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Original article

Mitigation strategies to minimize potential technical challenges of renewable energy integration

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ABSTRACT

A recent issue of increasing public focus is the need for robust, sustainable and climate friendly power systems that are intelligent, reliable and green. The intermittent nature of renewable energy generation and the associated power electronic inverters creates a number of potential challenges in integrating large-scale renewable energy (RE) into the grid that affects power quality of the distribution network. Therefore, this study initially, investigates the potential technical impacts in particular voltage regulation, active and reactive power variations, transformer loading and current and voltage harmonics causes with RE integration. Then, to reduce the level of impacts observed, STATCOM and energy storage system (both optimised) were integrated into the network that ensures a smooth power supply to the customers. As a case study, the Berserker Street Feeder, Frenchville Substation under Rockhampton distribution network, Central Queensland, Australia has been considered. Similar analyses also carried out with the IEEE 13 bus network to investigate the potential technical challenges of RE integration and identify suitable mitigation measures. Results shows that integration of both optimised STATCOM and energy storage enhances the overall power quality of the power network as it improves voltage regulation, power distribution, and transformer utilisation and reduce total harmonic distortion of the power network.

Introduction

In general, power flows from the upstream network (the transmission network) to the downstream network (the distribution or low voltage network). Integration of renewable energy (RE) causes reverse power flows, i.e., feeding back into the grid as they are generally connected near the load centre, if the power generation from these systems is greater than the load in the local network. Therefore, RE integration introduces bi-directional power flows across distribution transformer (DT) and hence distribution network (DN) experiences with several potential problems that includes voltage variation, over loading of DT, poor power factor and harmonics injection in the DN which detracts the overall power quality (PQ) of the network [1,2].

The intermittent nature of power output from renewable energy sources, in particular wind and solar, introduces potential technical challenges that affect quality of power observed including voltage fluctuation, frequency fluctuation, power system transients and harmonics, system blackouts, reactive power, low power factor, switching of electrical equipments, synchronisation problem, storage system, load management and forecasting and scheduling. Large scale RE integration in the DN causes voltage rise within the network and this voltage rise is significant in case of single phase PV system connections. The receiving end (customer premises) voltage may drop if RE is unable to support customer load demand, especially during peak demand periods [1–4]. Moreover, the intermittent nature of RE causes uneven generation and hence might exceed the capacity of the connected transformer. Integration of RE also causes phase unbalanced conditions in the network due to uneven connection of RE source into different phases. The operation of the distribution network involves reactive power due to customer loads, line impedances and RE sources, in particular induction generators used in wind turbines which are unreliable for the smooth operation of the network [5,6]. Inverters connected with RE sources, non-linear customer loads and power electronics devices introduce harmonics in the distribution network that causes overheating of transformers, tripping of circuit breakers, and reduces the life of connected equipment [6].

Significant research and development works are undertaken by various agencies throughout the world to investigate and mitigate the observed potential technical challenges to ensure reliable and uninterrupted power supply to the consumers. Albarracin and Amaris [6]

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investigated a voltage fluctuation model used for the evaluation of flicker assessment under sunny and cloudy conditions with photovoltaic energy sources. Results showed that irregular solar irradiation caused by cloud movement produced voltage and power fluctuations. The Gardner MA PV project [8] explores four areas: the effect on the system in steady state and during slow and cloud transients; responses of concentrated PV under fast transients; harmonic effects on the PV system; and the overall performance of distribution system, in which the total impact of high penetration of PV was evaluated. Results showed that 37% penetration of PV at Gardner was achieved without any significant problems. Asano et. al. [9], analysed the impact of high penetration of PV on grid frequency regulation which responds to short-term irradiance transients due to clouds. It was shown that break-even cost of PV is unacceptably high unless PV penetration reaches 10% or higher. Therefore, PV integration needs to be increased and impacts to be identified and mitigated. A comprehensive study was carried out by Fekete et al. [10] that analysed the harmonic impacts in both winter and summer seasons with 10 kW PV penetration on the distribution network. Recent studies by Ergon Energy, and Chant et al. [11] have explored the issues involved with small-scale PV penetration in urban networks. It was found that increased penetration exhibited increased voltage rise on LV networks, increased harmonic distortion and, as a result, load rejection occurs. The impacts of wind power on the power system, in particular voltage stability, power system stability and PQ characteristics were investigated by Pedro Rosas [12] using dynamic simulation. Results shows that wind turbine technologies with power converters can actively control the reactive power consumption which increased the voltage stability of the power system.

Appropriate design of electrical circuits with control systems can mitigate voltage fluctuations and harmonic distortion, provide reactive power compensation and power factor improvements and thus ensure PQ improvements of the power system. Customised power devices such as SVCs, STATCOMs, DVRs, thyristor controlled series compensators (TCSCs), static synchronous series compensators (SSSCs) and a combination of series and shunt active power filters are the latest developments of interfacing devices between grids and consumer appliances that overcome voltage and current disturbances and improve the PQ by compensating the reactive and harmonic power [13]. A STATCOM is the best performing device for reducing voltage fluctuations and harmonics as well as improving the PQ of the power network compared to other flexible AC transmission system (FACTS) devices. STATCOMs are faster, smaller and have better performance at low-voltage conditions, though the cost of STATCOMs is comparatively higher [14,15].

In order to enhance the terminal voltage quality, SVCs were used for reactive power compensation of wind power induction generators [16]. From simulation results, it was observed that the STATCOM can considerably improve the voltage profile at the PCC by regulating the reactive power of the grid during faults and maintaining an appropriate level of voltage sag on the grid and prevents the turbine from being disconnected from the grid during certain levels of voltage sag on the grid side [17]. A STATCOM based control mechanism is used to reduce the power quality problems as well as harmonics on integrating wind energy into the grid [15,18].

On the other hand, energy storage plays an important role in facilitating large-scale RE integration by supporting peak load demand and peak shaving, improving voltage stability and power quality. It also maintains constant grid power and reduces GHG emissions by maximising RE utilisation. Batteries are one of the most cost-effective energy storage technologies for power applications such as regulation, protection, spinning reserve and power factor correction [19]. Lead-acid and lithium-ion batteries are the renowned and effective storage technology today. Hybrid battery super capacitor energy storage systems are expected to be able to play a major role in power smoothing, power quality improvement and low voltage ride through in a wind energy conversion system [20].

From the literature, it is observed that most of the available research was carried out primarily in USA and Europe [5–7,9,10]. However, the distribution network characteristic of Australia is different compared to other developed countries in many forms and research conducted by other countries could not simply be adopted without further research in Australian context. For example, USA is a densely populated country with a population density of 32.86/km^2 and provide electricity to 323.1 million inhabitants as of 2016 [21]. On the other hand, Australia is very lightly populated country with a population density of 3.09/km^2 and provide electricity to 24.21 million inhabitants as of 2016 [22]. The total geographical area of USA and Australia are 9.525 million km^2 and 7.692 million km^2 respectively. USA's population is 13 times more than the Australian population though geographic area of USA is only 1.24 times larger than the Australia [23]. Therefore, USA's transmission and distribution network may comparatively larger but not disperse like Australia. Therefore, electricity costs are more than double in Australia compare to USA. Moreover, 1-phase and 3-phase nominal voltage at the rear end of the distribution network are 240 V and 415 V with line frequency of 50 Hz in Australia while 120 V and 208 V with line frequency of 60 Hz in USA respectively. On the other hand, higher end distribution voltages in Australia are 66 kV, 22 kV and 11 kV while in USA 69 kV, 13 kV and 4 kV.

Recently authors [24] conducted an experimental and simulation study to investigate the technical adverse impacts with PV penetration into the Australian low voltage distribution network and identify possible mitigation measures using FACTS devices. From both the experimental and simulation analyses it can be evident that the major impacts observed on integrating PV into the LV networks are: voltage fluctuations and harmonics injection that reduces the overall PQ of the power systems network. Study also proves that the use of FACTS devices reduces the level of potential adverse impacts in the LV network.

Therefore, this study aiming to develop a model that investigates the potential technical challenges with the higher renewable energy integration into the distribution network using power system simulator PSS SINCAL [25]. In addition to the Berserker Street Feeder (Frenchville Substation, Rockhampton, Australia), IEEE 13 Bus network was also selected as suitable network for investigation of large-scale deployment of RE into the grid. By increasing PV/wind integration into the network, the points at which distributed generation starts to have an impact on utility grid operations has investigated with regards to network performance standards. Worst-case scenarios were identified and measures were taken to reduce the level of adverse potential impacts.

Power quality problems

With increased penetration of RE to the grid, the key potential technical challenges that affect quality of power observed include: voltage fluctuation, active and reactive power, power factor and voltage and current harmonic.

Voltage fluctuation

Voltage fluctuation or instability as well as overvoltage/undervoltage, voltage sags/dips, noise, surges/spikes and power outages are the common problems encountered during integration of large-scale RE into the grid. Voltage regulation is the degree of control or stability of the rms voltage at the load which is mostly dependent on input-voltage changes, load changes due to line impedances and currents [3,26].

In general power is taken from the substation to all loads on the system and hence the voltage will always drop on the primary feeder as the distance from the substation increases. Distributed Generation (DG) increases the voltages on the distribution network because of reverse power flows. Effect of generators can be measured by using the standard voltage drop equations with reverse power flow. The voltage drops along a feeder due to a load is approximately equal to Eq. (1).