Performance Analysis of STATCOM Compensated DFIG connected system under Power Quality Issues using wavelet Analysis

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Abstract— **Power quality has been area very much based on measurements and observations. The major power quality issues is related to large difference between in the normal system and doubly fed Induction generator connected system. Power electronics and advanced control technologies have made it possible to reduce the power quality problems. Flexible AC transmission system is one aspect of the power electronics revolution that is taking place in all areas of electrical energy. The primary objective of applying a static compensator in a power system is to increase the power quality capability from the system comprising of Doubly Fed Induction Generator. The system model comprising of Doubly Fed Induction Generator (DFIG) and 48-Pulse voltage source converter based STATCOM is constructed using MATLAB/Simulink. The paper focuses on the design and evaluation of a control strategy for improving the quality of energy of a STATCOM Controlled grid-connected variable speed Doubly Fed Induction Generator (DFIG) wind energy conversion system. The proposed research work is carried to investigate the performance of Static synchronous Compensator within the power system using wavelet multi resolution analysis under various power quality problems. The simulation results showed that the proposed shunt compensator was efficient in mitigating the power quality problems. This approach is different from conventional methods and provides effective solution to analyses the power system networks under transients, faults and sudden load injections.**

Index Terms— **voltage source converter, STATCOM, sag and swell, transients, faults, power quality**

I. INTRODUCTION

In the present scenario, most of the power systems in the developing countries with large inter connected networks share the generation reserves to increase the reliability of the power system. Growing scarcity fossil fuels and pollutions, as a result of the use of these fuels, because that has been increased using renewable energy such as wind power. The integration of intermittent renewable energy sources into the electric grid presents some challenges in terms of power quality issues, voltage regulation and stability. Power quality [1] relates to those factors which affect the variability of the voltage level and distortion of the voltage and current waveforms which can cause severe adverse effects to the electric grid[2]. Power electronics and advanced control technologies have made it possible to reduce the power quality problems. Among power system disturbances, voltage sags, swells and harmonics are some of severe problems to the sensitive loads.

The FACTS devices can be categories as shunt, series, series-series and combine shunt-series controllers [3]. By the use of such controllable devices, line power flows can be changed in such a way that thermal limits are not violated, losses minimized, stability margin increased and contractual requirement fulfilled without violating specified power dispatch [4]. Static Synchronous compensator (STATCOM) is one among the different FACTS controllers introduced to improve the power flow control with stability and reliability.

Signal processing tools is used for the feature extraction of power signal. Wavelet analysis [5] has been proven to be an effective signal processing tool for the detection and analysis of power signals but other signal processing tools such as Fourier transform, S-transform, time-time transform, higher-order statistics have also been used to find out other salient features.

The system model comprising of Doubly Fed Induction Generator (DFIG) and 48-Pulse voltage source converter based Static Compensator (STATCOM)[6]is constructed using MATLAB/Simulink. The paper focuses on the design and evaluation of a control strategy for improving the quality of energy of a STATCOM Controlled grid-connected variable speed Doubly Fed Induction Generator (DFIG) wind energy conversion system. The proposed research work is carried to investigate the performance of Static synchronous Compensator within the power system using wavelet multi resolution analysis using Bior1.5 mother wavelet under various power quality problems. The simulation results showed that the proposed shunt compensator was efficient in mitigating the power quality problems.

II. STATCOM MODEL AND CONTROL SYSTEM

The Static Synchronous compensator (STATCOM) is a Voltage Source Converter (VSC) based Flexible AC Transmission System (FACTS) controller for shunt voltage sourced converters within the power system [7]. Single-line Diagram of a STATCOM and Its Control System illustrated is shown in Fig.2.

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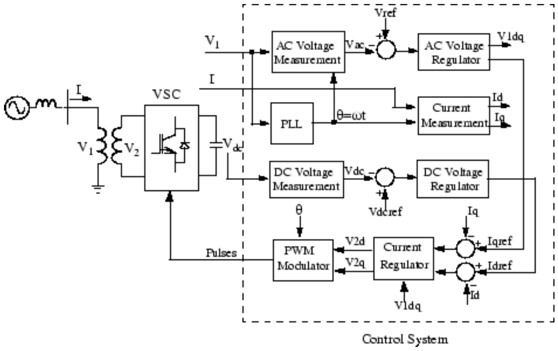


Figure.1: Single-line Diagram of a STATCOM and Its Control System Block Diagram.

The converter is established to increase the number of output voltage pulses and decrease the harmonic distortion of output voltage and current. Without PWM or increasing the number of bridges, the THD of the converter output voltage can be theoretically reduced. The basic objective of a good VSC scheme is to produce a near sinusoidal ac voltage with minimal wave form distortion or excessive harmonics content. The 24 to 48 pulse converters are obtained by combining 12-pulse voltage source Inverters, with the specified phase shift between converters. For high-power applications with low distortion, the best option is the 48-pulse converter, although using parallel filters tuned to the 23th–25th harmonics with a 24-pulse converter could also be adequately attentive in most applications, but the 48-pulse converter scheme can ensure minimum power quality problems and reduced harmonic resonance conditions on the interconnected grid network. By DC voltage injection, the voltage across the main bridge valves, which are being turned on, is theoretically decreased to zero. Thus the converter switching loses and switching device dynamic voltage stress is reduced significantly. This characteristic is very important for high voltage application.

III. DFIG-Based Wind Power System Model

The proposed circuit shown in Fig. 1 consists of a wind turbine connected to a DFIG. The DFIG is simulated as an induction machine having 3-phase supply in the stator and 3-phase supply in the rotor. The rotor coupled via two powers converters: the rotor-side converter (RSC) and the grid-side converter (GSC). The RSC ensures a decoupled active and reactive stator power control, P and Q according to the reference torque delivered by the maximum power point tacking control (MPPT). The GRC controls the power flow exchange with the grid via the rotor, by maintaining the DC bus at a constant voltage level.

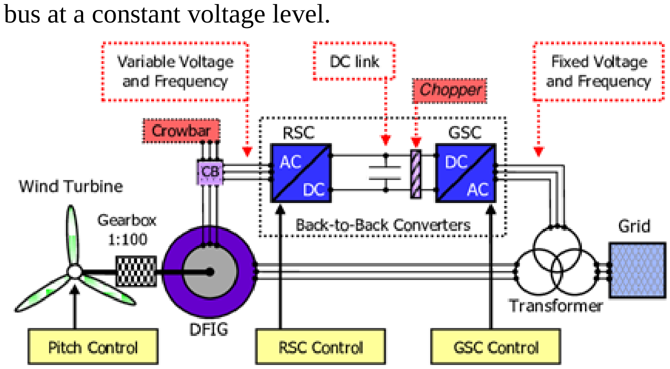


Figure. 2. Block diagram of the wind power system based in DFIG.

IV. WAVELET ANALYSIS

Concept of wavelet started to appear in early 1980's as a signal processing tool. Wavelet theory provided new method for decomposing a function or signal into various frequency components, and then study each component with a resolution match to its scale. A wavelet is a ―small wave‖, its energy is concentrated in time to give a tool for analysis of transients, non stationary, time varying phenomenon which generally occurs in the power system network [8]. Wavelet has ability to allow simultaneous time and frequency analysis of a signal with a flexible mathematical foundation. In wavelet analysis, signal broken into a series of local basis functions called wavelets, which are scaled and shifted versions of the original (or Mother) wavelet. Wavelet transform can be classified in three different ways known as the wavelet series, continuous Wavelet Transform and discrete Wavelet Transform.

Multiresolution analysis technique of wavelet is used in analysis of waveforms and images. Wavelet functions and scaling functions are used as building blocks to decompose and reconstruct the signal at different resolutions in Multi Resolution Analysis (MRA). The development of technologies used in power quality analysis, which is the major area of research in the field of power system [9]. For detecting and characterizing power system disturbances wavelet based systems have been found to be more robust and effective.

V. SIMULATION MODEL OF PROPOSED SYSTEM WITH VSI BASED STATCOM

The unified ac grid sample system with the Static synchronous compensator for the shunt VSC and control scheme [13-14] is connected to four bus system. The single line diagram representing the STATCOM and the host sample grid network as illustrated in Figure2. The feeding network are at bus S1 where the voltage source is represented by a 25 kV with 100 MVA and 3MW injected load connected at B2 , at bus B3 with 5MW and 2Mvar injected load, and at bus B4 with 25KV,5Mvar.

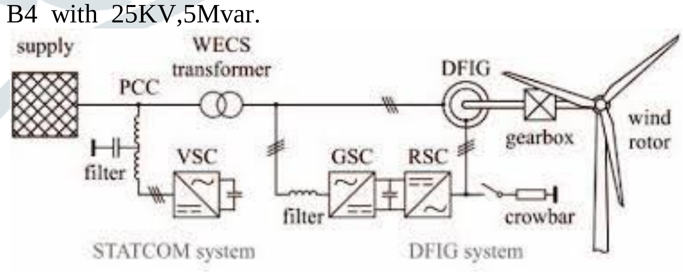


Figure 3: Single line diagram of DFIG connected Static synchronous compensator connected system.

The STATCOM located at the middle of the 10 km feeder from DFIG Wind generator. It consists of three 10-MVA, three-level, and 48-pulse GTO-based converters, connected as shunt controller. The shunt converter can exchange power through a DC bus. The shunt converter operates as a STATCOM. It controls voltage by controlling the absorbed or generated reactive power while also allowing active power transfer to the shunt converters through the

DC bus. The reactive power variation is obtained by varying the DC bus voltage. The four three-level shunt converters operate at a constant conduction angle (Sigma= 180-7.5 = 172.5 degrees), thus generating a quasi-sinusoidal 48-step voltage waveform. The digital simulation model comprises of five 12-pulse GTO-converters, phase-shiftedby $7.5^0$from each other and model, can provide the full 48-pulse converter operation. The transformer connections and the necessary firing-pulse logics to get this final 48-pulse operation are modeled. The 48-pulse converter can be used in high-voltage high-power applications without the need for any ac filters due to its very low harmonic distortion content on the ac side. The output voltage have normal harmonics $n = 48r \pm 1$, where r = 0, 1, 2, 3…i.e.

V. RESULT ANALYSIS

The variation of three phase voltages are shown in figure 4 under sudden load injected in the transmission system. The analysis of wavelet detailed coefficients current and voltage signals are illustrated under sudden load injection from bus2 are illustrated in figure5 and Figure6. Power quality problem can be observed by injecting sudden load in the system from figure4 to figure6.

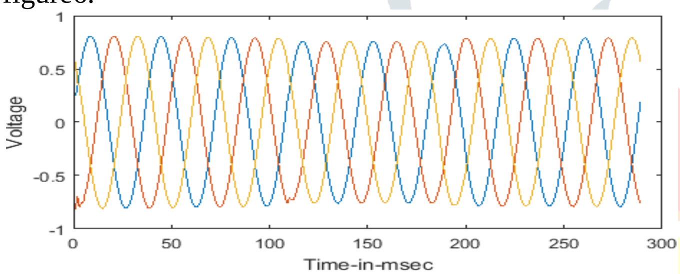


Figure4: variation of 3ph voltages under sudden load injected

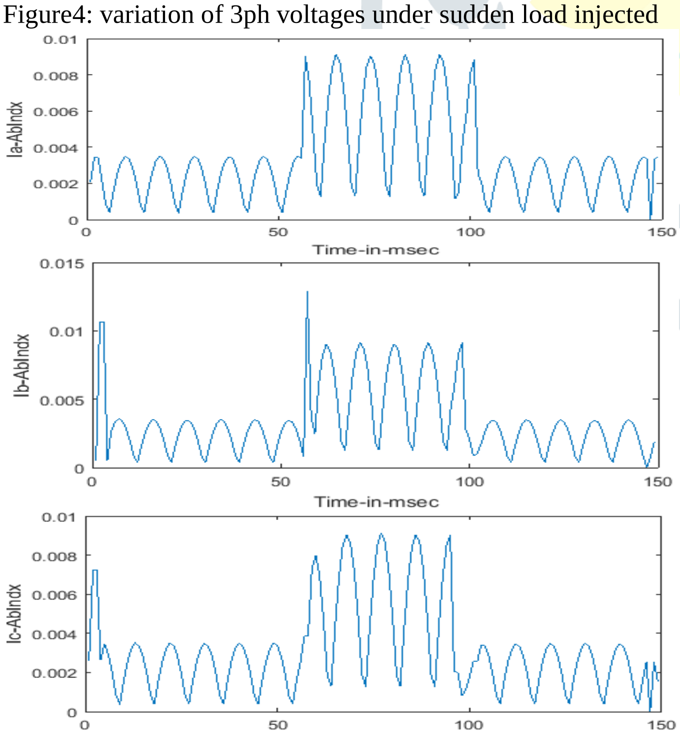


Figure 5: Analysis of wavelet detailed coefficients of current signal at sag due to under injecting sudden load.

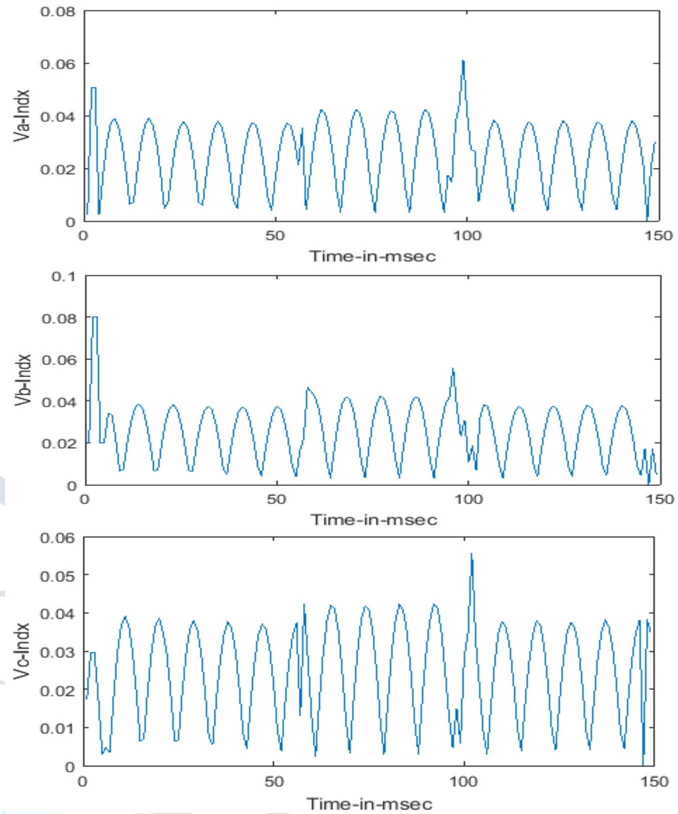


Figure 6: Analysis of wavelet detailed coefficients of voltage signal at sag due to under injecting sudden load.

The variation of three phase voltages are shown in figure7 under sudden load injected in DFIG connected transmission system. The analysis of wavelet detailed coefficients current and voltage signals are illustrated under sudden load injection from bus2 are illustrated in figure8 and Figure9 when DFIG connected at Bus3. The variation in Wavelet detailed coefficient of current and voltage signals with DFIG in the system from figure7 to figure9.

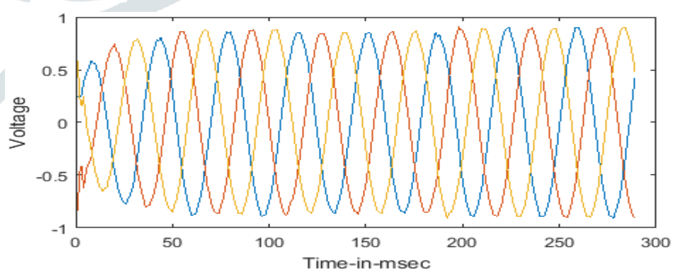


Figure 7: variation of three phase voltages at Bus B2 with DFIG Wind connected system when sudden load injected at Bus B2

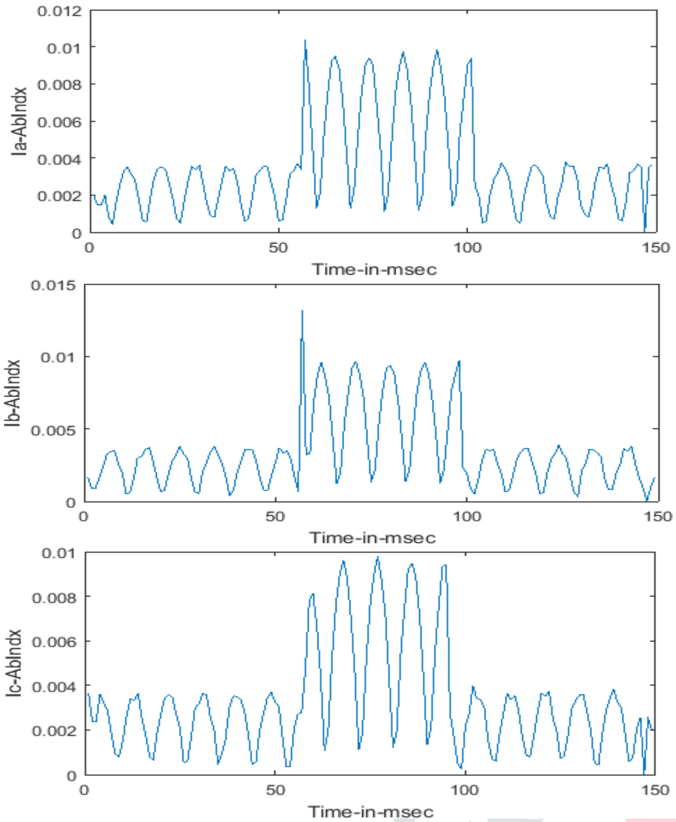


Figure 8: Analysis of wavelet detailed coefficients of current signal at Bus B2 of DFIG Wind generating system when sudden load injected.

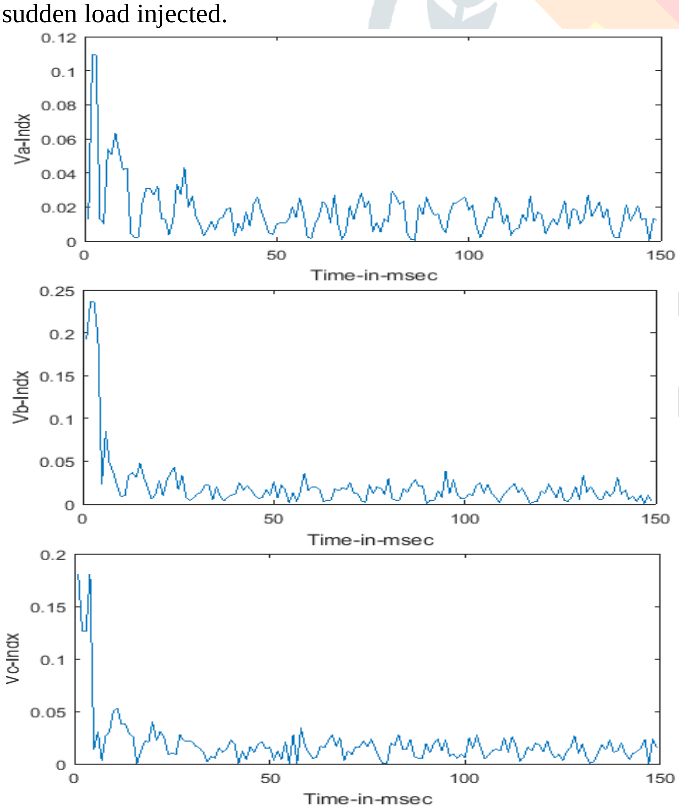


Figure 9: Analysis of wavelet detailed coefficients of Voltage signal at Bus B2 of DFIG wind generating system when sudden load injected.

The variation of three phase voltages are shown in figure10 under sudden load injected in DFIG with STATCOM controller connected transmission system.

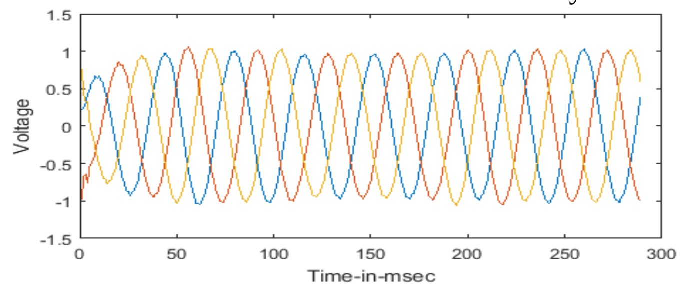


Figure 10: variation of three phase currents at Bus 32 with DFIG Wind connected and STATCOM controller connected system when sudden load injected at Bus B2

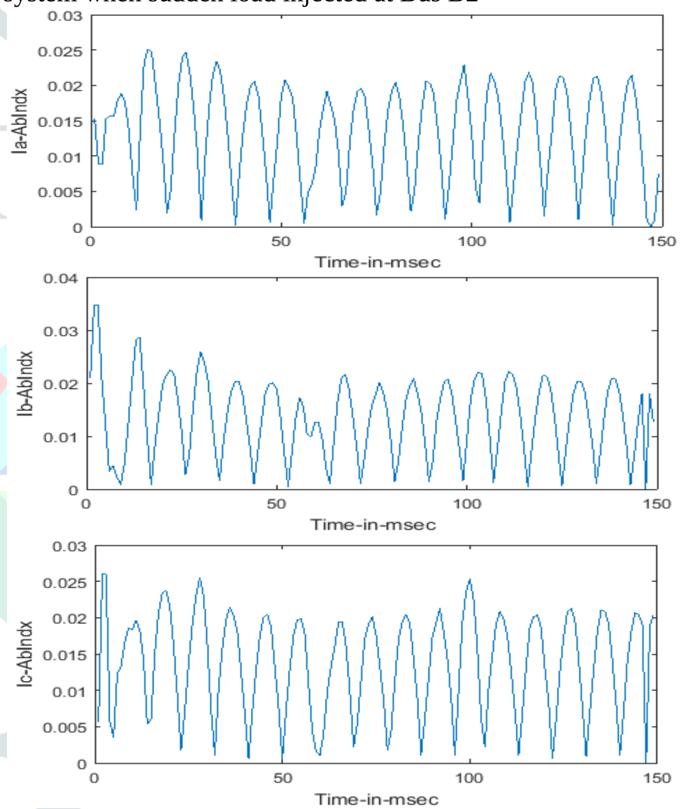
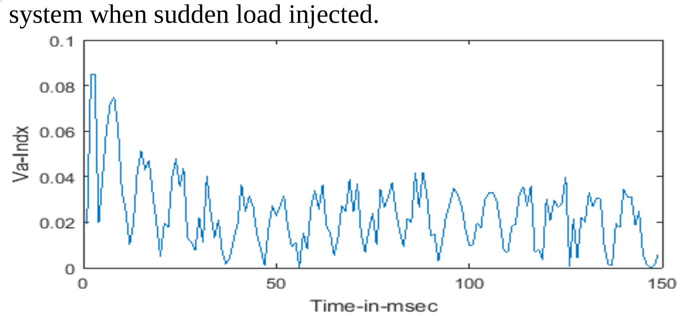


Figure 11: Analysis of wavelet detailed coefficients of Current signal at Bus B2 of DFIG and STATCOM connected system when sudden load injected.



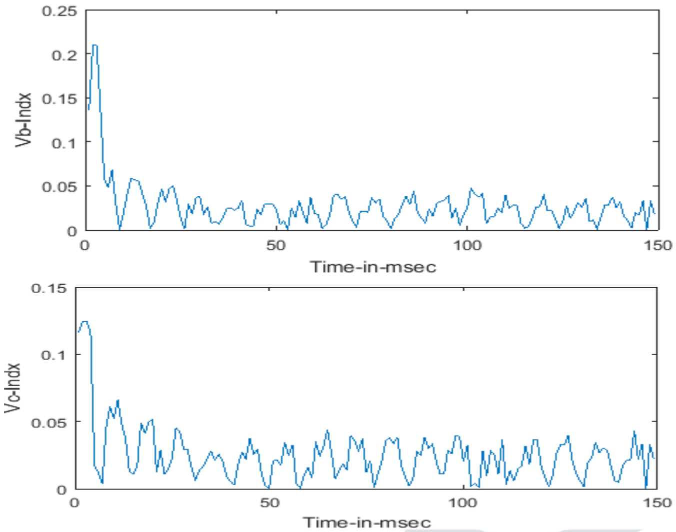


Figure 12: Analysis of wavelet detailed coefficients of Voltage signal at Bus B2 of DFIG and STATCOM connected system when sudden load injected.

The analysis of wavelet detailed coefficients current and voltage signals are illustrated under sudden load injection from bus2 are illustrated in figure11 and Figure12 when DFIG connected at Bus3 and STATCOM Controller near to Bus3. The variation in Wavelet detailed coefficient of current and voltage signals with DFIG and STATCOM in the system from figure10 to figure12.

The variation of three phase voltages are shown in figure13 under sudden transient injected in the transmission system. The analysis of wavelet detailed coefficients current and voltage signals are illustrated under sudden load injection from bus2 are illustrated in figure14 and Figure15. Power quality problem can be observed by injecting transient in the system from figure13 to figure15.

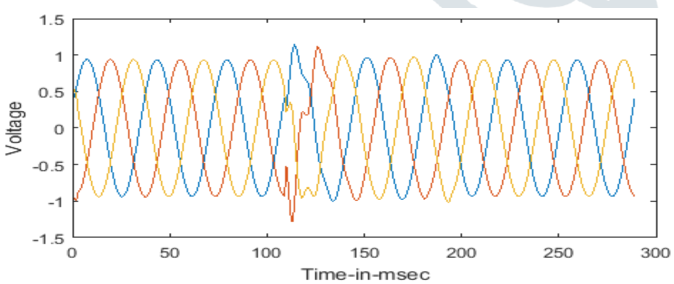
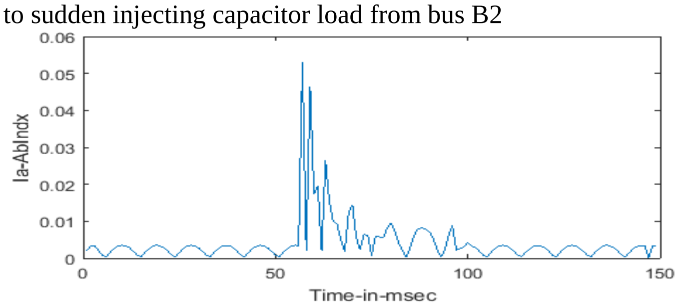


Figure 13: variation of 3ph currents under transient occur due to sudden injecting capacitor load from bus B2



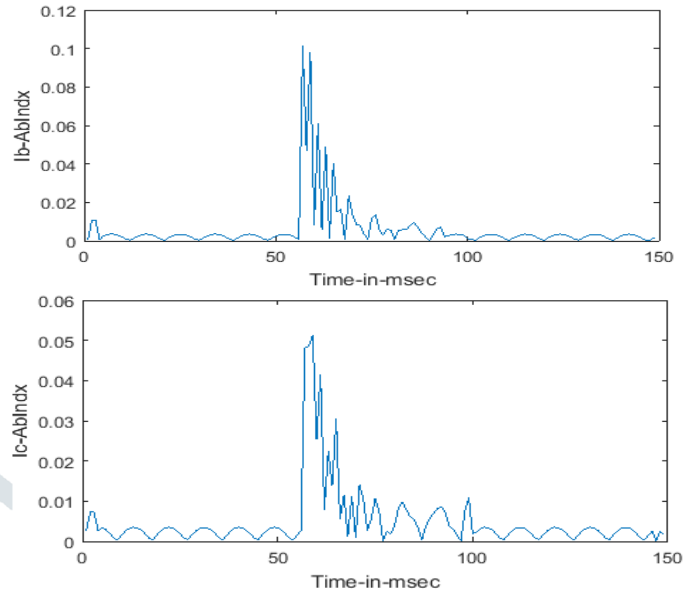


Figure 14 Analysis of wavelet detailed coefficients of current signal at Bus B2 when sudden transient injected.

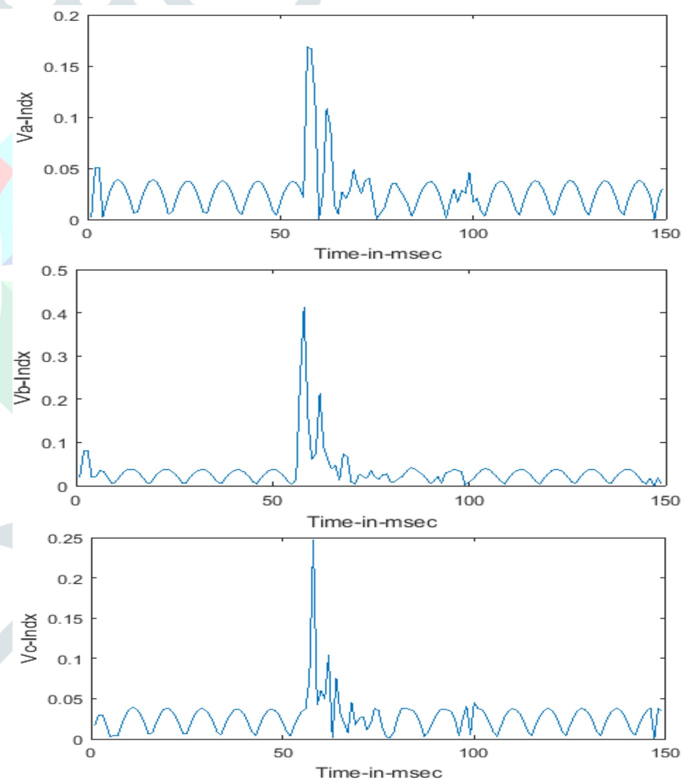


Figure 15: Analysis of wavelet detailed coefficients of Voltage signal at Bus B2 when sudden transient injected.

Figure [4-12] to figure12 illustrated that STATCOM controller can be utilised to compensate power quality problem under sudden load fluctuation in the system comprising of DFIG wind generation.

The variation of three phase voltages are shown in figure16 under sudden transient current injected in DFIG connected transmission system. The analysis of wavelet detailed coefficients current and voltage signals are illustrated under sudden load injection from bus2 are illustrated in figure17 and Figure18 when DFIG connected at Bus3. The variation in Wavelet detailed coefficient of current and voltage signals with DFIG in the system from figure16 to figure18.

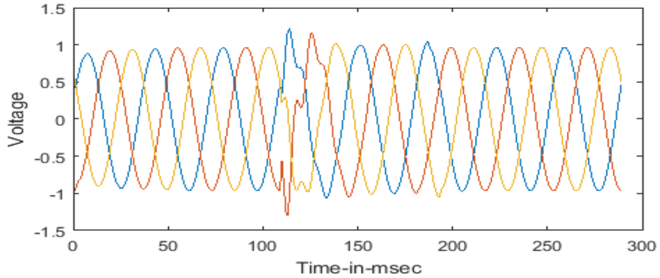


Figure 16: variation of 3ph currents under transient occur due to sudden injecting capacitor load from bus B2 of DFIG connected system.

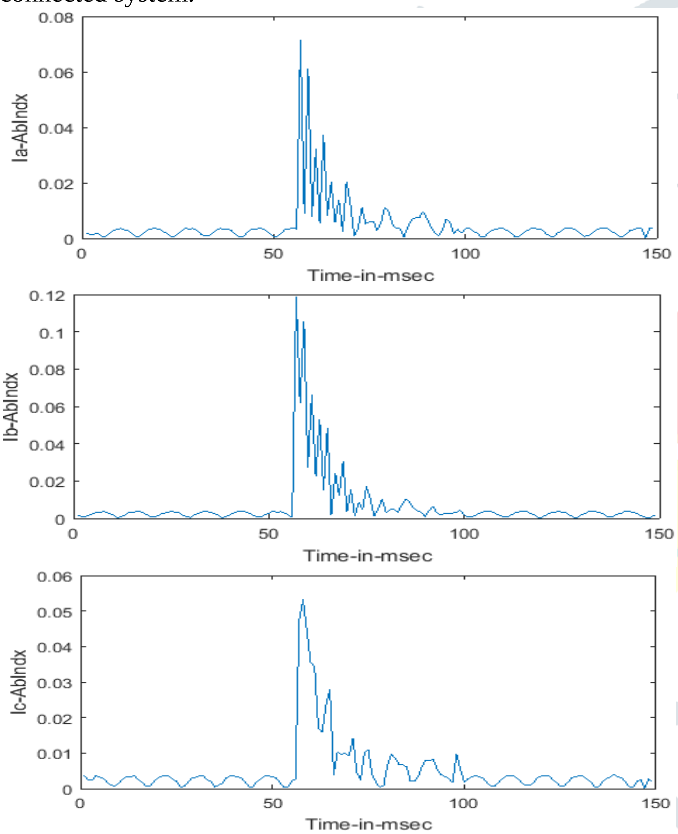
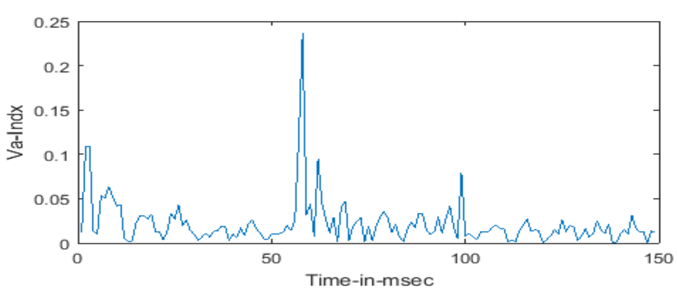


Figure 14 Analysis of wavelet detailed coefficients of current signal at Bus B2 of DFIG Wind generating system when sudden transient injected.



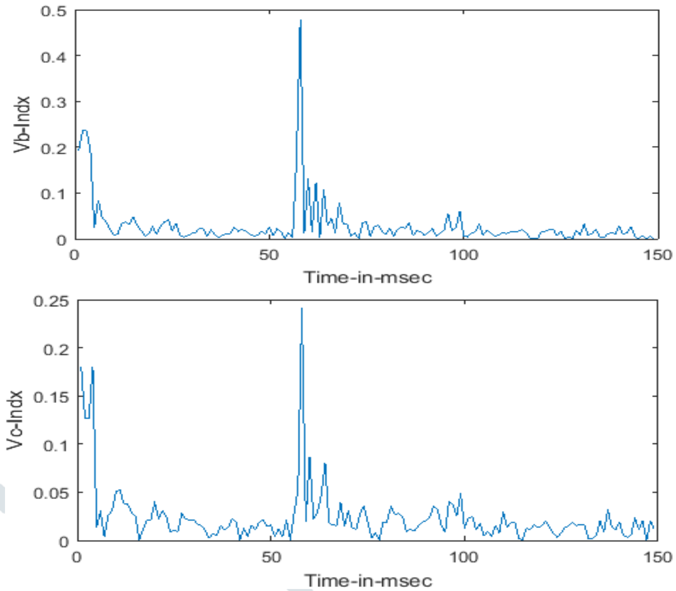


Figure 18: Analysis of wavelet detailed coefficients of Voltage signal at Bus B2 of DFIG connected system when sudden transient injected.

The variation of three phase voltages are shown in figure19 under transient current injected in DFIG with STATCOM controller connected transmission system. The analysis of wavelet detailed coefficients current and voltage signals are illustrated under transient current injection from bus2 are illustrated in figure20 and Figure21 when DFIG connected at Bus3 and STATCOM Controller near to Bus3. The variation in Wavelet detailed coefficient of current and voltage signals with DFIG and STATCOM controller in the system from figure19 to figure21.

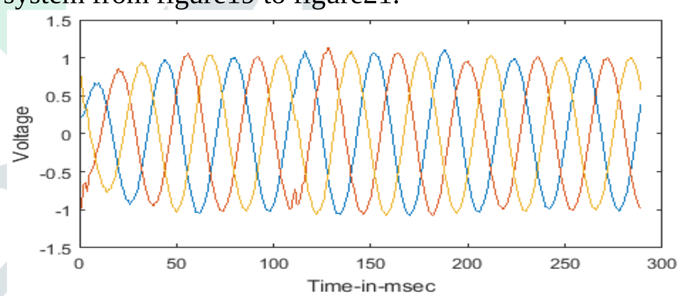
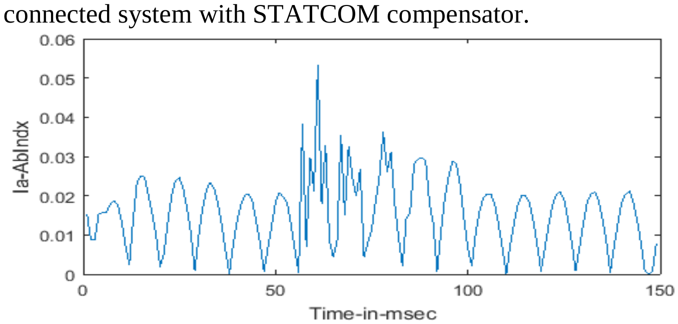


Figure 19: variation of 3ph currents under transient occur due to sudden injecting capacitor load from bus B2 of DFIG connected system with STATCOM compensator.



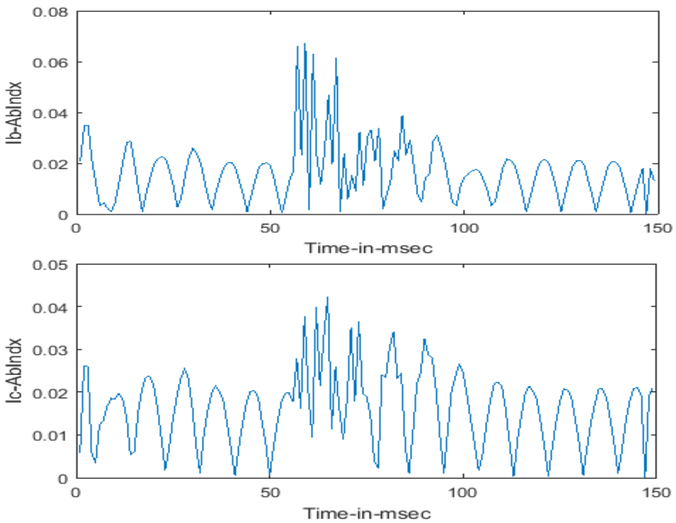


Figure 20: Analysis of wavelet detailed coefficients of current signal at Bus B2 of DFIG Wind generating system with STATCOM compensator at sudden transient injected

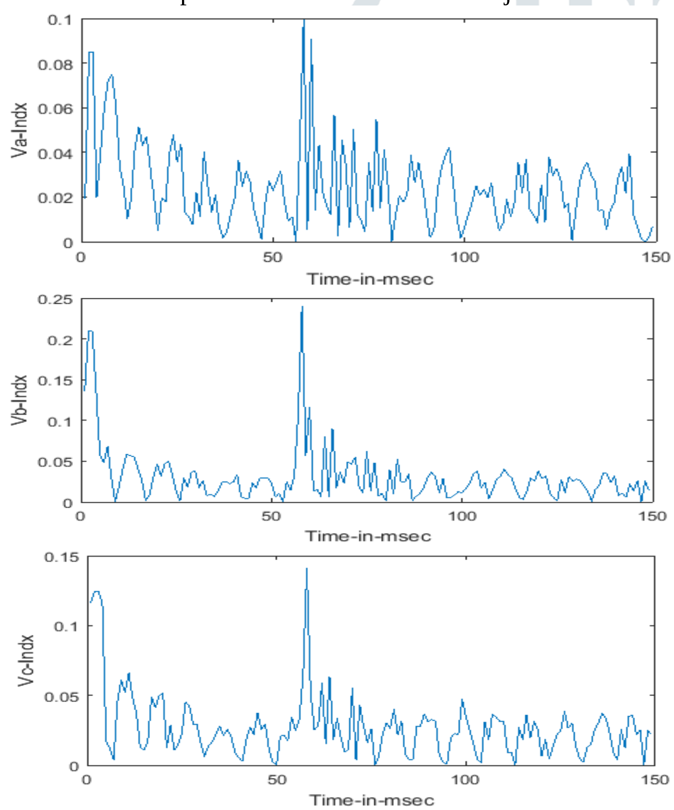


Figure 21: Analysis of wavelet detailed coefficients of voltage signal at Bus B2 of DFIG Wind generating system with STATCOM compensator at sudden transient injected.

Figure [13-21] illustrated that STATCOM controller can be utilised to compensate power quality problem under sudden transient currents in the system comprising of DFIG wind generation.

The variation of three phase voltages is shown in figure22 under temporary faults in the transmission system. The analysis of wavelet detailed coefficients current and voltage signals are illustrated under sudden load injection from bus2 are illustrated in figure23 and Figure24.

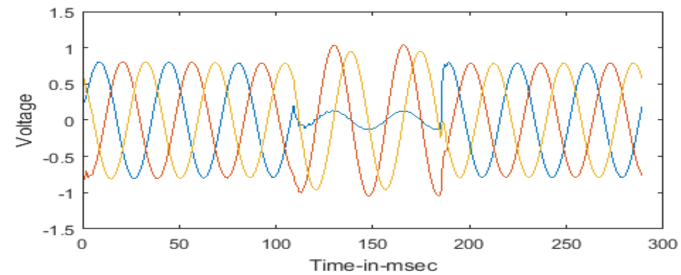


Figure22: variation of 3ph voltages under AG Fault occur at 5Km distance from bus B2.

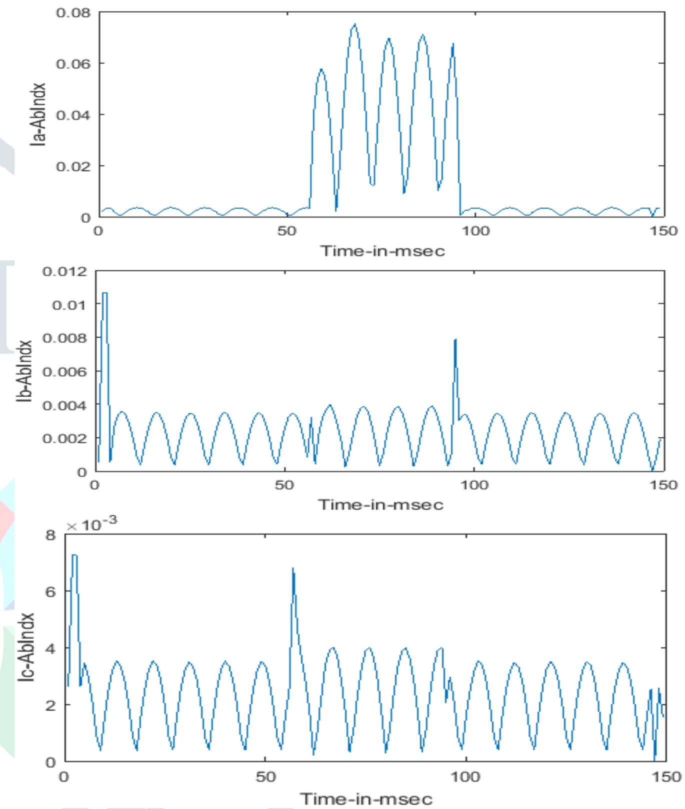
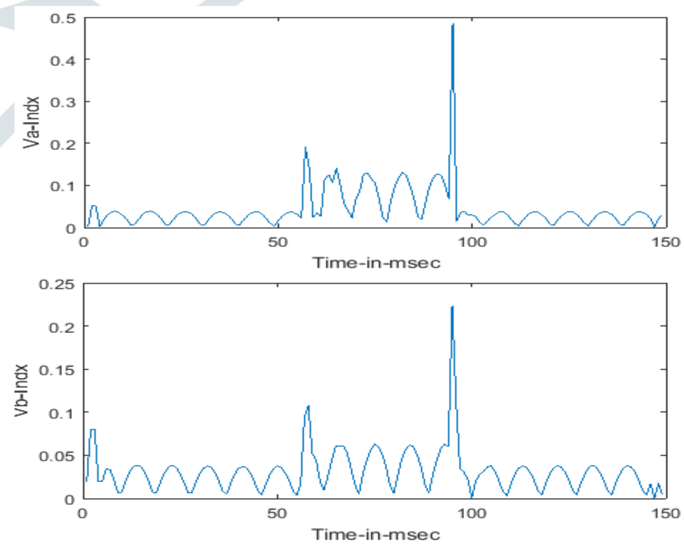


Figure 23: wavelet detailed coefficients of current signals under AG Fault occur at 5Km distance from bus B2.



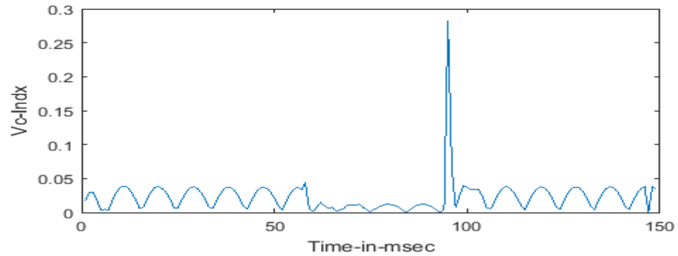


Figure 24: wavelet detailed coefficients of voltage signals under AG Fault occur at 5Km distance from bus B2.

Power quality problem can be observed by temporary single line to ground faults in the system from figure22 to figure24.

The variation of three phase voltages are shown in figure25 under temporary faults in DFIG connected transmission system.

The analysis of wavelet detailed coefficients current and voltage signals are illustrated under temporary fault from bus2 are illustrated in figure26 and Figure27 when DFIG connected at Bus3. The variation in Wavelet detailed coefficient of current and voltage signals with DFIG in the system from figure25 to figure27.

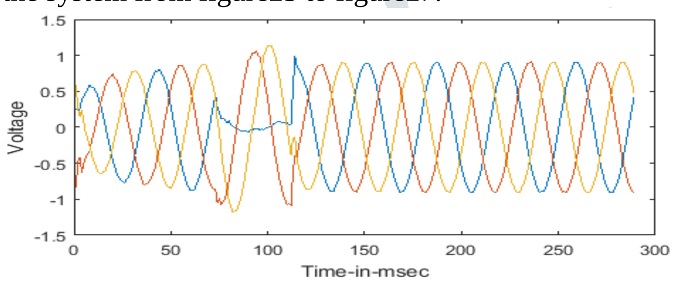
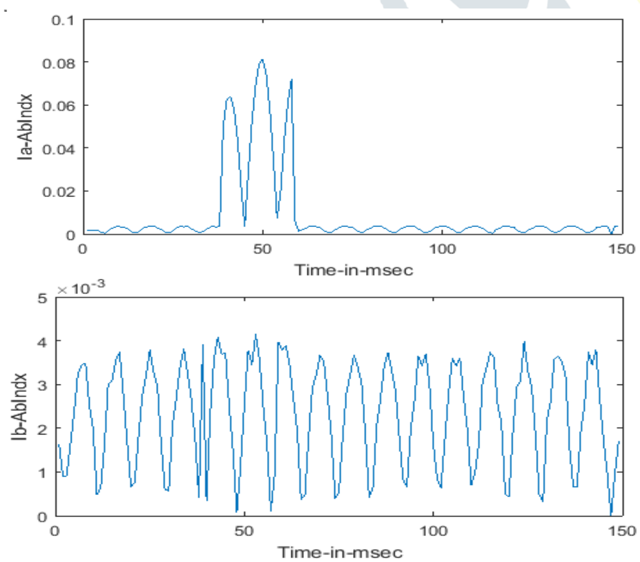


Figure 25: variation of Three phase currents at Bus B2 with DFIG connected system when AG Fault occurs at 5Km distance from bus B2.



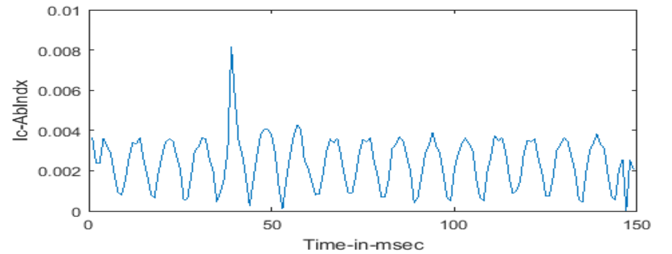


Figure 26: wavelet detailed coefficients of current signals at Bus B2 with DFIG connected system when AG Fault occurs at 5Km distance from bus B2.

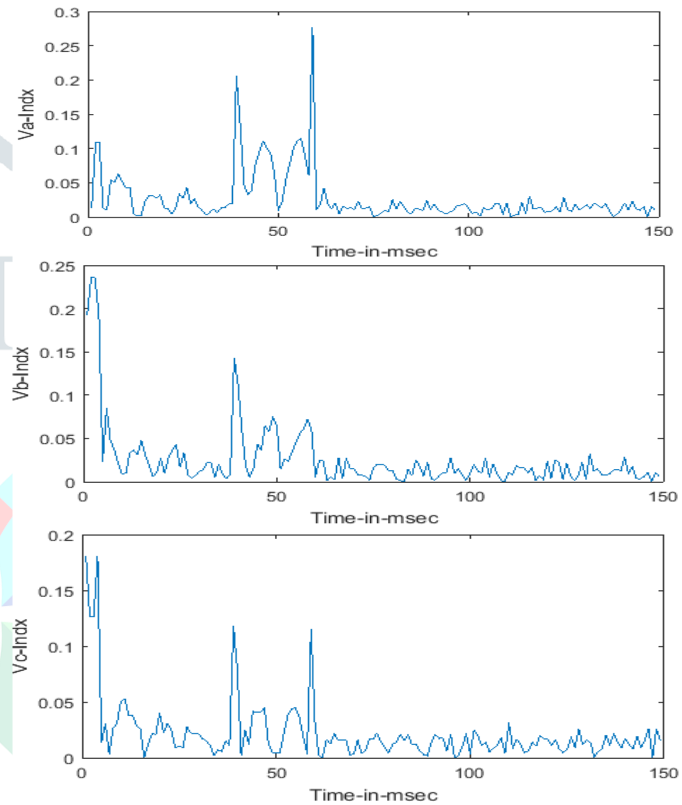


Figure 27: wavelet detailed coefficients of voltage signals at Bus B2 with DFIG connected system when AG Fault occurs at 5Km distance from bus B2.

The variation of three phase voltages are shown in figure28 under temporary faults in DFIG with STATCOM controller connected transmission system. The analysis of wavelet detailed coefficients current and voltage signals are illustrated under temporary faults from bus2 are illustrated in figure29 and Figure30 when DFIG connected at Bus3 and STATCOM Controller near to Bus3.

The variation in Wavelet detailed coefficient of current and voltage signals with DFIG and STATCOM controller in the system from figure28 to figure30.

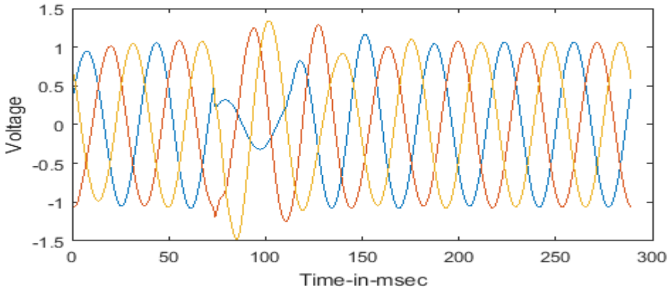


Figure 28: variation of Three phase currents at Bus B2 with DFIG and 48-pulse VST based STATCOM connected system when AG Fault occurs at 5Km distance from bus B2.

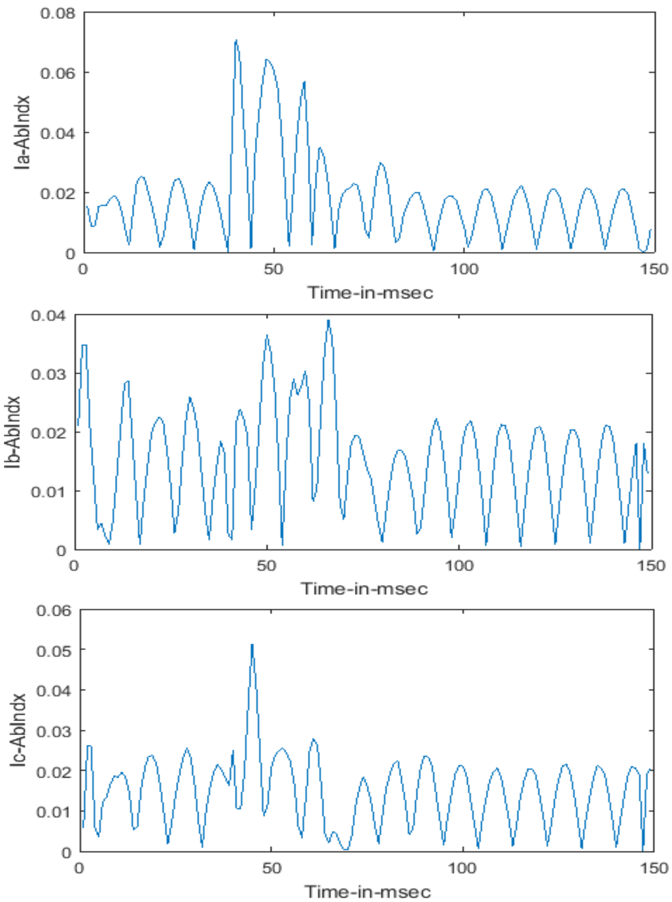


Figure29: wavelet detailed coefficients of current signals at Bus B2 with DFIG and 48-pulse VST based STATCOM connected system when AG Fault occurs at 5Km distance from bus B2

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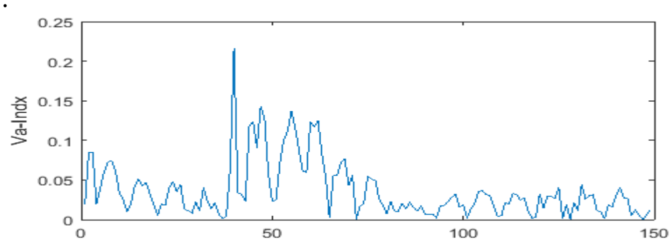

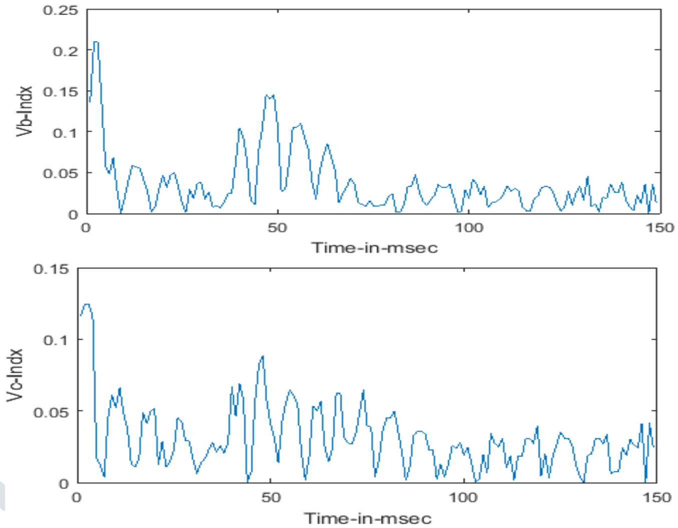

Figure 30: wavelet detailed coefficients of voltage signals at Bus B2 with DFIG and 48-pulse VST based STATCOM connected system when AG Fault occurs at 5Km distance from bus B2.

Figure [22-30] illustrated that STATCOM controller can be utilised to compensate power quality problem under sudden transient currents in the system comprising of DFIG wind generation. It is evident that STATCOM controller can mitigate power quality problems of the system comprising of DFIG wind generation.

VI. CONCLUSIONS

This paper presents comprehensive analysis on the development of technologies used to mitigate the power quality problem using Flexible AC transmission controller. Power electronics and advanced control technologies have made it possible to reduce the power quality problems. Among power system disturbances, voltage sags, swells, transients and temporary faults are some of severe problems to the power system loads are studied. The Static Synchronous Compensator (STATCOM) is a 48-pulse Voltage Source Converter (VSC) based shunt compensating transmission systems consisting of DFIG wind generation is developed using the MATLAB/Simulink. This paper presents the complete digital simulation of the improved configurations of STATCOM within the power system to handle power quality issues. The proposed system is tested under various power quality problems and found that voltage source converter based STATCOM can control power quality issues effectively. For detecting and characterizing power system disturbances wavelet based systems have been found to be more robust and effective. The proposed analysis on the development of technologies used in power quality analysis, which is the major area of research in the field of power system with renewable energy sources like wind generation.

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