Abstract

Renewable Energy Sources have been noted as a viable solution for sustainable development of global energy systems with growing concerns like environmental pollution, energy crisis, etc. Wind Energy (WE) is considered as one of the world's fastest developing green energy sources. Together with custom power devices, the WE promises a quantum improvement in expense, performance capability, quality power, and reliability. However, the Power Quality (PQ) deterioration associated with the system operation, especially with the rural (weak) grid, is significant due to the inconsistency of wind speeds, low Short Circuit Ratio (SCR), presence of non-linear loads and limitations of the Doubly Fed Induction Generator (DFIG). Thus, the wind energy penetration levels are limited unless mitigated by fast and effective methods by utilizing suitable Flexible AC Transmission System (FACTS) devices in association with modern control techniques capable of accurate tracking and adaptiveness (with the changes in the system). The proposed work aims to enhance rural WE penetration levels by employing an additional Distribution Static Compensator (DSTATCOM) infrastructure controlled by adaptive control techniques.

The reactive power support needed for DFIG based wind energy systems is generally provided by the built-in converter. The rural (weak) grid and the presence of non-linear loads demand large and fast reactive power compensation, which is not generally met by a built-in converter unless the design of the converter is tailor-made. Higher levels of WE penetration would further pose challenges in terms of PQ. Hence, PQ mitigation plays a critical role in enhancing WE penetration in the scenario of rural grid, presence of NL and unbalanced loads. An additional DSTATCOM infrastructure at Point of Common Coupling (PCC) is suggested in the literature to mitigate the PQ in the above scenario. A control algorithm that drives the DSTATCOM is also equally important, whose parameters can be tuned as per the changes in system parameters.

Various control algorithms employed for the control of DSTATCOM can be broadly classified as conventional (PLL based) and adaptive algorithms. The phase-locked loop (PLL) based schemes are applied for obtaining the phase and frequency of the voltage at the PCC as these methods work well under the stiff grid and linear load conditions. However, these algorithms face instability issues in case of weak grid penetration and the presence of non-linear loads due to negative resistance. The other limitations associated with these control methods include computational complexity, inaccuracy in power tracking and oscillations in DC-link voltage. Modifications /and additions have been suggested in the literature to improve the performance of these control algorithms, which could not yield satisfactory performance. Hence, the researchers have started exploring the capabilities of adaptive control algorithms to tackle these challenges and thereby enhancing WE penetration. A lot of research work has been reported in the literature targeting the enhancement of WE penetration with the help of different case studies. However, these case studies are found to address the individual challenges associated with low SCR, presence of NL loads, load unbalancing, etc.

The proposed research work is aimed to address the challenges associated with wind energy penetration in weak ac grid in the combined scenarios of variation in wind speed and presence of NL loads with the help of an additional DSTATCOM infrastructure controlled by various adaptive algorithms, namely, ADALINE-LMS algorithm, Least Mean Fourth algorithm and Delayed Least Mean Fourth algorithm. This is illustrated by PQ mitigation in the event of unbalanced load. The system configuration used for these case studies is a DFIG based wind energy system connected to

a weak grid with an additional DSTATCOM in the presence of NL loads at PCC.

The wind energy penetration levels achieved in a rural grid under variations of various parameters such as SCR, wind speed and load composition at PCC for different adaptive control algorithms have been detailed as follows:

1. **ADALINE-LMS Control Algorithm:**
    - Variations of SCR: 7 to 2.74
    - Wind speed variations: 15 m/s to 7.5 m/s
    - Load composition at PCC: 25% NL and 75% Linear
    - Penetration levels achieved: 25%
    - Reduction in DSTATCOM capacity: 70%
2. **Least Mean Fourth Algorithm:**
    - Variations of SCR: 7 to 2.74
    - Wind speed variations: 15 m/s to 7.5 m/s
    - Load composition at PCC: 40% NL and 60% Linear
    - Penetration levels achieved: 25%
    - Reduction in DSTATCOM capacity: 80%
3. **Delayed Least Mean Fourth Algorithm:**
    - Variations of SCR: 7 to 2.74
    - Wind speed variations: 15 m/s to 7.5 m/s
    - Load composition at PCC: 40% NL and 60% Linear
    - Penetration levels achieved: 30%
    - Reduction in DSTATCOM capacity: 85%

These achievements have been verified with simulation in MATLAB environment, followed by experimental investigations complying with international EN-50160 and IEEE 519-2014 PQ standards.