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Wavelet Based Control of DSTATCOM for Power Quality Improvement

Priya Kumari, Amol Barve and Anand Singh
Department of Electrical Engineering, Laxmi Narayan College of Technology, Bhopal, (M.P.)

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ABSTRACT: Power quality disturbances like sag, swells, transients, harmonics &flicker are not new to our researchers as such it still prevails in modern power industry. This paper describes the technique of reducing the voltage sag and interruptions in a distribution system by controlling DSTATCOM using wavelet based denoising controller (multi-resolution analysis).Wavelet transform has received greater attention in power quality as this is well suited for analyzing certain types of transient waveforms. The proposed methodology states that the distorted signal is first identified, decomposed and then reconstructed using wavelet transform. These signals are then fed to two level voltage source inverter (VSI) (designed as DSTATCOM) to produce refined signal. Modeling and Simulation of the above mentioned DSTATCOM controller with necessary block diagrams are presented and implemented along with the necessary equations in the MATLAB simulink using the simpower systems tool boxes. Conclusions are based on the simulation results.

Index terms: DSTATCOM, power quality, wavelet control, multi-resolution signal analysis, voltage sag mitigation.

I. INTRODUCTION

In the recent years power quality(PQ) issues have been a centre of attraction . All categories of power consumers are becoming increasingly sensitive to PQ problems, in distribution system it affects all the connected electrical and electronics equipments. The dynamic PQ problems like voltage sag, swell, transients are always occurring in electrical power distribution system. These are caused by switching of large loads, capacitor switching and occurrence of fault in the power system. Its occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Voltage sags are defined by a short duration reduction in RMS (root mean square) voltage [1]. However, the magnitude and duration do not completely characterize the voltage sag. In developing countries like India, where the variation of power frequency and many such other determinants of power quality are themselves a serious question, it is very vital to take positive steps in this direction. One of the commonly used shunt controller in order to mitigate voltage sag and transient is DSTATCOM. Many different techniques namely Synchronous Reference Frame (SRF) theory, Instantaneous Reactive Power (IRP) theory, Power Balance Theory, Instantaneous Symmetrical Components (ISC), PI based controller and Neural Network (adaline) control scheme have been developed which proved to be the brain of the DSTATCOM [2-5]. With the advent of high-speed computers and fast A/D converters, many digital methods for Power Quality enhancement have evolved namely moving averages, FFT thresholding, digital filtering (infinite impulse response), IIR and finite impulse response, (FIR), adaptive filtering, and more recently, wavelets as well. All these digitalized techniques have shown far stronger effect than the above power apparatus. Above all The transients in voltage sags can be detected by means of the discrete wavelet transform (DWT), which is a prominent tool for analyzing non-stationary signals. The well-known application of the DWT and locate power system transients is given in [6]. Much research has been focused on wavelet based techniques applied on analyzing power system transients [7-8], detecting and classifying power quality disturbances [9-12].

In this paper DSTATCOM is controlled using wavelet based denoising controller, which is further utilized for compensating the voltage sag and momentary interruptions. The proposed paper focuses on the design of the wavelet controller using multi-resolution decomposition technique in discrete wavelet transform.

In this technique the original (distorted) signal is identified then decomposed into number of scales or components (detailed and scaling) via low pass filter (LPF) and high pass filter (HPF) banks and is further reconstructed using the same that is, in first phase original signal is identified and decomposed using wavelet transform and then inverse wavelet transform is used to reconstruct the original signal in which transients in the voltage sag is reduced.

II. DSTATCOM CIRCUIT

A. Basic building blocks of DSTATCOM

When the distribution side voltage is low, the static compensator (STATCOM) is identified as Distribution STATCOM (DSTATCOM). It is a power electronics based device comprising of Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating or absorbing reactive power. The best feature of this shunt compensator is that it can operate either for lagging, leading or unity power factor loads and provide reactive compensation in both leading or lagging Vars. The major components of a DSTATCOM are shown in Fig.1. It consists of a dc capacitor , voltage source converter, ac filter, coupling transformer and a control strategy [11].

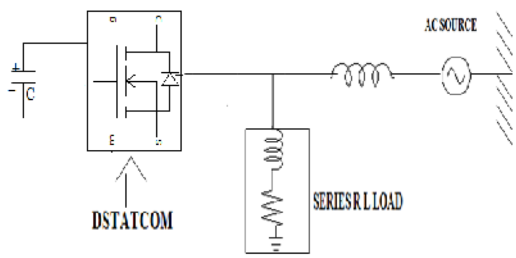

Fig. 1. Basic components of DSTATCOM circuit.

B. Configuration and operation of the DSTATCOM

Now the proposed model of DSTATCOM is composed of Two level pulse width modulated (PWM) voltage source converter (VSC) is realized using six MOSFETs (metal-oxide semiconductor field-effect transistor) switches with anti parallel diodes. The basic objective of a VSI is to convert the DC link voltage V_{dc} on the capacitor to a voltage source of adjustable magnitude and phase and current. Therefore the D-STATCOM can be treated as a voltage controlled source. The D-STATCOM can also be seen as a current controlled source.

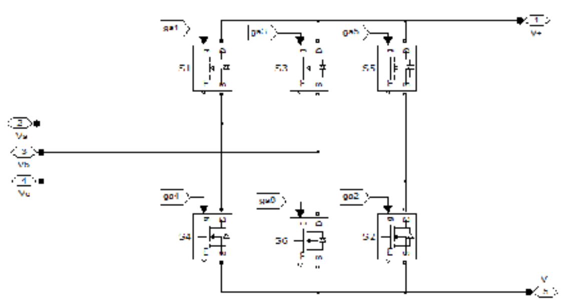

Fig. 2 Matlab circuit of voltage source converter.

Now the basic operation of the DSTATCOM is as similar as synchronous machine. The synchronous machine will provide lagging current when under excited and leading current when over excited similarly DSTATCOM can generate and absorb reactive volt ampere (VAr) and it can also exchange real power if provided with an external device DC source. Here the voltage is compared with the AC system (Vs) that is if the voltage of the ac system is above that of the voltage of VSI (Vc) then the AC system consider the D-STATCOM as inductance . Otherwise it is considered as capacitance if the VSI voltage is above that of the AC system voltage, the AC system. If the voltage magnitudes are equal, the reactive power exchange is zero.

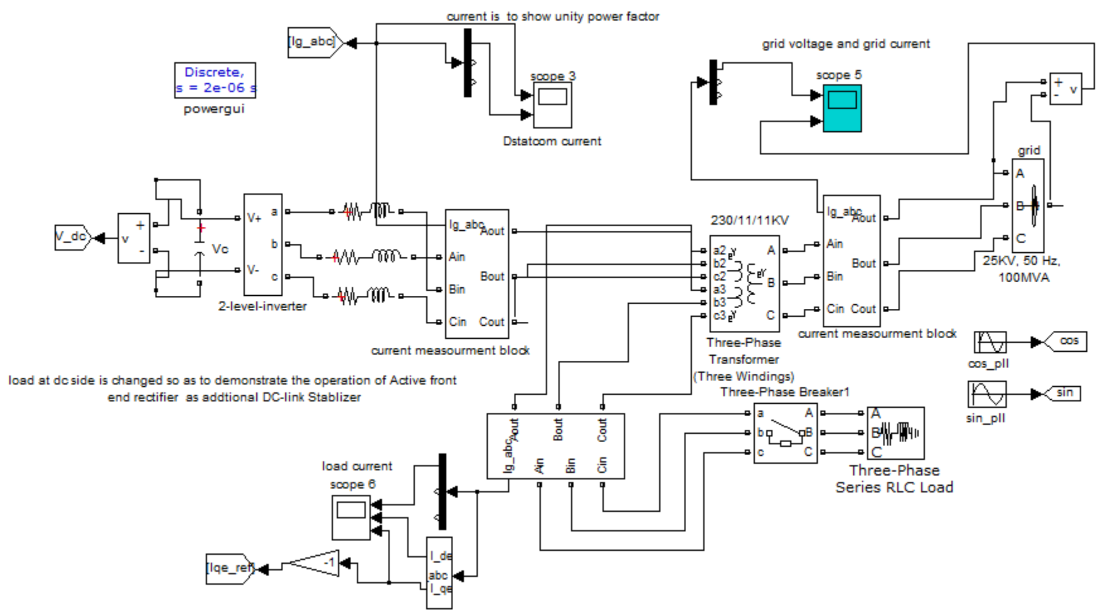

Fig. 3. Matlab model of the DSTATCOM.

The three phase voltages (V_a V_b V_c) generated by the VSC is given by

$V_a = V_m \sin\theta$ … (1a)

$V_b = V_m \sin(\theta - 2\pi/3)$ …(1b)

$V_c = V_m \sin(\theta + 2\pi/3)$ …(1c)

Where Vm is the peak amplitude and w is an angular frequency, respectively, of the system voltage. The three phase source currents (i_{sa}, i_{sb}, i_{sc}) and bridge inverter currents (i_{va}, i_{vb}, i_{vc}) are converted into equivalent direct axis and quadrature axis component currents (i_d, i_q) by using equation given below in the current transformation block,

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} \cos\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ -\sin\theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix}$$

… (2)

Further the three-phase load currents (I_{La} I_{Lb} I_{Lc}) can be expressed as

$I_{La} = ILa \ \sin(\theta - \varphi)$ …(3a)

$I_{Lb} = \mathrm{ILb} \sin(\theta - \varphi - \frac{2\pi}{3})$ …(3b)

$I_{Lc} = \mathrm{ILc} \ \sin(\theta - \varphi + \frac{2\pi}{3})$ …(3c)

Where φ is the phase angle of load current between I_{La} , I_{Lb} and I_{Lc}.

In order to maintain the reactive power drawn from the source as zero, the output currents of the three phase bridge inverter are controlled in such a way that the inverter supplies the required reactive power.

Thus for sag mitigation, the source reactive power has to be zero. Therefore i_q reference (i_{qref}) is set at zero for inverter control. The reactive current supplied by the source (i_q) is subtracted from the reference value (i_{qref} = 0) to obtain the error in reactive current for full compensation. This error signal is processed through a wavelet(multi-resolution analysis) based denoising controller block to obtain the reference voltage signal (V_{qref}), which is fed to the dq0- abc transformation block. The reference for id (i_{dref}) comes from the DC link voltage wavelet controller, which maintains the DC link voltage (V_{dc}) at reference value.

The output voltage signals of transformation block (dq0-abc) (shown in Fig. 4) act as reference voltages (V_{iaref}, V_{ibref} and V_{icref}) for PWM signal generators of bridge inverter. These signals are compared with a triangular carrier wave block (Fig. 5) to obtain PWM signals for bridge inverter phases.

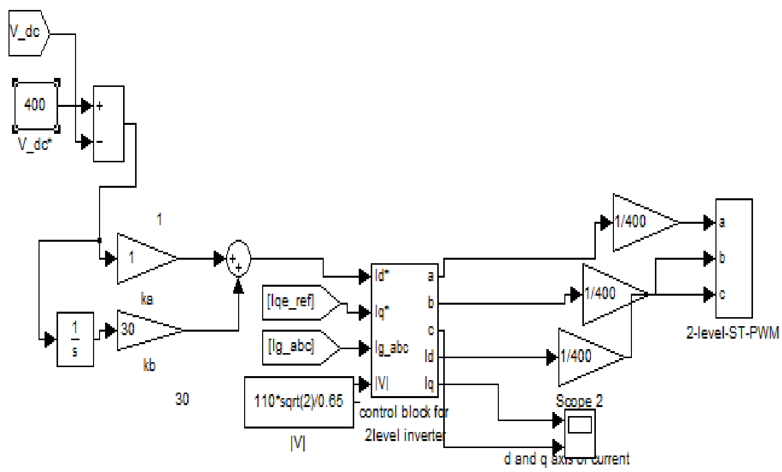

Fig. 4. Matlab transformation block (dq0-abc) for PWM signal generators of VSI.

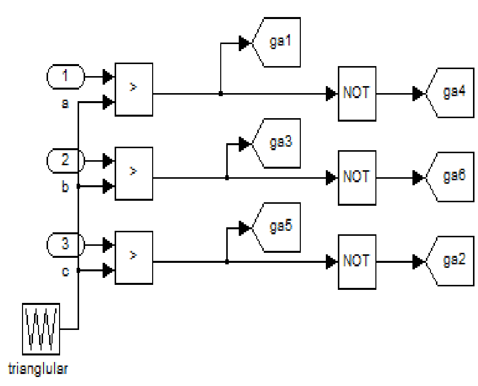

Fig.5. Triangular carrier block to obtain PWM signals for VSI.

III. DSTATCOM CONTROLLER

the proposed work basically relys upon the wavelet controller for the control of dstatcom,which is sub-merged in the "control block for 2 level inverter", which is shown in fig. 4.

Wavelet transforms (WTs) prove to be an effective and reliable tool for detection and reduction of the PQ disturbances, in power system. WT can be continuous or discrete. Discrete WT (DWT) can be viewed as a subset of Continuous WT (CWT).

In this proposed work, the DWT is used which employs dyadic analysis filter bank and dyadic synthesis filter bank. both this filter banks are com posed of low pass and high pass FIR filter which divide the frequency-band of the input signal f(k) in respective

The scaling functions is given as,

where, *n* is integers and represent the number of samples. While the low-pass filtering and the high-pass filtering produces the approximations A_i and the details Di of the decomposition respectively. The relationship of the approximation coefficients and detail coefficients between two adjacent levels are given as,

These high pass and low pass filters are exactly half-band filters, thus are prone to develop a perfect error-free reconstruction of the signal. For reconstruction, the above procedure is followed in reverse order i.e. the signals at every level are up-sampled by two and passed through a set of synthesis filters (synthesis filters are derived from analysis filters). For further details, please refer to [13]. Thus, for an M level decomposition-

low and high-frequency components into octave bands, that is to say, the distorted signal is decomposed into approximate and detail components up to a desired number of levels with the help of multi-resolution analysis. This is done by first choosing a mother wavelet according to the signal characteristics. Once, the mother wavelet is chosen, decomposition-reconstruction up to the required number of levels is carried out by, scaling and dilating the mother wavelet. The low-pass filter g(x) is determined from the scaling function. The high-pass filter h(x) is determined from both the wavelet and scaling functions.

The wavelet function is given as,

$$\Phi(x) = \sqrt{2} \sum_{n} g(n)\, f(2x-n) \qquad \ldots(4)$$

$$f(x) = \sqrt{2} \sum h(n)\, f(2x-n) \qquad \ldots(5)$$

$$A_{i+1}(x) = \sum_{n} h(n-2x)\, A_i(n) \qquad \ldots(6)$$

$$D_{i+1}(x) = \sum_{n} g(n-2x)\, A_i(n) \qquad \ldots(7)$$

where, *i* is frequency band level.

reconstruction, the input signal can perfectly be recovered by adding the reconstructed time domain approximate component at level *M* and all the reconstructed time-domain detailed components from level **1** to *M* i.e.

Reconstructed_signal = $(\text{Approximate\_component})_M + \sum(\text{Detail\_ component})$ $J=1$

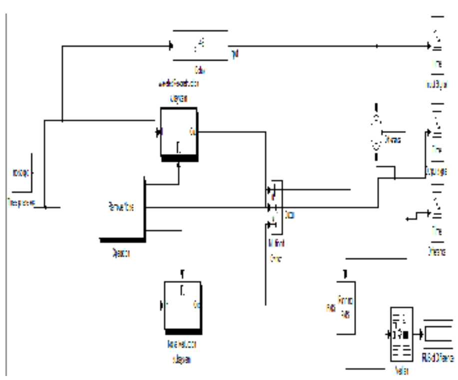

Fig 6. Matlab model of the proposed wavelet controller block.

The above equation is represented by one set of scaling (approximation) coefficients, and one or several sets of wavelet (detailed) coefficients, which can be further rewritten as

$$R(x) = \sum_{n} A_1(n)\, f(x-n) + \sum_{n} \sum_{J-1} h(n-2x)\, D_i(n) 2^{-j/2} \Phi(2^j x-n) \quad \text{. ..(8)}$$

IV. SIMULATION RESULTS

Fig. 2 shows the three phase system with R-L load, which receive power from 25KV grid system, a capacitor of 2000μF is used for self supporting the DC bus of DSTATCOM to charge the capacitor initial voltage of 400V is applied. The DSTATCOM model developed using the matlab is allowed to run for 1 second. The increase or decrease in voltage is performed by using circuit breakers with a delay of 0.4 second from the start of the simulation. In the proposed paper variations in the results of the Simulation were noted when the wavelet based DSTATCOM wasn't connected and when it is connected to the system . The scopes in the following sections show the simulated results with time as the X-axis parameter. The Y-axis parameters are shown on the top of the graphs.

A. Without DSTATCOM

After 0.4 second the circuit breaker is closed and the terminal voltage is decreased to 0.8pu. The top window shows the change in the three phase voltage waveforms, the second window shows the change in the source current when the inductive load is applied after 0.4seconds and the bottom window shows the change in the load current. Here the three phase load is applied for 20 cycles, so the voltage dip and variations in the current is shown in Fig.7.

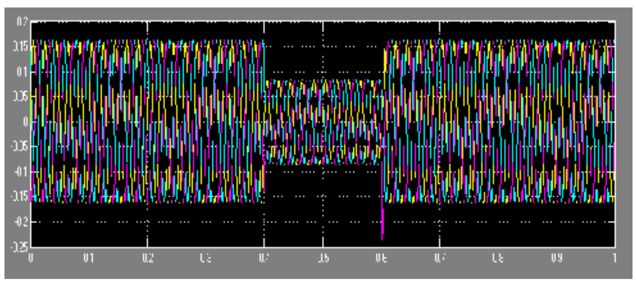

Fig. 7(a) Variations in the supply voltage.

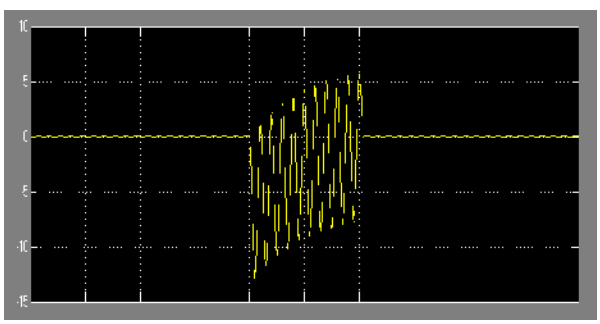

Fig. 7(b) Variations in the supply current.

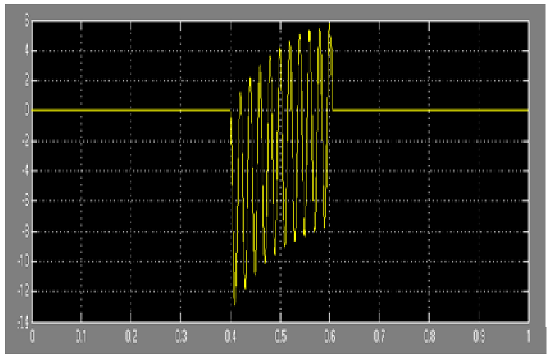

Fig. 7(c) variations in the load current.

Fig. 7 Output waveform of voltage dip and variations in the current without DSTATCOM.

B. With DSTATCOM controller

Similarly, a new set of simulation was carried out when the DSTATCOM was connected to the system. The top window shows the change in the three phase voltage waveforms, the second window shows the changes in the source current , third window shows the performance of the DSTATCOM when it is connected to the system and the bottom window shows the change in the load current with d component (Id) and q component (Iq) .

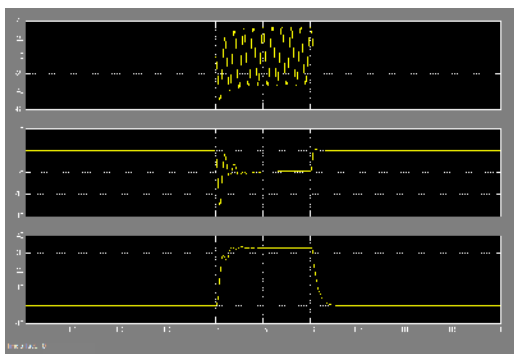

Fig. 8(a) Variations in the supply voltage.

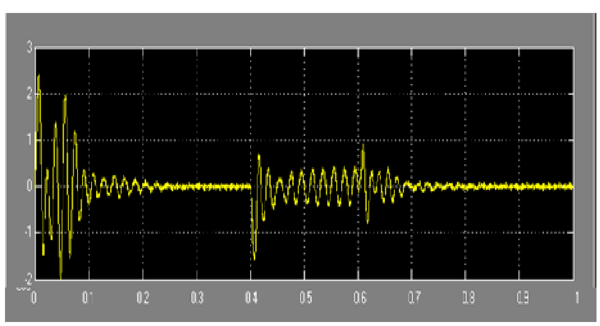

Fig. 8(b) Variations in the supply current.

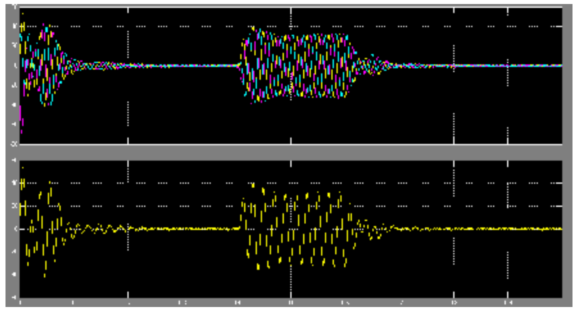

Fig. 8(c) Variations in the DSTATCOM current (with three phase and single phase).

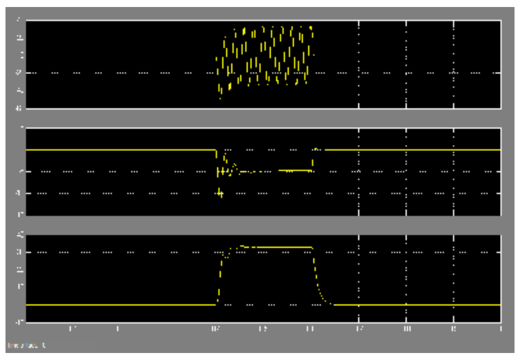

Fig. 8(d) Variations in the load current.

Fig. 8. Output waveform of voltage and current with DSTATCOM.

C. Simulation results of voltage interruption during short circuits

The Simulation here contains no DSTATCOM and the three phase Short circuit is applied for 20 cycles. The voltage at the load point is negligible with respect to the reference voltage as shown in fig. 9. Similarly, a new set of simulations were carried out with the DSTATCOM connected to the system, the load voltage is shown in fig. 10.

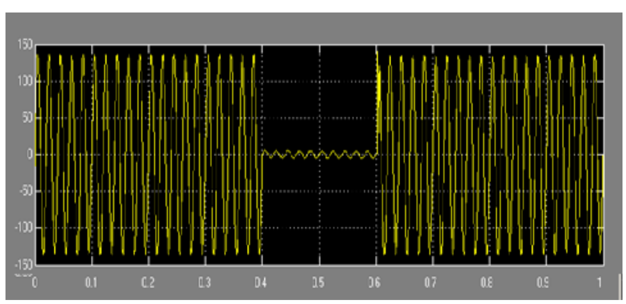

Fig. 9. Output waveform without DSTATCOM showing the result of short circuit.

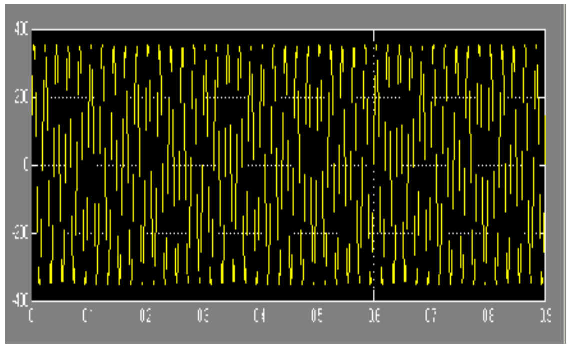

Fig. 10. Output waveform of the load voltage with DSTATCOM.

V. CONCLUSION

This paper has presented the power quality problems like voltage sag and interruptions which has been minimized using DSTATCOM which is further designed using wavelet(multi-resolution analysis) based denoising control technique. This wavelet based control scheme has been implemented to control the gating pulse of the two-level VSC used in the DSTATCOM. The design and applications of D-STATCOM for voltage sags, interruptions and comp- rehensive results are presented. It was also observed that DSTATCOM capability of power compensation and voltage enhancement depends on the rating of the dc storage device.

Discrete wavelet transform has proved to be a stepping stone in the enhancement of power quality, its reliability and fast dynamic response is already a convincing factor which compelled the technique of incorporating it in the custom power device (DSTATCOM). This scheme has been simulated in the MATLAB / SIMULINK environment.

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