Optimal Penetration of Combined Wind DG and VAR Compensation for Voltage Stability Improvement

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Wind energy is one of the fastest growing and most promising renewable energy resources and this is the reason for its recent surge in capacity, installation and usage. This capacity is estimated to increase from 60W in 2012 to 87W in 2040 [1]. Wind energy is a type of clean energy that addresses global warming, ameliorates environmental pollution, enhances system reliability and efficiency, improves power quality and reduces power loss and rapid depletion of other conventional energy resources [2]. Despite the several advantages of wind energy, its intermittent nature is a major drawback due to its impact on the grid operation, security, and market economics. Utilities are seeking to understand possible impacts on system operations when wind turbines are introduced into the electric power system. Maintaining voltage stability is a key criteria to achieve a successful integration of wind Distributed Generations (DGs) into distribution network that needs to be addressed and analyzed [3]. The level of voltage stability/instability depends, amongst other factors, on the penetration factor of wind generations and on their connected locations [4]. Therefore, it becomes imperative to determine the optimal penetration level of wind DGs when integrated into a weak power grid. It is worth noting that The penetration factor is defined as a ratio of the DG active power injected to the total active power load of the network. In the literature, different methods have been considered and applied for sizing DG to improve voltage stability [5].- [8] For instance, the work in [5] presents a method to size wind DG to improve voltage profile considering self VAR control. Authors in [6] proposed a method of locating and sizing DG units with an objective function to improve the voltage stability margin considering the uncertain nature of renewable DGs. In [7], An improved nondominated sorting genetic algorithm is proposed for optimal sizing of multiple distributed generation (DG) units with multiobjective functions that take minimum line loss, minimum voltage deviation, and maximal voltage stability margin into consideration. The work in [8], presents a novel chaotic symbiotic organisms search (CSOS) algorithm for determining the optimal location and sizes of real power DGs for loss minimization and voltage stability improvement

In the context of DG sizing applications for voltage stability enhancement, limited work can be found in the literature, mainly considering the impact of capacity factor variation due to wind uncertainty on voltage profile when wind DG is integrated to a weak distribution network. Thus, forecasting the hourly variation of wind DG capacity factor (CF) is crucial in capturing the impact of wind variation on voltage profile. The capacity factor of wind DG is defined as the ratio of average delivered power to the maximum rated power. In this paper, an optimization algorithm is developed to determine the optimal penetration level of aggregated wind DG, as well as the required reactive power (VAR) compensation to minimize total investment cost and improve voltage stability. The investment cost includes the capital costs of wind DG and the reactive power compensation, respectively. The impact of wind intermittency has been considered in the model development by accounting it into forecasting. A probabilistic technique has been employed for forecasting the produced average power of the integrated wind DG. Bus voltage profile is obtained from running a power flow program of the test system (IEEE 5-Bus system), while the optimization problem is formulated as a mixed integer linear programming (MILP) problem. One year wind speed date is divided into 24 states in the planning formulation. In the probabilistic forecasting, the continuous probability density function (pdf) has been divided into 24 states, in each of which the wind speed is within specific limits and the step is adjusted to be 1 m/s.

Results are obtained for two different reactive compensation techniques namely, capacitor bank, and static synchronous compensator (STATCOM). Both optimal solutions have maintained the voltage profile within the acceptable limit (0.95pu<V<1.05 pu). Obtained results are summarized in Table I. Fig 1 shows the impact of the capacity factor variation due to wind speed variability on the voltage profile of the connected bus. It was found that 5% DG penetration factor (9.15 MW) is the optimal solution when capacitor bank technique is adopted for compensation. On other hand, a higher penetration factor of 10% (18.3 MW) is found to be the optimal solution when more expensive compensation techniques (STATCOM) is used for compensation. Results are plotted for both optimal penetration factor cases of 5% and 10%. Where, PF is the penetration factor, and CF is the capacity factor.

In conclusion, the proposed model determines optimal trade-off between DG capital cost and compensation cost to obtain optimal solution. This result advocates that the optimal penetration level of the installed wind DG to enhance voltage profile is greatly affected by the selected compensation devise and its associated capital cost.

TABLE I. OPTIMAL RESULTS FOR DIFFERENT COMPENSATION TECHNIQUES

Compensation Method	Optimal penetration factor	Approx. Number of turbines	Annual Compensation in MVAR	Total Annual Cost
Capacitor Bank	5% (9.15 MW)	6	512.34	$ 919,002
STATCOM	10% (18.3 MW)	12	409.82	$ 2,452,598

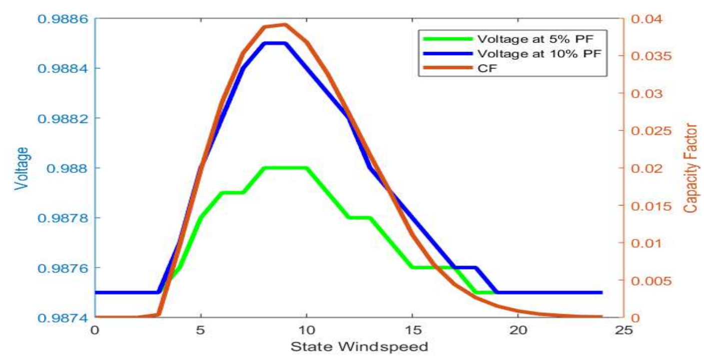

Fig.1 Impact of capacity factor variation on the voltage profile of the connected bus

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