Detection of Anomalies in the Quality of Electricity Supply

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***Abstract*—**From the last two decades, power quality is getting much attention. Proper functioning of the equipment depends upon the quality of power supplied. Every year, demand of electric power goes on increasing and the power system network is expanding and becoming more complex. On account of thrust on clean power supply, use of renewable sources has dramatically increased in grid but it simultaneously causes power quality problems. In this work, power quality disturbance detection in wind farm integrated with grid is presented. For disturbance detection, time-time transform has been employed. The disturbance signal for the detection purpose is generated in MATLAB/Simulink environment by using a Simulink model.

Keywords*-distributed generatio, power quality;reliability; active power filter*

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I. Introduction

Over the last few years, power scenario has changed a lot; it has become more and more complex due to system extension to meet the energy demand gap [26, 37]. With the progressive development in the field of electrical and electronics, equipment and devices such as microprocessor, microcontroller etc., have been added to the power system network in a huge amount. But, they are highly sensitive and susceptible to power quality problems. Power quality either good or bad depends on the proper functioning of these devices and equipment.

Many disturbances are due to normal operations of load switching and opening of circuit breaker during clearing of faults. Although, electric utilities have invested a lot to prevent power disturbances, but it is not possible to completely control them [43, 45-49]. A large number of disturbances are also generated by power plant operation and customer-owned equipment that are beyond the utility's control.

Power quality assurance demands a systematic research and deep study on the subject of electric PQ. Hence, electric power quality has become a topic of concern for both utility as well as its customers. PQ disturbances are depends on amplitude, phase or frequency of a signal [1, 2, 40, 41, 42].

Our society has a significant growing need for electricity over at higher level of service, quality and consumer satisfaction in the past decades [27-36, 38]. The extensive usage of conventional sources of energy mainly fossil fuel has resulted in their own reserve depletion and an increase in the level of environmental pollution. Primarily due to environmental concerns caused by burning of fossil fuels, researches are going on to find alternative sources of energy.

In recent trend of clean power, the electric power industry are generating power from renewable energy sources (RES) like wind, photovoltaic and hydro power etc. and feeding back to the utilities through transformers, transmission lines, and distribution lines. For this purpose the distributed generations DGs are used, DGs are the smaller-sized generators located close to consumers with normal power rating of 1 KW to 100 MW. On the bases of three different perspectives some of the benefits of distributed generators are mentioned below [3]: DGs are mostly found close to the end-user. They have a backup generation, which improves reliability. DG can use existing transmission and distribution T&D lines depending upon load demand for new T&D lines.

DG can be look as ancillary service into the area of power market. The DG can be directly connected to the grid or in isolated mode.

II. Literature Review

In early twenties, C. Lin and C. Wang [4], have developed the DEDS (disturbance event detection system) using AWNs (adaptive wavelet networks) and used this on a 14-bus system. They have used AWN, which is a combination of Morlet wavelets and adaptive probabilistic neural network for recognition of PQ disturbances like harmonics and voltage fluctuation [44].

A practical investigation has been presented in [5], on two wind farms having different power output (10.2MW and 30MW) at the PCC with the HV transmission line for power quality issues. A measurement system consisting of the data acquisition board (DAQ), LabVIEW, MATLAB software and a portable computer is used for recording real field measurement results for power quality events like flicker, harmonics, voltage sags, swell, and unbalance based on current regulations in Turkey. In [6], the authors have proposed a combination of wavelet and Prony methods for voltage dip and transient in wind farms. Their proposed methodologies are tested on measured signals at a fixed-speed wind turbine with two-step compensation capacitors. By Prony method, the accurate amplitude, phase, frequency and time constant of the transient components are estimated. Then, The starting and the ending of transient is detected using wavelet. An experimental model of the single machine drive of rating 3.5 KW, has been tested in the laboratory and investigated for PQ issues in wind farms in PSCAD [7].

A control strategy is proposed in the [8], based on fractional-order controllers, which can decrease the THD (total harmonic distortion) in speed changing conditions of wind turbines. Harmonic analysis of PMSG wind turbines with full-power converters is focused which shows that the train-mass model can be more useful. They have presented and compared simulated results using IEEE-519 standard as a guideline. In [9], the authors have studied the voltage profile at the PCC in DG based hybrid system with non-linear load. They have proposed wavelet and S-transform for the processing. These approaches are used for islanding detection and non-linear load rejection disturbances at PCC under normal and noisy condition.

Authors in [10], have proposed a control technique for the grid-interfacing inverters. Here 3-phase 4-wire linear/non-linear unbalanced load act as balanced linear load when installed at the PCC of the grid. The proposed approach has features like i) injects real power from RES (renewable energy resources) to the grid, and/or, ii) can operate as a shunt Active Power Filter (APF) hence no need for additional power conditioning. This control technique tested with MATLAB/Simulink and experimental setup.

Authors in [11], have presented a fast and modified recursive Gauss–Newton algorithm (MRGN) for the assessment of PQ indices in DG for islanding and non-islanding conditions. In [12], authors have presented detection of islanding and PQ disturbances using S-transform in grid-connected hybrid power system. This technique helps in extracting important characteristic features followed by classification of disturbance with two classifiers: MPNN (modular probabilistic neural network) and SVM (support vector machine) classifier. A suitable threshold value is selected for separating out islanding disturbance from the PQ disturbances [39]. The study is also supported with signals obtained on experimental setup.

Authors in [13], classification of PQ disturbances like voltage sags and voltage swell that are caused load change, solar insolation and wind speed variation of renewable source connected to grid. Ten different features are extracted through S-transform, and then fed into LS-SVM classifier. Simulated and experimentally generated signals obtained on a prototype of wind energy conversion and PV array are used in study.

In [14], the authors have studied various latest developed inverter technology for micro wind turbine and PV arrays. On the basis of result analysis a modeling framework has been proposed to study the PQ effect of small scale renewable generation cells. In [15], authors have studied the effect of high penetration of WPGS on the distributed system. Installation of different DGs on the distribution system affects not only the system operation, but also the planning and maintaining strategies of utilities. They have selected Taiwan Power Company (Taipower) for practical implementation and investigation of PQ events. Various PQ issues like voltage variation, flicker, short-circuit current and harmonics are presented in this paper. The authors in [16] have proposed a morphological filter for detection and classification of various disturbances in micro grid, installed with the DFIG wind farm. Mathematical morphology with de-noising technique is used to estimate signal characteristics accurately and efficiently. The target distributed generation (DFIG), raw voltage and current signals are passed through morphological filters. They have computed feature sets comprising of kurtosis and energy. These feature sets are classified by a decision tree for classification of islanding and power quality events.

In [17], authors have presented PQ disturbance classification due load change and environmental issues. Features are extracted by hyperbolic S-transform and using genetic algorithm optimal features are selected. From given optimal feature set, PQ disturbances are classified using support vector machines (SVMs) and decision tree (DT).

Authors in [18], have presented an algorithm for assessment and causes of flicker in wind turbines. They have modeled some aerodynamic factors for fixed speed wind turbine. Wavelet and S-transform are used for feature extraction.

In [19], authors have presented a comparison of wavelet transform and S-transform feature extraction techniques in hybrid DG system for islanding and PQ disturbances detection. In [20], authors have performed a case study for the detection of the PQ events caused by penetration of wind energy into the distribution network. For the case study modified IEEE 13 bus distribution network is used with wind and diesel generator installation. They have simulated the proposed test model in MATLAB/Simulink environment.

In [21], authors have described the case study of electric power grid connected wind turbine of Maharashtra, India. They have used wavelet transform technique for PQ disturbance analysis to detect the PQ disturbances. Effect of wind speed variation on power quality of supply system of the case study has been described.

At present, development in the field of electric power generation from renewable sources of energy is growing at a very fast rate. This is mainly due to environmental concern and energy security, as fossil fuels are limited in amount. Renewable source (like wind, solar, hydro etc.) of energy is pollution free, clean & infinite in nature. In compression to other renewable energy sources, wind energy is popular due to mature technology, good infrastructure and cost comparison [22].

The output power of wind turbines varies depending upon environmental conditions, which are change in wind speed; turbulence; switching events of turbine. Therefore, penetrating power from wind-turbine into the grid has potential to cause power quality problems in a distribution feeder. These PQ disturbances as voltage sag/swells,

III. PROPOSED METHODOLOGY

Power quality signals are non-stationary signals i.e., the frequency is varying with respect to time. It means that the said signal is having multiple number of dominating frequency content. Hence there is need to have the processing by use of signal process technique to deal with such type of signal. The processing contains many stages, from signal processing technique till extraction of certain number of features which are able to characterize the signal. Then these are fed to the classifier for the classification purpose. In this work only detection of PQ disturbances in wind-grid integration is presented using TT transform.

A. *Signal Generation*

In the first stage, PQ disturbances are generated taking special network of wind-grid integrated Simulink model in MATLAB. DFIG wind turbine of discrete-type is used. In this model various power quality events are generated by creating situation like grid fault, wind speed variation and load variation cases etc.

Four types of power quality events are presented:

- Normal Voltage Signal
- Voltage Sag
- Voltage Swell
- Voltage Harmonics

In pre-processing stage two important processing i.e. normalization and segmentation process is applied to this three-phase event data. As a result, a data with p.u. value, start and end of the event is obtained. Then, the data is separated into three separate single-phase event data for analysis.

IV. TT-TRANSFORM

TT-transform technique gives time-time representation of the time series signal which contain power disturbance event. TT-transform is derived from S-transform [23]. It is time-time decomposition method, which divides the primary time series. The TT-transform (stands for Time-Time Transformation) applied for recognition of the PQ disturbance present in the wind-grid integrated network. TT-transform is useful for extracting high-frequency components. It has been generalized to have an arbitrary window size. Basically TT-transform decomposes one dimensional time series into two-dimensional series known as TT-series. The signal component localization is frequency depended.

TT-transform is robust to noise as compared with wavelet-based method used techniques. Moreover, unlike S-transform based methods it does not have difficulty in detecting disturbances. TT transform has high rate of accuracy with quick response time. One of the main advantages of using this technique in the presented work is that only its diagonal part has been analyzed. By computing diagonal elements of TT spectrum, the overall computational efficiency improves which further make the T-transform technique more practical [24, 25].

V. RESULTS

A simulated model for the generation of various events is developed having DFIG as a wind turbine. PQ Disturbance that are considered in this study, namely: voltage sag, voltage swell, voltage harmonics. Their synthetic results are obtained and the proposed technique is applied on these PQ events in MATLAB environment.

The voltage signal is extracted from the PCC of the developed Simulink model made in MATLAB/Simulink environment, having a fundamental frequency of 50 Hz and the sampling frequency of 10 kHz. The monitored PQ event signal at PCC is three-phase voltage signal. Normalization and segmentation process is applied to all three-phase PQ events. After processing, for each PQ event a segment is obtained with per unit value and also having event starting and ending point. After that, the signal is separated into three separate single-phase event signal.

TT-transform is applied on each phase of the three-phase distorted voltage waveform. After applying TT-transform, time-time representation plots known as TT- plots are obtained. The events can also be located from TT-plots. For verification and validation of the proposed method, a wind-grid model is simulated in MATLAB/Simulink [50]. Four types of PQ disturbances that are discussed in this study are as follows:

- Normal Voltage Signal
- Voltage Sag
- Voltage Swell
- Voltage Harmonics

Figure 1 represents the single line diagram of the proposed system. The model consists of 120kV grid, which is connected to the power system network through a 47 MVA, 120kV/25kV transformer at grid end and a 25kV line. The proposed model consists of doubly fed induction generator (DFIG) based wind farm (9 MVA). The models have been simulated with a system frequency and the sampling time (Ts) of 50 Hz and 1 x 10-4 sec respectively.

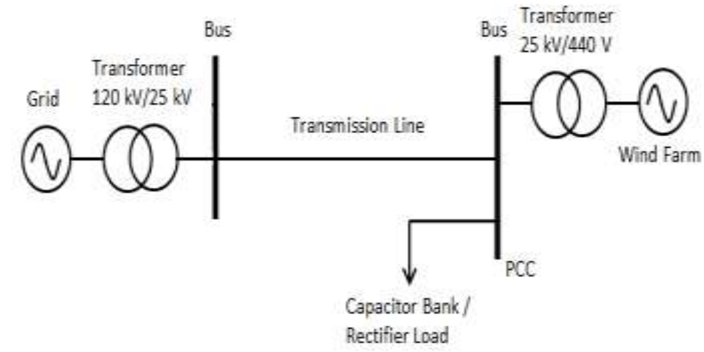

Fig. 1 Single line diagram of the proposed system

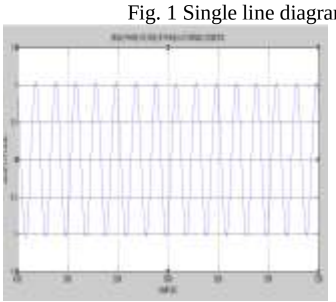

Fig. 2(a) Normal Voltage Signal

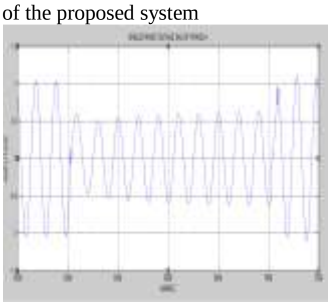

Fig. 2(b) Voltage Sag

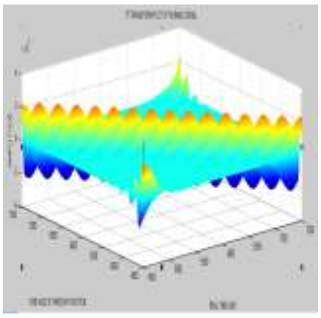

Fig. 2(c) TT plot of Normal Voltage Signal

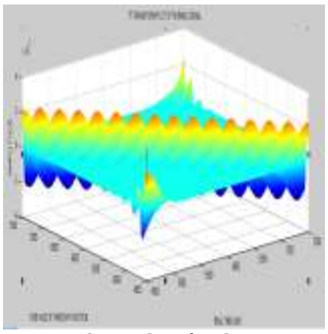

Fig. 2(d) TT plot of Voltage Sag

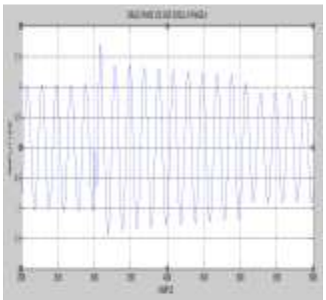
Fig. 3(a) Voltage Swell

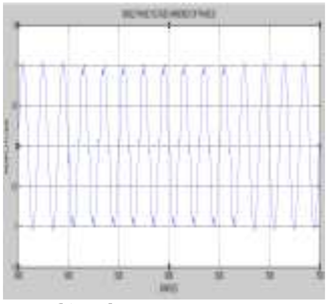
Fig. 3(b) Voltage Harmonics

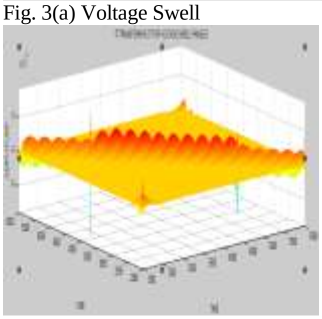
Fig. 3(c) TT plot of Voltage Swell

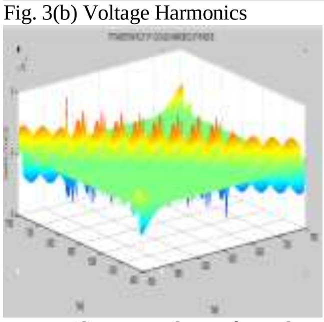
Fig. 3(d) TT plot of Voltage Harmonics

This paper work can be helpful in the direction of recognition of various PQ disturbances in wind-grid integrated network. There have been numerous work done in signal processing and soft computing tools for recognition of PQ disturbances accurately. In this work, TT-transform technique has been used to plot TT-plots for detecting the event signal

VI. Conclusion

First of all, the wind-grid connected Simulink models are developed in the MATLAB/Simulink environment using DFIG as an integrated wind-turbine. Then, different cases of PQ disturbances are synthetically generated namely voltage sag, voltage swell, and voltage harmonics and are monitored at PCC. These signals are three-phase voltage signal. Now, on the monitored signal, TT-transform is implemented and TT-plots are obtained. These TT-plots give the picture of occurrence of the event if present in the signal, hence PQ event are detected.

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