7
Summary and Conclusions

This chapter presents the summary of proposed research work, core findings of the research work and closing comments.

7.1 SUMMARY

An extensive review of the existing work related to the detection of power quality disturbances, mitigation of power quality disturbances, distribution static compensator, solar technologies and wind technologies is carried out. It has been observed that the literature focussed on the power quality issues which are due to design constraints of the converters used for grid integration of various RE sources, solar PV plates, wind turbine and wind generator. However, the PQ issues associated with various operations of RE sources such as islanding, outage and grid synchronization of wind and solar PV generators, wind speed variations and variations in the solar insolation have not been covered. Hence, the same has been recognized as research gap for this thesis work. Thus, this thesis covers the detection of various PQ events associated with these operations of RE sources. Efforts have been made to mitigate the power quality by using a DSTATCOM which works on a control based on SRF theory. The simulation results obtained from IEEE-13 bus test system have been tested in real time using RTDS.

7.2 CONCLUDING REMARKS

7.2.1 Detection of PQ Disturbances

Methods based on Stockwell's transform have been proposed for the detection of power quality disturbances. Firstly, the single stage and complex PQ disturbances generated using mathematical modelling as per IEEE-519 standard are detected using Stockwell's transform and then classified using decision tree and proposed decision tree initialized fuzzy c-means clustering. Then experiments are performed for the detection of PQ disturbances associated with the grid interfaced DFIG based wind energy conversion system and solar PV system with the available single bus hardware. Based on the experimental results detailed simulation study has been carried out for the detection of PQ disturbances associated with the operational events such as outage and synchronization of wind generator and solar PV system. The PQ disturbances associated with the islanding, wind speed variations and variations in the solar insolation have also been detected. Results are tested in real time using the real time digital simulator. Power quality index is proposed to find out the relative effect of various events and high penetration level of renewable energy in the grid on power quality. Core findings related to the detection of PQ disturbances are detailed below:-

- The algorithm based on Stockwell transform and decision tree technique proved to have an efficiency greater than 98% even in the noisy environment for the detection of single stage PQ disturbances.
- The algorithm based on Stockwell transform and decision tree initialized Fuzzy C-means

clustering technique proved to have an efficiency greater than 99% even in the noisy environment for the detection of single stage PQ disturbances.

- An efficiency of 98.70% has been achieved without the presence of noise for the classification of complex PQ disturbances with the help of decision tree using Stockwell transform based features. The efficiency of proposed algorithm has been found to be 97.41% with noise level of 20 dB SNR.

- Experimental investigations established that PQ disturbances such as harmonics, voltage unbalance, impulsive transient, oscillatory transient and voltage sag are associated with the outage of DFIG from the utility grid. PQ events such as harmonics, flicker, voltage unbalance and transients are associated with the synchronization of DFIG to the weak utility grid. Power quality index is high with the events of synchronization compared to the respective events of outage indicating that power quality is adversely affected with synchronization as compared to the outage. Presence of the non-linear load at PCC deteriorates the quality of supply more adversely as compared to the other types of loads.

- It has been establsihed with the help of experimental investigations that the PQ disturbances such as harmonics, impulsive transient, oscillatory transient and voltage sag are associated with the outage of solar PV system from the utility grid. The PQ disturbances such as voltage swell, voltage unbalance, flicker, harmonics and high frequency transients are associated with the synchronization of solar PV system with the utility grid. Presence of inductive components in the load affects the power quality adversely. Power quality index is high with the events of synchronization compared to the respective events of outage. Hence, PQ disturbances are dominant with the synchronization as compared to the outage event.

- Simulation studies indicate that power quality disturbances such as voltage fluctuations with sag and swell, flicker, transients and power frequency deviations are detected with grid synchronization of wind generator. Voltage swell, low magnitude transients and power frequency deviations are asscoiated with the outage of wind generator. High magnitude voltage sag and swell, oscillatory transient, harmonics, transients, flicker and power frequency variations have been detected with the islanding of test system from the utility grid. Low magnitude voltage fluctuations, flicker and frequency variations are observed with the wind speed variations. Power quality index indicates that overall power quality deteriorates with the increase in wind energy penetration level. Maximum effect is observed with the islanding followed with the synchronization, wind speed variations and minimum with the outage of wind generator.

- From the simulation studies it has been observed that the PQ disturbances such as voltage fluctuations, sag, swell, flicker and transients are present with the grid synchronization of the solar PV generator. Synchronization increases voltage level in the feeder whereas the voltage level decreases with the outage of solar PV generator. An impulsive transient is detected with outage event. The high frequency transients and flickers have not been detected with the outage. The voltage fluctuations with decreases in the voltage have been detected with the abrupt change in solar insolation. Low frequency magnitude transients and flicker have also been detected with the abrupt change in solar insolation. The power frequency variations have been observed with all the cases of study having maximum effect with the change in solar insolation and minimum effect with the outage. The PQ index indicates that power quality deteriorates with increase in penetration level of the solar PV energy into the utility grid and maximum effect is observed with the synchronization followed by change in solar insolation and minimum with outage.

- Based on the simulation studies related to hybrid power system it can be concluded that the

proposed algorithm effectively detects the events such as islanding, outage of wind/solar generators, and grid synchronization of wind/solar generators in the RE sources based hybrid power system. Proposed algorithm can also effectively recognize the PQ events associated with these events. High values of THD_v and THD_i are observed with the islanding events. However, the values are below 5% for the outage and synchronization events. Power quality index indicates that the power quality is adversely affected with the islanding event. However, with the outage and synchronization events power disturbances are acceptable whereas it is quite high with the synchronization events as compared to the outage events.

7.2.2 Mitigation of PQ Disturbances

This research work proposes the implementation of DSTATCOM with battery energy storage system in the three phase balanced distribution network addressing PQ issues. Synchronous reference frame theory based control algorithm is used for the control of DSTATCOM. Power quality improvement during disturbances in the grid due to feeder tripping, feeder re-closing, load switching, voltage sags and swells have been investigated. Power quality events with wind energy operations such as outage of wind generator, grid synchronization of wind generator and wind speed variations have also been investigated. The proposed DSTATCOM is also implemented for the improvement of power quality in distribution utility network in the presence of solar PV system during the events such as grid synchronization of solar PV system, outage of solar PV system and variation in solar insolation. Finally, the proposed DSTATCOM is also used for PQ improvement in the hybrid power system. The results are tested in real time using the RTDS. The core findings related to the mitigation of PQ disturbances are detailed below:-

- The distribution static compensator with BESS using SRF control theory can effectively be used for mitigation of PQ events associated with distribution network due to grid disturbances such as voltage sag, swell, load switching, feeder tripping and re-closing. An improvement up to 65% in the values of THD_v has been achieved by the use of DSTATCOM.

- It has been established that the DSTATCOM with BESS using SRF control theory can effectively be used to improve the power quality in distribution network with wind generator operations such as outage, grid synchronization and wind speed variations. Improvement in the values of THD_v up to 100% has been achieved using the DSTATCOM in the presence of wind generation.

- The synchronous reference frame theory based control of the DSTATCOM with BESS has been proved to be effective in improving the power quality at grid level during the operational events of solar PV system such as grid synchronization, outage and sudden change in solar insolation. An improvement up to 92.28% in the values of THD_v has been achieved by the use of DSTATCOM in the presence of solar PV system.

- It has also been established that the DSTATCOM with BESS using SRF control theory can effectively be used to improve the power quality in the hybrid power system events of operations of wind generator and solar PV system. An improvement up to 60% in the values of THD_v has been achieved by the use of DSTATCOM in the hybrid power system.

7.3 CLOSING COMMENTS

Efforts have been made to detect the operational events of renewable energy sources in the distribution system and PQ disturbances associated with these events. The study has been carried out using single bus experimental set ups and IEEE-13 bus test system. The mitigation of PQ disturbances using DSTATCOM has been carried out during the operational events using IEEE-

13 bus test system. Besides the research work carried out in the thesis, the proposed algorithms may also be tested on the large test systems such as IEEE-123 bus test system. The presented research work can also be extended to explore design of the converters used for grid interfacing of the renewable energy sources to minimize the effect of PQ disturbances due to outage and grid synchronization of RE sources as well as the environmental characteristics such as wind speed variations and changes in solar insolation. The implementation of custom power devices such as UPQC and DVR for PQ improvement in the events of outage and grid synchronization of RE sources can also be explored.

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