSTATCOM

Hence, the DSTATCOM is able to compensate the harmonic current and reactive power demanded by the load and also supplies the real power generated from PV system. Therefore, source current becomes free from harmonics and supplies only real power, improving the source power factor.

CONTROL STRATEGY

A) SRF THEORY: The synchronous reference frame theory is one of the methods in time-domain based reference current generation techniques.

Important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation. The d-q transformation output signals depend on the load currents (fundamental and harmonic frequency components) and the performance of the phase locked loop. The PLL circuit is providing sinθ and cosθ for synchronization. It performs the operation in steady-state or transient state as well as for generic voltage and current waveforms. The reference frame transformation is formulated from a three-phase abc stationary system to the direct axis (d) and quadratic axis (q) rotating coordinate system [2].Park's Transformation and Clarke's Transformation are used to decouple the active and reactive components (4). Park's Transformation is used to simplify the computational complexity by converting the three phase components into equivalent two phase components (5). The block diagram of the synchronous reference frame controller is shown in fig 2.

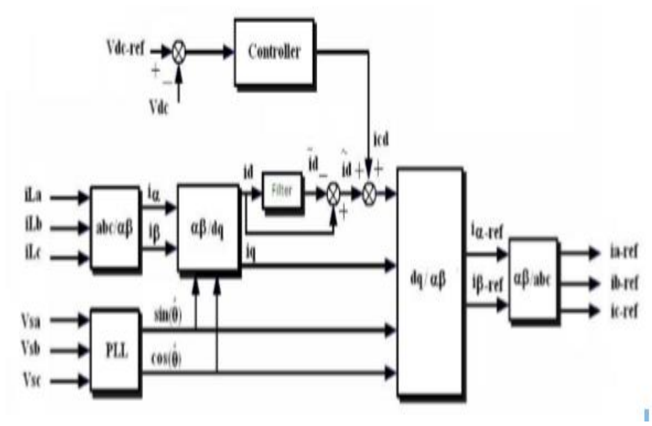


Fig.2: Block diagram of srf theory

$$\begin{bmatrix} ids \\ iqs \\ i_0 \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} \cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ \sin\theta & \sin(\theta-120) & \sin(\theta+120) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_d{}^e \\ i_q{}^e \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} ids \\ iqs \end{bmatrix}$$

$$\begin{bmatrix} ILd \\ ILq \end{bmatrix} = \begin{bmatrix} \tilde{I}Ld + \bar{I}Ld \\ \tilde{I}Lq + \bar{I}Lq \end{bmatrix}$$

When Ld I ~, Ld I , Lq I ~, Lq I are the DC components and AC component of the load currents on Dq frame, respectively. From equation (6), it is shown that the dq load currents consist of two terms. The high-pass filter (HPF) is used to separate the harmonic components from the dq load currents (iLd, iLq), Half of the fundamental is taken as the cut-off frequency of the high pass filter frequency

$$\begin{bmatrix} ids \\ iqs \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} i_d{}^e \\ i_q{}^e \end{bmatrix}$$

$$\begin{bmatrix} i_a{}^* \\ i_b{}^* \\ i_c{}^* \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120) & \sin(\theta-120) & 1 \\ \cos(\theta+120) & \sin(\theta+120) & 1 \end{bmatrix}\begin{bmatrix} ids \\ i_q{}^s \\ i_0{}^s \end{bmatrix}$$

Finally, the harmonic components are converted back into three phase quantities by applying Reverse Park's and Reverse Clarke's Transformations as shown in equations (7) and (8). These signals are taken as reference signals to the hysteresis current controller to generate the gate pulses to the inverter.

ISSN: 2278-0181
NCSMSD – 2020 Conference Proceedings

IV.FUZZY LOGIC CONTROLLER

The concept of Fuzzy Logic Controller (FLC) was proposed by Professor Lotfi Zadeh in 1965, at first as a way of processing data by allowing partial set membership rather than crisp membership. Soon after, it was proven to be an excellent choice for many control system applications.

Fuzzy control is based on a logical system called fuzzy logic. It is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays, fuzzy logic controller is used in almost all sectors of industry, power systems and science. One of them is the harmonic current and reactive power Compensation control

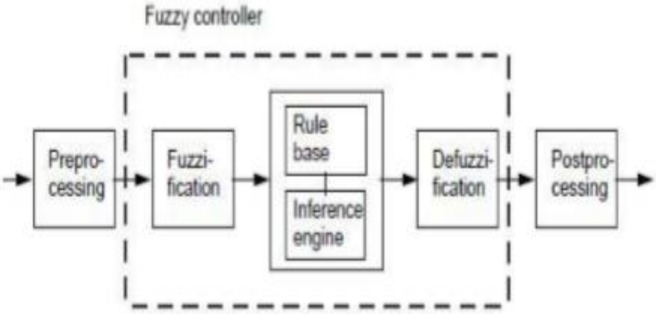


Fig.4: Block diagram of Fuzzy Logic Controller

a) Fuzzification: Just like an algebraic variable takes numbers as a value, a linguistic variable takes words or sentences as values. The set of values that it can take is called its term set. Each value in the term set is a fuzzy variable defined over a base variable. Lofti Zadeh proposed the concept of linguistic or fuzzy variables. In a control system, error between reference and output can be labeled as zero (ZE), positive small (PS), negative small (NS), positive medium (PM), negative medium (NM), positive big (PB), negative big (NB). The process of converting a numerical Variable (real number) to a linguistic variable (fuzzy number) is called Fuzzification. The membership function of a fuzzy logic control system is shown in figure 5. This figure shows two inputs the error (E), its variation (ΔE) and one output.

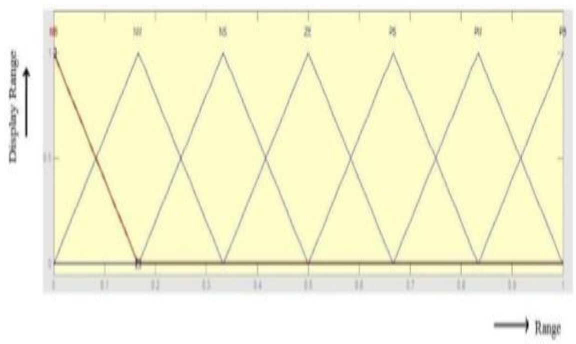


Fig.5: Membership functions for error, change in error and output

b) Defuzzification: The rules of FLC generate required output in a linguistic variable (Fuzzy Number) according to real world requirements. The choices available for Defuzzification are numerous. The conversion of a fuzzy set to a single crisp value is called Defuzzification. Finally, crisp output is obtained by using

Output = ΣAi* xi / Σ Ai

c) Rule Base: The Rule base stores the linguistic control rules required by rule evaluator (decision making logic the formulation of its rule set plays a key role in improving the system performance

Table: 1 Fuzzy control rule

E/CE	NB	NN	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	NS
NM	PB	PM	PM	PS	PS	Z	NS
NS	PM	PM	PS	Z	Z	NS	NS
Z	PM	PS	PS	Z	NS	NS	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NS	NM	NM	NB
PB	Z	NS	NS	NM	NM	PB	NB

HYBRID PI-FUZZY CONTROLLER: The objective of the hybrid controller is to utilize the best attributes of the PI and fuzzy logic controllers to provide a controller which will produce better response than either the PI or the fuzzy controller. There are two major differences between the tracking ability of the conventional PI controller and the fuzzy logic controller. Both the PI and fuzzy controller produce reasonably good tracking for steady-state or slowly varying operating conditions. However, when there is a step change in any of the operating conditions, such as may occur in the set point or load, the PI controller tends to exhibit some overshoot or oscillations. The fuzzy controller reduces both the overshoot and extent of oscillations under the same operating conditions. Although the fuzzy controller has a slower response by itself, it reduces both the overshoot and extent of oscillations under the same operating conditions. The desire is that, by combining the two controllers, one can get the quick response of the PI controller while eliminating the overshoot possibly associated with it.

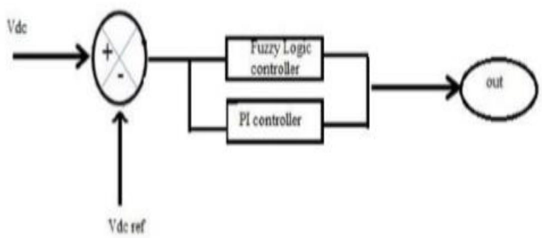


Fig.6: PI-fuzzy controller

V.HYSTERESIS BAND CURRENT TECHNIQUE

The hysteresis band is used to control load currents and determine switching signals for inverters gates. Suitable stability, fast response, high accuracy, simple operation, inherent current peak limitation and load parameters variation independency make the current control methods of voltage source inverters.

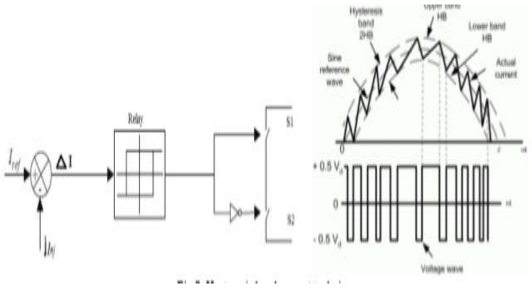
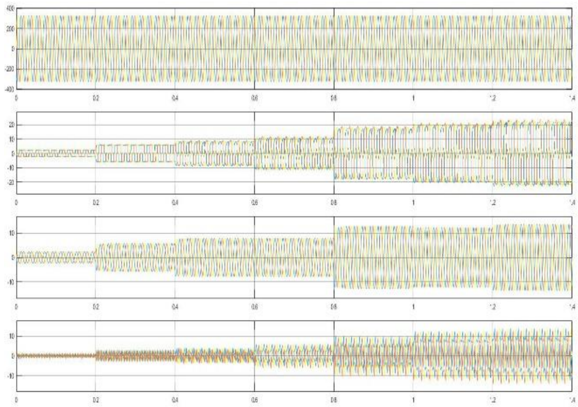


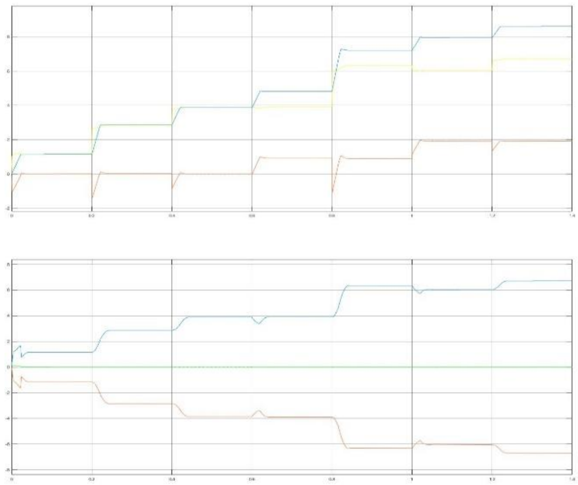
Fig.7: Hysteresis band current technique

The switching takes place when carrier signals crosses the error signal of iref and iact.a comparision of carrier signals with the error signal of iref and iact realizes the PWM switching law described below: If (iact) < (ia* + hb) upper switch of a leg is OFF and lower switch is ON If (iact) > (ira*+ hb) upper switch of a leg is ON and lower switch is OFF

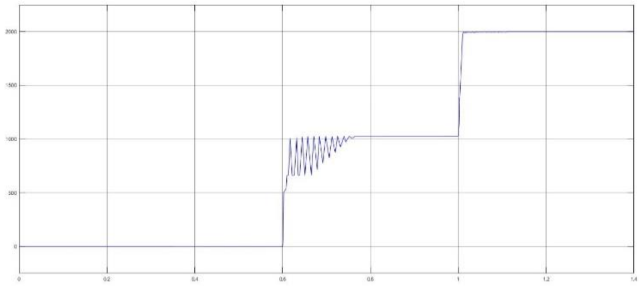
VI.SIMULATION RESULT

DSTATCOM1 RESULTS:

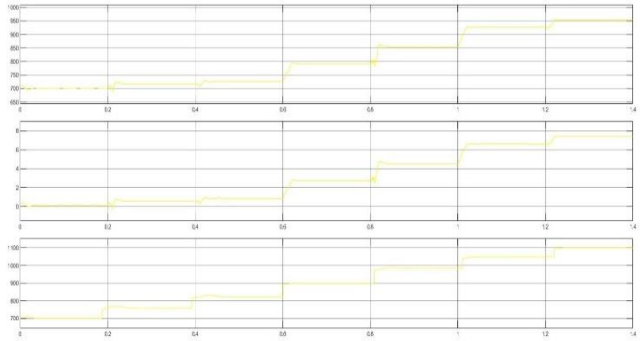




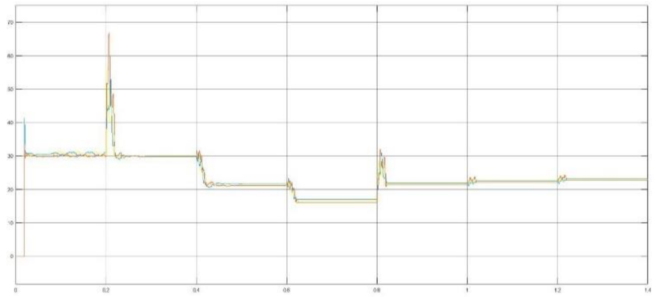
Real and reactive power



Vdc

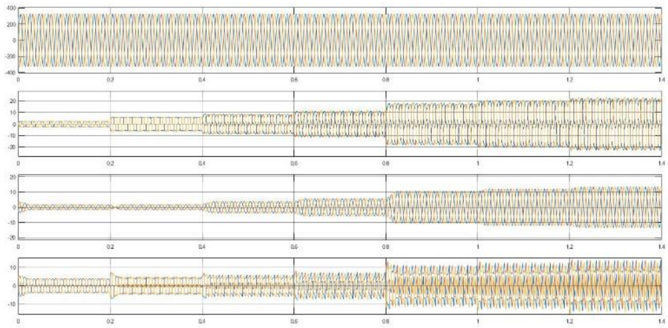


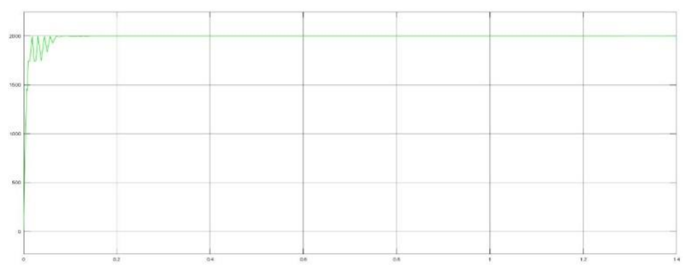
Vdcref, Idcref



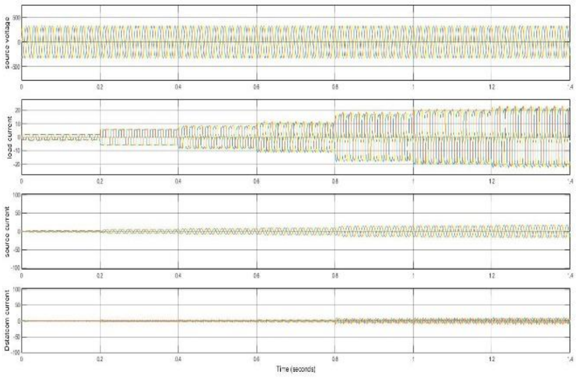
THD (IabcL)

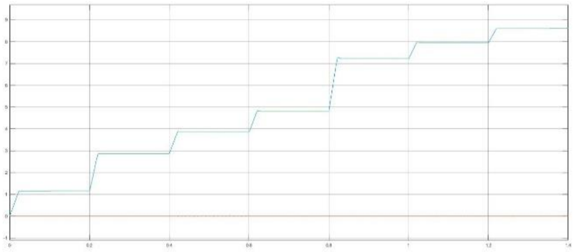
DSTATCOM CONSTANT RADIATION:

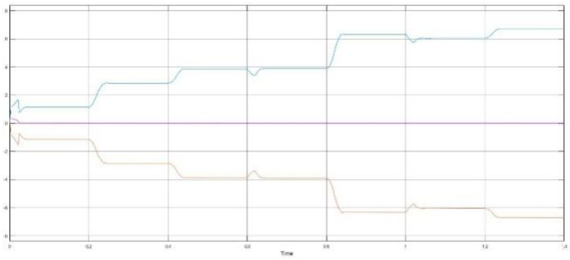




DSTATCOM WITHOUT PV REAL POWER:







Voltage current and power

VII.CONCLUSION

The paper proposes fuzzy logic controller for a DSTATCOM to improve power quality and dynamic performance of a distribution power system has done. FLC is designed for the DC voltage regulator, AC voltage regulator. The effect of Harmonic compensation using PI and Fuzzy Controller was evaluated. The results were compared with those of a conventional PI controlled DSTATCOM in the presence of source voltage variation and large load variations. The results show that the system's performance was dramatically improved by using FLC. DC link voltage is maintained constant in PI and fuzzy controller. The efficacy of the proposed controller is established through a simulation. It is observed from the above studies the proposed fuzzy logic controller gives the fast transient response for fast varying loads.

REFERENCES

[1] J. Arrillaga, N. R. Watson, "Power system harmonics," John Wiley and Sons, 2004.

[2] A. Ghosh A, G. Ledwich, "Power Quality Enhancement using Custom Power Devices," Springer Science and Business Media, 2012.

[3] M. H. J. Bollen, "Understanding Power Quality Problems: Voltage Sags and Interruptions," Wiley - IEEE press, Piscataway, NJ, USA, 2002 .

[4] B. Singh, S. R. Arya, C. Jain, S. Goel, "Implementation of Four-leg Distribution Static Compensator," IET Gener. Transm. Distrib., vol. 8, no. 6, pp. 1127-1139, June 2014.

[5] R. P. Tondare, S. P. Gawande, M. R. Ramteke, "Modeling of Split Capacitor Based DSTATCOM and Voltage Balancing Scheme for Load Compensation," International Conference on Emerging Trends in Communication, Control, Signal Processing and Computing Applications (C2SPCA), Bangalore, pp. 1-6, 2013.

[6] M.V.ManojKumar,M.K.Mishra,"Three-legInverter-basedDistribution Static Compensator Topology for Compensating Unbalanced and NonlinearLoads," IET Power Electron., vol. 8, no. 11, pp. 2076-2084, Nov. 2015.

[7] B. Singh, P. Jayaprakash, D. Kothari, "A T-Connected Transformer and Three-leg VSC Based DSTATCOM for Power Quality Improvement," IEEE Trans. Power Electron., vol. 23, no. 6, pp. 2710-2718, Nov. 2008.

[8] M. Hareesh, G. Siva Kumar, D. Sreenivasarao, "Dynamic DC Voltage Regulation of Split-Capacitor DSTATCOM for Power Quality Improvement," IET Gener. Transm. Distrib., vol. 11, no. 17, pp. 4373-4383, Dec. 2017.

[9] M. K. Mishra, K. Karthikeyan, "An Investigation on Design and Switching Dynamics of a Voltage Source Inverter to Compensate Unbalanced and Nonlinear Loads," IEEE Trans. Ind. Electron., vol. 56, no. 8, pp. 2802-2810, Aug. 2009.

[10] B. Singh, A. Chandra, K. Al-Haddad, "Power quality: problems and mitigation techniques," John Wiley & Sons Ltd., United Kingdom, Dec. 2014.

[11] T. B. Johansson, "Renewable energy: sources for fuels and electricity," Island press, California, 1993.

[12] L. Wang, Q. S. Vo, A. V. Prokhorov, "Dynamic Stability Analysis of a Hybrid Wave and Photovoltaic Power Generation System Integrated Into a Distribution Power Grid," IEEE Trans. Sustain. Energy, vol. 8, no. 1, pp. 404-413, Jan. 2017.

[13] S. Mishra, P. K. Ray, "Power Quality Improvement Using Photovoltaic Fed DSTATCOM Based on JAYA Optimization," IEEE Trans. Sustain. Energy, vol. 7, no. 4, pp. 1672-1680, Oct. 2016.

[14] R. K. Varma, R. Salehi, "SSR Mitigation With a New Control of PV SolarFarmasSTATCOM (PV-STATCOM)" IEEE Trans. Sustain. Energy, vol. 8, no. 4, pp. 1473-1483, Oct. 2017.