ANALYSIS AND SIMULATION OF DSTATCOM FOR POWER QUALITY IMPROVEMENT USING WAVELET BASED MULTI-RESOLUTION CONTROLLER

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ABSTRACT

In this paper, we present a novel control scheme of mitigating the voltage sag and flickers in power system by a popularly known custom power device i.e DSTATCOM. This control strategy is further controlled by the wavelet based denoising technique based on the multi-resolution analysis (MRA) of the error signal. Discrete wavelet transform (DWT), which is purely digitalized, based on the multi-resolution signal decomposition (MSD), analyzes the signal at different frequencies with variant resolutions; therefore, we could observe any transient in time domain as well as in frequency domain. The proposed methodology states that the distorted signal is first identified, decomposed and then reconstructed using wavelet transform. Here the MATLAB model of the wavelet controller and side by side Proportional-Integral (PI) controller is presented. Further the simulation results found that the new methodology proposed is analogous to PI controller and that, the wavelet approach emerges to be dynamically superior and has the unique capability of successfully enhancing the power quality by compensating the above mentioned problems in power system.

KEYWORDS: DSTATCOM, Wavelet Control, Multi-Resolution Signal Analysis (MRA) and Power Quality

INTRODUCTION

Power quality is a prior issue that is becoming increasingly important to electricity consumers at all levels of usage. Persistence of problems like Voltage sag, interruption, transients, swell, voltage flickers, etc results in a collapse of regularities, reliability and sustainability of the distributed system. Among all the above problems voltage flicker is quite common and occurs when large loads are periodically switched on and off in a weak distribution system. Switching of capacitor and occurrence of short circuit in the power system may also give rise to voltage flicker. A sag in voltage can also cause a voltage flicker [1]. One of the commonly used shunt controller in order to suppress not only voltage flicker and transient but also power quality solutions such as voltage stabilization, voltage sag suppression, power factor correction and harmonic control is DSTATCOM [2]. As far as control strategy is concern 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 [3] to [7]. With the era 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 prominent effect than the above power apparatus. In this paper DSTATCOM is controlled using wavelet (MRA) based denoising controller, which is further utilized for compensating the voltage sag and flickers. The proposed paper focuses on the design of the wavelet controller using multi-resolution decomposition technique in discrete wavelet transform (DWT) [8] to [10]. 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 voltage flicker and transients in the voltage sag is reduced.

In the present work the design of the wavelet controller is discussed. A comparative case study is performed where it is found that the wavelet controller is much faster than the conventional PI controller in case of dynamic response. The work also investigates PI controller and wavelet controller as concerned to DSTATCOM application for power quality improvement. A comparison with standard PI controller shows that the dynamic response of the proposed wavelet (MRA) based denoising controller is much faster. This is of advantage in specific applications where the fast computation of the errors through the controller is of importance to achieve a desired reference within a short duration of time.

**CONFIGURATION AND OPERATION OF CUSTOM POWER DEVICE (DSTATCOM)**

DSTATCOM basically is a voltage source converter (VSC) that is connected in shunt with the distribution system by means of a tie reactance connected to compensate the load current. In general, a coupling transformer is installed between the distribution system and the DSTATCOM for isolating the DSTATCOM from the distribution system. It is a three-phase and shunt connected power electronics based device, prone to generate or absorb reactive power. The best feature of this shunt compensator is that it can either operate 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 Figure 1. It consists of a dc capacitor, one or more inverter modules, ac filter, coupling transformer and a control strategy [11].

![Figure 1: Basic Components of DSTATCOM Circuit](image)

Now the proposed model of DSTATCOM is composed of two level pulse width modulated (PWM) voltage source converter (VSC), 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 (VSC). The D-STATCOM can also be seen as a current controlled source (CSC).

![Figure 2: Matlab Circuit of Voltage Source Converter](image)
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 that is, if the voltage of the ac system is above that of the voltage of VSI 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. If the voltage magnitudes are equal, the reactive power exchange is zero.

\[ V_a = V_m \sin \theta \]
\[ V_b = V_m \sin(\theta - \frac{2\pi}{3}) \]
\[ V_c = V_m \sin(\theta + \frac{2\pi}{3}) \]

Where \( V_m \) is the peak amplitude and \( \theta \) is an angular frequency, respectively, of the system voltage. The three phase source currents \( (i_a, i_b, i_c) \) are converted into equivalent dq component currents \( (i_d, i_q, i_0) \) by using equation given below,

\[ i_a = \frac{2}{3} (i_d \sin(\omega t) + i_q \cos(\omega t) + i_0) \]
\[ i_b = \frac{2}{3} (i_d \sin(\omega t - \frac{2\pi}{3}) + i_q \cos(\omega t - \frac{2\pi}{3}) + i_0) \]
\[ i_c = \frac{1}{3} (i_a + i_b + i_c) \]

\( \omega \) is the synchronous speed of the rotating magnetic field of the three phase supply and \( t \) is the time. Again, there is another block for \( dq0\_abc \) conversion, which is based on inverse Park transformation, which transforms three quantities \( (i_d, i_q, i_0) \) expressed in a two-axis reference frame back to phase quantities \( (i_a, i_b, i_c) \),

\[ i_a = i_d \sin (\omega t) + i_q \cos (\omega t) + i_0 \]
\[ i_b = i_d \sin (\omega t - \frac{2\pi}{3}) + i_q \cos (\omega t - \frac{2\pi}{3}) + i_0 \]
\[ i_c = i_d \sin (\omega t + \frac{2\pi}{3}) + i_q \cos (\omega t + \frac{2\pi}{3}) + i_0 \]
The three-phase load currents \( (I_{La}, I_{Lb}, I_{Lc}) \) can be expressed as:

\[
\begin{align*}
I_{La} & = I_La \sin(\theta - \varphi) \\
I_{Lb} & = I_Lb \sin(\theta - \varphi - \frac{2\pi}{3}) \\
I_{Lc} & = I_Lc \sin(\theta - \varphi + \frac{2\pi}{3})
\end{align*}
\]

Where \( \varphi \) 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 or flicker mitigation, the source reactive power has to be zero. Therefore reference current \( (i_{qref}) \) 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(MRA) based denoising controller block to obtain the reference voltage signal, which is fed to the dq0-abc transformation block to obtain \( (V_a, V_b, V_c) \). The reference for d- component current \( (i_{dref}) \) 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 figure 5) act as reference voltages for PWM signal generators of bridge inverter. These signals are compared with a triangular carrier wave block (shown in figure 4) to obtain PWM signals for bridge inverter phases.

**Figure 4: Triangular PWM Signals for VSI Carrier Block to Obtain**

**DSTATCOM CONTROLLER**

Control strategy plays a vital role in overall performance of the compensating device. This control section separately describes about two controllers namely PI and wavelet and tries to show the strict comparison between the two. Till today pi controller has been used extensively in almost all FACTS controllers to compensate varieties of power disturbances but a fast reliable and flexible controller ie. wavelet controller has been introduced in dstatcom to control the gating pulse of vsc to generate PWM signal.

**PI Controller**

In the case of PI controller, the dc link voltage is sensed at frequent intervals and is compared with a reference value. The error signal thus obtained is processed in a PI controller. A limit is put on the output of the controller to ensure that the shunt active power filter supplies active power of the load through the series active power filter. The proposed model consists of three PI controllers with
K_p = 1, K_i = 30 for first PI
K_p = 2.5, K_i = 25 for second PI
K_p = 2.5, K_i = 25 for third PI

Where K_p and K_i is proportional constant and integral constant, respectively.

Figure 5: Matlab Model of Dstatcom Based on PI Controller

Figure (5) depicts the PI based Control system block for DSTATCOM where the reference control currents for current control loop is generated by the voltage control loop. Measured three phase voltages (V_a, V_b, V_c) are transformed into positive and negative sequence components in synchronous reference frame and is compared with the reference quantities to generate a dc component and oscillating component with the frequency twice that of the fundamental frequency. For elimination of oscillating component, an appropriate filter is applied, thus, positive sequence of synchronous reference frame is generated [12]. Error (distorted) signals are then passed through PI controllers to produce reference currents. These reference quantities are fed to the current control loop so that reference voltages are generated. According to the reference voltage, PWM block generates switching pulses.

WAVELET CONTROLLER

The proposed work basically relies upon the wavelet controller for the control of dstatcom, which is submerged in the “control block for 2 level inverter”, which is shown in figure 5. Wavelet transform (WT) prove to be an effective and reliable tool for detection and reduction of the PQ disturbances, in power system. In the present work, DWT employs dyadic analysis filter bank and dyadic synthesis filter bank, both these filter banks are composed of numbers of low pass and high pass FIR (finite impulse response) filter, which divide the frequency-band of the input signal f(k) in respective low and high-frequency components into octave bands, which means the distorted signal is decomposed into approximate and detail components up to a desired number of levels with the help of MRA. 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(p) is determined from the scaling function. The high-pass filter h(p) can be determined from both the wavelet and scaling functions.

The wavelet function is given as,

\[ \psi(p) = \sqrt{2} \sum g(t) f(2p-t) \]

the scaling function is given as,

\[ \phi(p) = \sqrt{2} \sum h(t) f(2p-t) \]
where, \( t \) is the integer and represent the number of samples. While the low-pass filtering and the high-pass filtering produces the approximations \( A_i \) and the details \( D_i \) of the decomposition respectively. The relationship of the approximation coefficients and detail coefficients between two adjacent levels are given as:

\[
A_{i+1}(p) = \sum h(t-2p) A_i(t)
\]

\[
D_{i+1}(p) = \sum g(t-2p) A_i(t)
\]

where, \( i \) is frequency band level. These high-pass and low-pass filters are exactly half-band filters, thus are prone to develop perfectly 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)[13]. Thus, for an \( M \) level decomposition-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.

\[
\text{Reconstructed signal} = \left( \text{Approximate component} \right)_M + \sum ( \text{Detail component} )_{J=1}
\]

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:

\[
R(p) = \sum A_i(t) f(p-t) + \sum \sum h(t-2p) D_i(t) 2^{J/2} \phi(2^J p - t)
\]

**Figure 6: Matlab Model of the Proposed Wavelet Controller Block**

**SIMULATION RESULTS AND DISCUSSIONS**

The test system with R-L load, employed to carry out the simulations for DSTATCOM is shown in figure 3. Such system is composed of a 25 kV, 50 Hz generation system, with a 3-winding transformer connected in Yg/Yg/Yg, 230/11/11 kV, a capacitor of 2000uF 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 seconds. The increase or decrease in voltage is performed by using circuit breakers with a delay of 0.4seconds from the start of the simulation. In the proposed paper variations in the results of the Simulations were noted when no DSTATCOM was connected to the system and when DSTATCOM incorporates PI as well as wavelet controller to the system. The scopes in the following sections show the simulated results with time as the X-axis parameter and Y-axis parameters are shown on the top of the graphs.
Simulation Result without DSTATCOM

Initially there is a fixed RL load connected to the system. 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 0.4 seconds 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 figure 7.

![Figure 7(a): Variations in the Supply Voltage](image)

![Figure 7(b): Variations in the Supply Voltage](image)

![Figure 7(c): Variations in the Load Current](image)

Simulation Result of DSTATCOM Using PI Controller

Now this time simulation was carried out when DSTATCOM using PI controller was connected to the system. The main motive behind using this controller is just to compare its waveform with wavelet controller. When the DSTATCOM with PI controller was run, it was observed that the voltage sag and transients are suppressed as shown in figure 8.
Similarly, a new set of simulation was carried out when DSTATCOM was connected to the system. This time DSTATCOM was run with the wavelet controller. In this simulation it was found that the suppression rate of sag and transient was more than pi controller. The rich performance of the wavelet based DSTATCOM can be observed in figure 9. 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 0.4 seconds and the bottom window shows the change in the load current.

Simulation Result of DSTATCOM Using Wavelet Controller

Figure 8(a): Variations in the Supply Voltage

Figure 8(b): Variations in the Supply Current

Figure 8(c): Variations in the Load Current
COMPARISON BETWEEN DSTATCOM CURRENT USING WAVELET AND PI CONTROLLER

From the above results it is perfectly noted that the voltage dip or sag was considerably minimized with PI as well as wavelet controller and the waveform of the supply voltage, supply current and load current of the system was found to be approximately the same under both the conditions, but when the waveform of DSTATCOM current was compared, it was still left to say that the flicker (error) in the current was computed online and perfectly minimized when wavelet controller was introduced in the system. Figure 11 shows the graph for input, output and difference in the waveform in millisecond. The errors were first of all identified, decomposed and finally reconstructed waveform is shown in the figure 10.
Figure 10(a): DSTATCOM Current with PI Controller

Figure 10(b): DSTATCOM Current with Wavelet Controller

Figure 11(a): Waveform of the Samples Fed to the Wavelet Controller Block

Figure 11(b): Output Waveform of the Signal from the Wavelet Controller Block
CONCLUSIONS

In the present work wavelet (multi-resolution analysis) based denoising controller has been proposed in place of conventional PI controller. Wavelet controller provides an online technique of calculating the errors such as voltage dip and flicker wavelet transform decomposes the distorted signal into approximate and detail components up to a desired number of levels with the help of multi-resolution analysis (MRA) and inverse wavelet transform is used to reconstruct the original waveform, which was simple and easier than manual computational done with PI controller, further it is less time consuming and it is more accurate than PI controller. Results obtained from the simulation shows better performance of DSTATCOM when wavelet (multi-resolution analysis) based denoising controller is used then that of PI controller in terms of voltage dip and flicker. Under this conditions the dynamic response of wavelet controller proved to be faster than PI controller. Hence it is proved that wavelet controller is superior than PI controller.

REFERENCES


