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Power quality improvement in distribution network using DSTATCOM with battery energy storage system

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ABSTRACT

The distribution static compensator (DSTATCOM) provides fast control of active and reactive powers to enable load compensation, harmonics current elimination, voltage flicker mitigation, voltage and frequency regulation. This paper presents power quality improvement technique in the presence of grid disturbances and wind energy penetration using DSTATCOM with battery energy storage system. DSTATCOM control is provided based on synchronous reference frame theory. A modified IEEE 13 bus test feeder with DSTATCOM and wind generator is used for the study. Power quality events during grid disturbances such as feeder tripping and re-closing, voltage sag, swell and load switching have been studied in association with DSTATCOM. The power quality disturbances due to wind generator outage, synchronization and wind speed variations have also been investigated. The study has been carried out using MATLAB/SIMULINK and the simulation results are compared with real time results obtained by the use of real time digital simulator (RTDS) for validating the effectiveness of proposed methodology. The proposed method has been proved to be effective in improvement of power quality with all disturbances stated above.

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Introduction

Power quality (PQ) has been a topic of consideration for last twenty years to both utility and end use customers. It has recently acquired intensified interest due to wide use of power electronics, microprocessor based devices, controllers in industrial processes, non linear loads and proliferation of computer network [1]. Further, the grid integration of distributed generation (DG) such as wind, fuel cell, and solar photovoltaic also affects the quality of supplied power [2]. Power quality is any deviation in current, voltage and frequency from their standard values which results in failure or miss operation of customer equipments [3]. PQ is attributed to the various disturbances such as harmonics, voltage flicker, multiple notches, voltage sag, swell, momentary interruption, impulsive and oscillatory transients [4]. The mathematical techniques such as Fourier transform (FT), short time Fourier transform (STFT), S-transform, Hilbert Huang transform, and wavelet transform are used for detection of PQ disturbances. Artificial intelligent (AI) techniques such as support vector machine, neural network, fuzzy expert system, genetic algorithm are used for classification of PQ events. Different PQ detection and classification techniques have been reported in [5]. Both the passive and active filters are used for PQ improvement. A group of controllers known as custom power devices such as unified power quality conditioner (UPQC), dynamic voltage restorer (DVR), and distribution static compensator (DSTATCOM) are used for improving the quality of electrical power [6]. Mahela and Shaik [7], presented the detailed analysis of various power quality improvement techniques.

The distribution static compensator is a voltage source converter (VSC) based device usually supported by short-time energy stored in the dc link capacitor. It can compensate for reactive power, load unbalancing, voltage variations and current harmonics in the distribution network [8]. Performance of the DSTATCOM depends on estimation of active and reactive powers, harmonic currents, and control algorithm used for estimation of reference currents [9]. The control techniques of DSTATCOM like instantaneous $p-q$ theory, synchronous reference frame theory (SRF), modified synchronous reference frame theory (MSRF), instantaneous symmetrical control theory, and average unit power factor theory (AUPF) have been reported in the literature [10]. The battery energy storage system (BESS) connected to the dc bus in parallel with dc link capacitor improves the dynamic performance of the system such as frequency and voltage regulation. The battery

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energy storage system provides the additional capacity of DSTATCOM for load balancing, reactive power compensation, harmonic current elimination, and also functions as un-interruptible power supply (UPS) [11]. Detailed analysis of DSTATCOM topologies and control techniques for the improvement of power quality has been reported in [12].

Implementation of the DSTATCOM, addressing power quality improvement, for specific applications such as isolated wind power generation, residential low voltage network, load compensation, isolated asynchronous generator, standalone solar photovoltaic system and water pumping system has been reported in the literature. However, very less number of articles are available for implementation of DSTATCOM at grid level addressing PQ improvement specifically with renewable energy sources. Ghosh and Joshi [13], proposed a DSTATCOM with battery energy storage system for voltage regulation in the mini custom power park. The voltage flicker mitigation of electric arc welder has been achieved using DSTATCOM with BESS and reported in [14]. The improvement of load voltage for a constant speed wind energy system supplying the power to inductive load has been achieved with the help of Fuzzy logic based control of DSTATCOM in [15]. Singh et al. [16], proposed the DSTATCOM for compensation of linear and non-linear loads in both steady state and dynamic conditions. The self-charging control technique of DSTATCOM for mitigation of voltage sag, swell and momentary interruption has been proposed in [17]. The power quality improvement with wind energy system has been presented by the authors in [18].

This paper 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. The 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 study has been carried out using MATLAB/SIMULINK and the simulation results are compared with real time results based on the real time digital simulator (RTDS) for validating the effectiveness of proposed system. Based on the studies, it is concluded that the SRF based control of DSTATCOM is easy to implement at grid level for reducing the total harmonic distortion below 5% as per IEEE-519 standard even with wind energy penetration into the grid. Hence, main contribution of present work is the design and implementation of SRF control theory based DSTATCOM with BESS at grid level for PQ improvement. Addressing the PQ improvement during the wind operations such as outage of wind generator, grid synchronization of wind generator and wind speed variations is a new contribution to the earlier studies. The reported literature only focusses on the disturbances due to the design constraints of the converter and wind generator where wind generator operation part is missing which has been addressed in this study.

This paper is divided into five sections. Section "Proposed power quality improvement strategy and test system" describes the proposed PQ improvement strategy, IEEE-13 bus test system, wind generator, DSTATCOM topology utilized for the study and control algorithm used for the control of DSTATCOM. The important mathematical design considerations of the proposed system have also been described in the Section "Proposed power quality improvement strategy and test system". The simulation results and their discussions are presented in Section "Simula tion results and discussion". The real time validation of simulation results utilizing the RTDS is presented in the Section "Real time validation of results". Finally, the conclusions are drawn in the Section "Conclusion".

Proposed power quality improvement strategy and test system

This section details the proposed strategy for mitigation of power quality disturbances in the distribution system caused due to grid disturbances, wind generator operations and wind speed variations. The test system utilized for the study, DSTATCOM topology and design of parameters, control technique used for the control of DSTATCOM and proposed strategy have been detailed in the following subsections.

Test system

This subsection describes the proposed test system and wind generator utilized for the study.

IEEE 13 bus test feeder

The proposed study is carried out using a modified IEEE 13 bus test system. The original system is a 60 Hz, 5 MVA radial distribution feeder with voltage levels of 4.16 kV and 0.48 kV feeding balanced and unbalanced loads [19]. The original test feeder is modified to incorporate the DSTATCOM with battery energy storage system (BESS) and wind generator as shown in Fig. 1. In the proposed study DSTATCOM is connected at bus 632 and wind generator is connected at bus 680 through a transformer (XWG). In Indian power system, the renewable energy (RE) sources are installed at remote locations situated far away from the load centres where land is easily available and connected to the transmission network through local network developed for the RE sources. Therefore, we have selected bus 680 for wind connection and bus 632 near grid integration point for installation of DSTATCOM. The feeder and load characteristics are provided in Tables 1 and 2 respectively. The feeder is connected to the utility grid via a substation transformer. The transformer connected between the nodes 633 and 634 is XFM-1. Transformer characteristics are given in Table 3. The voltage regulator between nodes 650 and 632 is realized by on load tap changer (OLTC) transformer.

All the system feeders are three phase with three phase balanced loads where considered. The aerial feeders use configuration 601 with phase conductor type 556, 500, 26/7 ACSR and

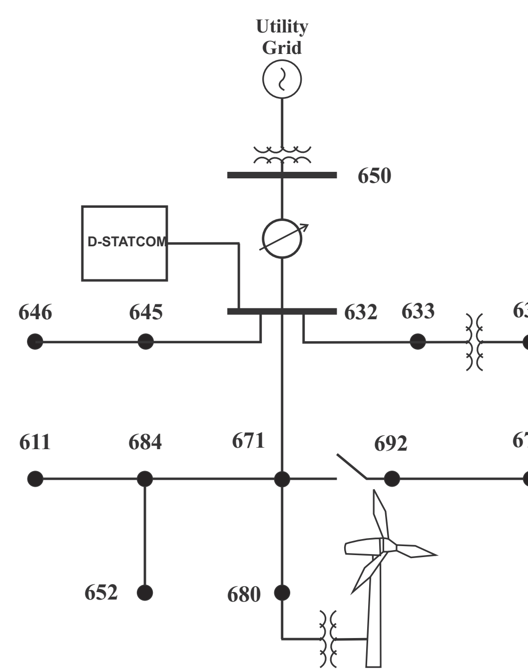

Fig. 1. Modified IEEE 13 bus test system.

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