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Recognition of Power Quality Disturbances in Distribution Utility Network with Wind Energy Penetration

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Abstract

This paper presents the recognition of the power quality disturbances in the utility network associated with the different operating scenarios in the presence of wind energy. The investigated events include the grid synchronization of the wind generator, outage of wind generator, healthy condition, feeder tripping and feeder reclosing in the presence of wind energy. The voltage signal is captured on a bus of test system and decomposed using the Stockwell transform to obtain the S-matrix. The amplitude curve and frequency curve are obtained from the S-matrix to detect the power quality disturbances relate to the voltage magnitude and frequency components in the presence of the wind power generation. The proposed study is performed in MATLAB/Simulink environment using the IEEE-34 bus test system.

Keywords: *Power quality disturbance, renewable energy, Stockwell Transform, utility grid network, wind energy.*

1. Introduction

Power Quality (PQ) issues have become important in the recent years due to increased nonlinear loads. The power quality disturbances are the measurement of the deviation of voltage and current waveforms from the standard pure sinusoidal waveform as well as deviation of the frequency from the standard frequency of 50 Hz or 60 Hz. The important power quality disturbances include the voltage sag, voltage swell, harmonics, inter harmonics, oscillatory transient, impulsive transient, notch, spike etc. The new scenario foreseen for renewable energy penetration in to the utility grid reinforces the growing concern for PQ disturbances and main reasons for this are: the growth of distributed and diversified generations, the new uses predicted for power systems (e.g. electric car stations) and the increasing demand for power system self monitoring, control and operation. The proper and effective diagnosis of the power quality problems requires a highly efficient technique. Various signal processing and mathematical techniques are used for the detection of the power quality disturbances associated with the grid integration of renewable energy sources. A detailed study of these technique is reported in [Mahela, Shaik, 2015]. High-penetration renewable energy-based generators (REGs) in distribution systems have grown the importance of impact assessment involving these systems [Farhoodnea, Mohamed, 2013]. This evaluation concreted on power quality (PQ) and compatibility between REGs and existing system components. Frequency and voltage fluctuations, voltage drop, harmonic distortion and power factor reduction occurs due to the presence of high-penetration EVSs and REGs. Renewable sources can be used for the insertion of PEVs in households which is also very economical [Romo, Micheloud, 2015]. In [Mahto, Mukherjee, 2015], an autonomous isolated hybrid power and an energy storage system (IHPS) contain of wind turbine generators (WTGs), diesel engine generators system and an energy storage system (ESS) is considered. Because of the stochastic behavior of wind, electric power generated by wind turbine generator is highly erratic and can also affect power supply quality. All the tunable variable of the studied IHPS model along with those of ESS are optimized by taking quasi-oppositional harmony search algorithm and differencing simulation results between various ESSs application in IHPS model for frequency and power deviation are their in terms of rise time, settling time and steady state error for immediate changes in load/generation or both. With different performance indices the performance analysis of the system with

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different ESSs has been also carried. Photovoltaic (PV) and wind Renewable Energy Sources (RESs) mainly are becoming important sources for power generation [Shivashankar, Mekhilef, 2016]. Frequently changing output of PV and wind caused by weather condition and wind speed make them intermittent and unreliable sources when connected to grid. In [Farhoodnea, Mohamed, 2013], author presented power quality analysis contact of high penetration of electric vehicle charging stations (EVCSs) and renewable energy based generators (REGs) which contain wind turbines, grid-connected photovoltaic and fuel cell power generation units on the 16-bus test distribution system. Simulation results show that the presence of high penetration EVCS and REGs can cause severe power quality disturbance such as frequency and voltage fluctuations, voltage drop, harmonic distortion and power factor reduction. Hybrid filter made up of a shunt active filter and distributed passive filters used for power quality improvement in dispersed generation system is presented [Ahrabian, Shahnia, 2013]. Power system Frequency oscillation and power fluctuation occurs by intermittent characteristic of renewable resource in case of standalone Micro grid such as island. This frequency oscillation and power fluctuation can be a cause of system stability problem and operation efficiency drop. To improve power quality and operating efficiency in a diesel and wind-turbine based stand-alone micro grid a unified compensation control strategy of a hybrid electric energy storage system is presented in paper presents. For damping system frequency and power fluctuation a compensation control strategy with modified droop and wind power compensation is used. This method is efficient and this method is proposed control method. It is difficult to obtain good quality power, since wind speed fluctuations reflect on the voltage and active power output of the electric machine connected to the wind turbine due to the wind speed's uncertain behavior [Abrantes, 2012]. A study on the impact of grid disturbances on the output of grid connected wind power generation has been reported in [Sharma, Ola, 2015].

2. The Proposed Test System

This section presents the description of the proposed IEEE 34 bus system used for the recognition of power quality disturbances associate with the various types of the operational events in the presence of wind and solar energy. The schematic diagram of IEEE 34 bus system is shown in Fig. 1. Various buses of the system are designated by the numbers such as 800, 802, 806 etc. This test system is integrated to the utility grid on the bus 800. Voltage and current are recorded on the bus 800 of the test system.

3. Simulation Results and Discussion

This section presents the simulation results related to the detection of the power quality disturbances in the distribution utility network with wind energy penetration. The power quality disturbances related to the voltage magnitude and frequencies dependent PQ disturbances have been investigated using the plots obtained from the Stockwell transform based decomposition of the voltage signals. The total harmonic distortions have been obtained using the Fast Fourier Transform (FFT). Simulation results are detailed in the following sections.

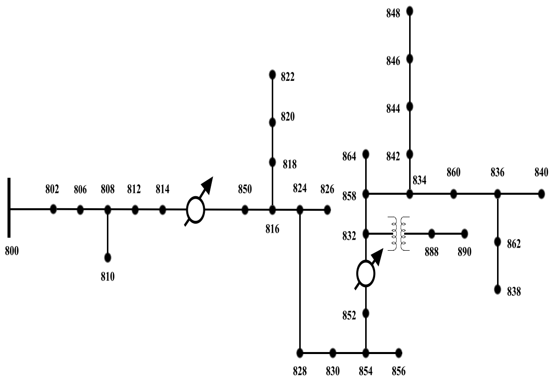

Fig. 1. Proposed IEEE-34 Bus Test System

3.1 Healthy Condition

Healthy condition of the power distribution network with wind energy penetration is simulated using the IEEE-34 bus test system with wind energy conversion system of capacity 1.5 MW integrated on the bus 838 of the test system. Any type of disturbance or event is not created in the test system during the healthy condition. The voltage and current signals have been recorded on the bus 800 of the test system. The voltage signal of phase-A captured on the bus 800 of the test system has been decomposed using the Stockwell transform and S-matrix is obtained. The amplitude plot and frequency amplitude plot obtained from the S-matrix for the healthy condition are shown in Fig. 2 (a) and (b) respectively. It can be observed from the Fig. 2 (a) the voltage magnitude is always constant at a normalized value of 1. Hence, it is concluded that the any type of power quality disturbance related to the voltage magnitude are not present during the healthy condition. It can also be observed from the Fig. 2 (b) that only the frequency component corresponding to the fundamental frequency is available. Any other frequency component is not detected with the frequency amplitude curve. Hence, these plots are taken as the reference plots for the detection of the power quality disturbances present in the other investigated events.

Analysis of the current waveform during the healthy condition has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 3. It is observed that the total harmonic distortions (THD) of the current waveform are 0.08%. The observed THD value is very low and current waveform can be considered to be pure sinusoidal waveform during the healthy conditions in the presence of the wind power generation.

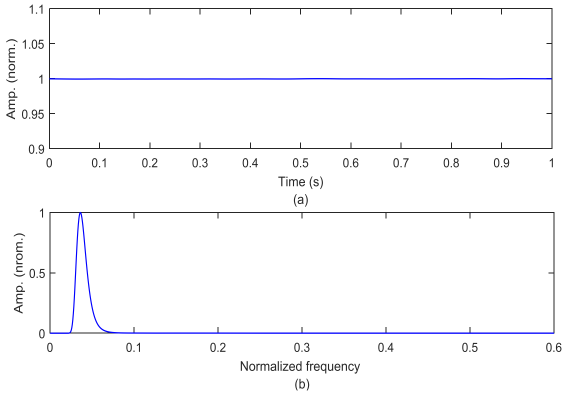

Fig. 2 Stockwell transform based plots during healthy condition in the presence of wind power generation (a) amplitude curve (b) normalized frequency curve.

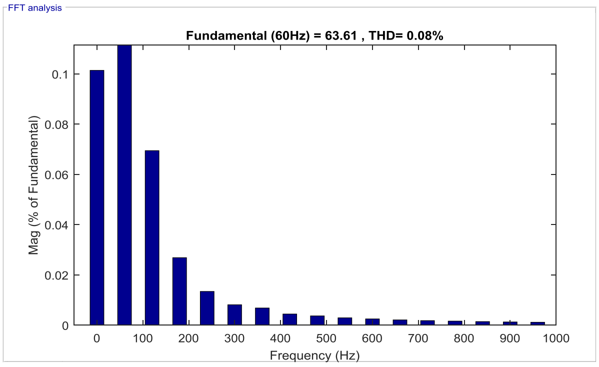

Fig. 3 Total harmonic distortions of current signal during healthy condition in the presence of wind power generation.

Analysis of the voltage waveform during the healthy condition has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 4. It is observed that the total harmonic distortions (THD) of the voltage waveform are 0.16%. The observed THD value is very low and voltage waveform can be considered to be pure sinusoidal waveform during the healthy conditions in the presence of the wind power generation.

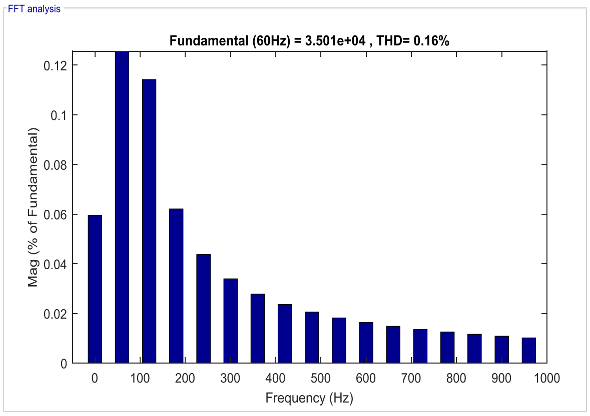

Fig. 4 Total harmonic distortions of voltage signal during healthy condition in the presence of wind power generation.

3.2 Grid Synchronization of Wind Generator

The wind generator of capacity 1.5 MW has been integrated (synchronized) on the bus 838 of the power distribution network of IEEE-34 bus test system at 20th cycle from start of the simulation. The voltage and current signals have been recorded on the bus 800 of the test system. The voltage signal of phase-A captured on the bus 800 of the test system has been decomposed using the Stockwell transform and S-matrix is obtained. The amplitude plot and frequency amplitude plot obtained from the S-matrix for the grid synchronization event of the wind energy conversion system are shown in Fig. 5 (a) and (b) respectively. It can be observed from the Fig. 5 (a) that the voltage sags and swells followed by the voltage fluctuations have been observed after the grid synchronization of the wind generator event. It can also be observed from the Fig. 5 (b) that only the frequency component corresponding to the fundamental frequency is available. Hence, it is concluded that voltage sag, voltage swell and voltage fluctuations are associated with grid synchronization event of the wind power generator. Any other frequency component is not detected with the frequency amplitude curve.

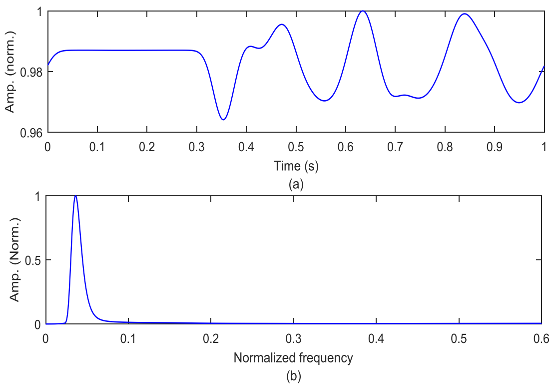

Fig. 5 Stockwell transform based plots during the event of grid synchronization of wind generator (a) amplitude curve (b) normalized frequency curve.

Analysis of the current waveform during the event of the grid synchronization of the wind generator to the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 6. It is observed that the total harmonic distortions (THD) of the current waveform are 15.84%. The observed THD value is high. Hence, it is concluded that the waveform distortion has occurred with the event of the grid synchronization of the wind generator.

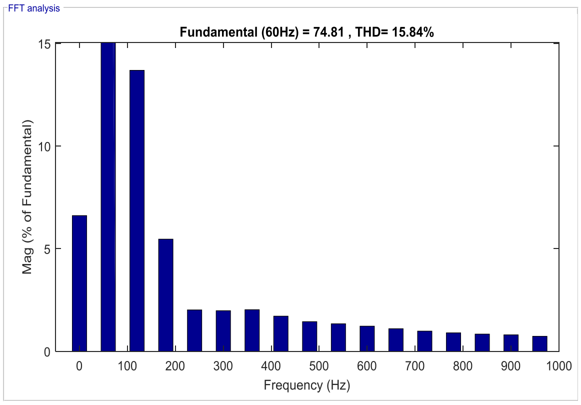

Fig. 6 Total harmonic distortions of current signal during the event of grid synchronization of wind generator.

Analysis of the voltage waveform during the event of the grid synchronization of the wind generator to the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 7. It is observed that the total harmonic distortions (THD) of the voltage waveform are 0.54%. The observed of the voltage waveform has occurred with the event of the grid synchronization of the wind generator.

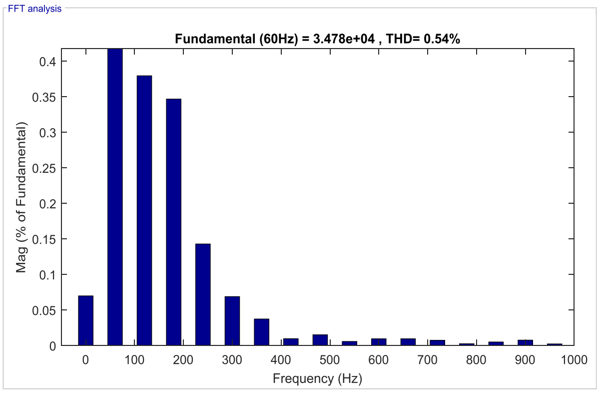

Fig. 7 Total harmonic distortions of voltage signal during the event of grid synchronization of wind generator

3.3 Grid Outage of Wind Generator

The wind generator of capacity 1.5 MW integrated on the bus 838 of the power distribution network of IEEE-34 bus test system has been switched off at 20th cycle from start of the simulation to simulate the event of the outage of wind generator. The voltage and current signals have been recorded on the bus 800 of the test system. The voltage signal of phase-A captured on the bus 800 of the test system has been decomposed using the Stockwell transform and S-matrix is obtained. The amplitude plot and frequency amplitude plot obtained from the S-matrix for the outage event of the wind energy conversion system are shown in Fig. 8 (a) and (b) respectively. It can be observed from the Fig. 8 (a) that voltage sag of high magnitude is observed at the time of outage of wind generator. The voltage is also decreases slightly after the event of the outage of the wind generator. It can also be observed from the Fig. 8 (b) that only the frequency component corresponding to the fundamental frequency is available. Hence, it is concluded that voltage sag low voltage are associated with grid outage event of the wind power generator.

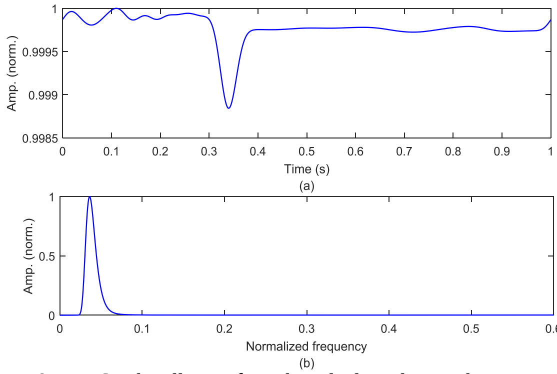

Fig. 8 Stockwell transform based plots during the event of grid outage of wind generator (a) amplitude curve (b) normalized frequency curve.

Analysis of the current waveform during the event of the grid outage of the wind generator from the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 9. It is observed that the total harmonic distortions (THD) of the current waveform are 14.32%. The observed THD value is high. Hence, it is concluded that the waveform distortion has occurred with the event of the grid outage of the wind generator.

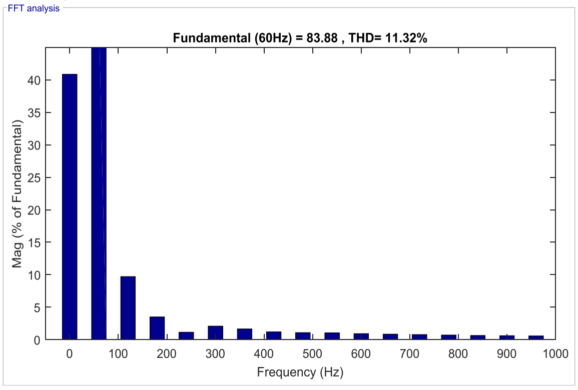

Fig. 9 Total harmonic distortions of current signal during the event of grid outage of wind generator.

Analysis of the voltage waveform during the event of the grid outage of the wind generator from the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 10. It is observed that the total harmonic distortions (THD) of the voltage waveform are 0.32%. The observed THD value is quite high compared to the healthy condition. Hence, it is concluded that the distortion of the voltage waveform has occurred with the event of the grid outage of the wind generator.

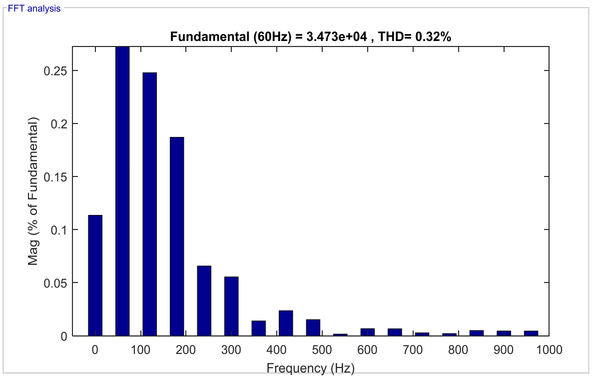

Fig. 10 Total harmonic distortions of voltage signal during the event of grid outage of wind generator.

3.4 Feeder Tripping

The feeder comprising of the buses 842, 844, 846 and 848 has been tripped at 20th cycle from start of the simulation to simulate the event of the feeder tripping in the presence of the wind power generation integrated on the bus 838 of the power distribution network of IEEE-34 bus test system. The voltage and current signals have been recorded on the bus 800 of the test system. The voltage signal of phase-A captured on the bus 800 of the test system has been decomposed using the Stockwell transform and S-matrix is obtained. The amplitude plot and frequency amplitude plot obtained from the S-matrix for the outage event of the wind energy conversion system are shown in Fig. 11 (a) and (b) respectively. It can be observed from the Fig. 11 (a) that voltage sag is observed at the time of feeder tripping in the presence of the wind power generation. It can also be observed from the Fig. 11 (b) that only the frequency component corresponding to the fundamental frequency is available. Hence, it is concluded that voltage sag is associated with the event of feeder tripping in the presence of the wind power generation.

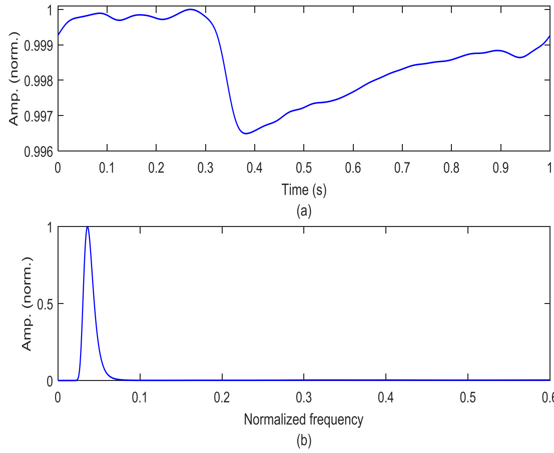

Fig. 11 Stockwell transform based plots during the event of feeder tripping in the presence of wind power generation (a) amplitude curve (b) normalized frequency curve.

Analysis of the current waveform during the event of the feeder tripping in the presence of the wind power generation in the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 12. It is observed that the total harmonic distortions (THD) of the current waveform are 6.81%. The observed THD value is high. Hence, it is concluded that the waveform distortion has occurred with the event of the feeder tripping in the presence of the wind power generation in the distribution utility network.

Analysis of the voltage waveform during the event of the feeder tripping in the presence of the wind power generation in the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 13. It is observed that the total harmonic distortions (THD) of the voltage waveform are 0.32%. The observed THD value is quite high. Hence, it is concluded that the waveform distortion of current signal has occurred with the event of the feeder tripping in the presence of the wind power generation in the distribution utility network.

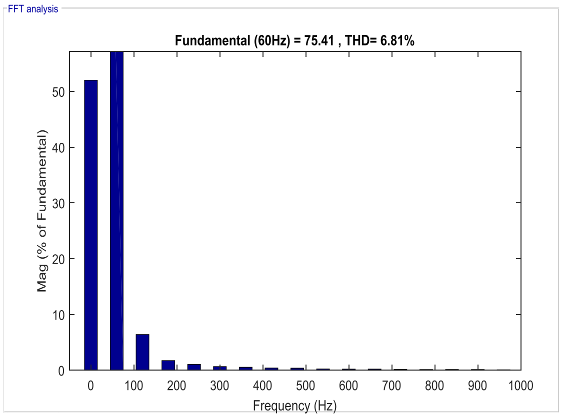

Fig. 12 Total harmonic distortions of current signal during the event of feeder tripping in the presence of wind power generation.

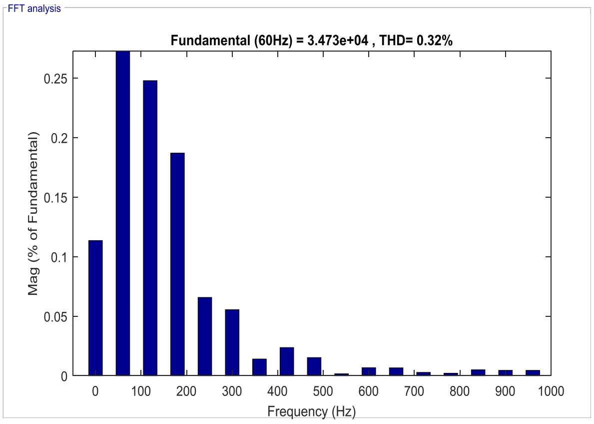

Fig. 13 Total harmonic distortions of voltage signal during the event of feeder tripping in the presence of wind power generation.

3.5 Feeder Reclosing

The feeder comprising of the buses 842, 844, 846 and 848 has been first opened and reclosed at 20th cycle from start of the simulation to simulate the event of the feeder reclosing in the presence of the wind power generation integrated on the bus 838 of the power distribution network of IEEE-34 bus test system. The voltage and current signals have been recorded on the bus 800 of the test system. The voltage signal of phase-A captured on the bus 800 of the test system has been decomposed using the Stockwell transform and S-matrix is obtained. The amplitude plot and frequency amplitude plot obtained from the S-matrix for the outage event of the wind energy conversion system are shown in Fig. 14 (a) and (b) respectively. It can be observed from the Fig. 14 (a) that voltage swell is observed at the time of feeder reclosing in the presence of the wind power generation. It can also be observed from the Fig. 14 (b) that only the frequency component corresponding to the fundamental frequency is available. Hence, it is concluded that voltage swell is associated with the event of feeder tripping in the presence of the wind power generation.

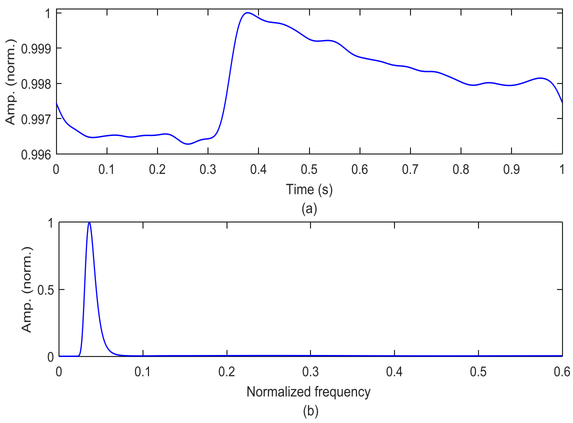

Fig. 14 Stockwell transform based plots during the event of feeder reclosing in the presence of wind power generation (a) amplitude curve (b) normalized frequency curve.

Analysis of the current waveform during the event of the feeder reclosing in the presence of the wind power generation in the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 15. It is observed that the total harmonic distortions (THD) of the current waveform are 5.79%. The observed THD value is high. Hence, it is concluded that the waveform distortion has occurred with the event of the feeder reclosing in the presence of the wind power generation in the distribution utility network.

Analysis of the voltage waveform during the event of the feeder reclosing in the presence of the wind power generation in the distribution utility network has been carried out using the Fast Fourier Transform and FFT plot is shown in Fig. 16. It is observed that the total harmonic distortions (THD) of the voltage waveform are 0.36%. The observed THD value is quite high. Hence, it is concluded that the waveform distortion of current signal has occurred with the event of the feeder reclosing in the presence of the wind power generation in the distribution utility network.

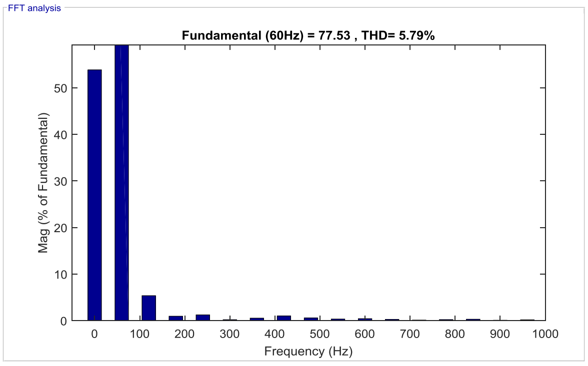

Fig. 15 Total harmonic distortions of current signal during the event of feeder reclosing in the presence of wind power generation.

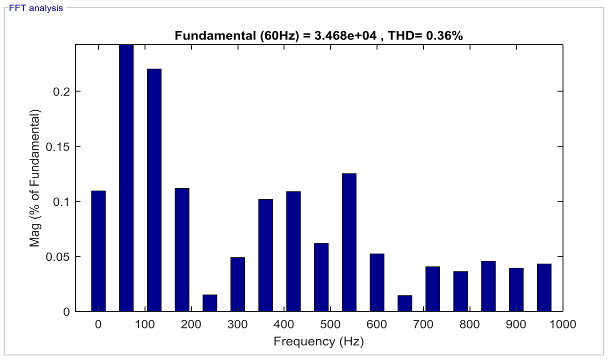

Fig. 16 Total harmonic distortions of voltage signal during the event of feeder reclosing in the presence of wind power generation.

The total harmonic distortions of current and voltage during the various operational events is provided in the Table 5.1. It is observed from this Table that the total harmonic distortions of the current are affected adversely by the investigated operational events. Maximum THD of voltage is observed with the grid synchronization of the wind generator followed by outage of wind generator, feeder tripping, feeder reclosing and minimum in the healthy conditions. Significant changes are not observed in the values of the THD of voltage during the investigated operational events.

TABLE 1 THD OF VOLTAGE AND CURRENT IN THE PRESENCE OF WIND POWER GENERATION

Operational Event	Total Harmonic Distortions (%)	
	Current	Voltage
Healthy Condition	0.08	0.16
Grid Synchronization of Wind Generator	15.84	0.54
Grid Outage of Wind Generator	11.32	0.32
Feeder Tripping	6.81	0.32
Feeder Reclosing	5.79	0.36

4 Conclusion

The research work presented in this thesis has considered the the detection of the power quality disturbances in the distribution utility network with wind energy penetration. The power quality disturbances associated with the events such as healthy condition, grid synchronization of wind generator, outage of wind generator, feeder tripping and feeders reclosing are studied in detail. The MATLAB simulation result related to these events are discussed in detail. The power quality disturbances related to the voltage magnitude and frequencies dependent PQ disturbances have been investigated using the plots obtained from the Stockwell transform based decomposition of the voltage signals. The total harmonic distortions have been obtained using the Fast Fourier Transform (FFT). Based on the proposed study it has been concluded that the power quality disturbances such as voltage sag, voltage swell and waveform distortions are associated with the wind energy penetration into the utility distribution network. It is also concluded that the distortions of current waveform are high compared to the voltage waveform. Maximum values of the THD of current waveform are observed equal to the 15.84 and maximum value of THD of the voltage waveform is equal to the 0.54.

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