Power Quality Analysis of Electrical Distribution Systems with Renewable Energy Sources

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Abstract: ***Renewable energy sources are promising solutions to cater the energy demand. In this context, research works have been reported by focusing on various aspects of renewable energy sources, for their successful integration into the Electrical Distribution Systems (EDS). Among various renewable energy sources, wind and solar photovoltaic (SPV) units have assumed more prominence. However, in such systems, Power Quality (PQ) problems are encountered during the operation of a EDS. Such problems in a wind unit are mainly due to the rapid output power variations (flicker) from wind turbines. The reasons for flicker are variations of wind speed, wind gust, wind turbulence, tower shadow and wind shear. Further, PQ problems are also probable in EDS with SPV, mainly with a fluctuating cloud affecting irradiation and hence the generation of power. In this context, studies on EDS with Distributed Generation are presented from Power Quality perspective. Suitable Power Quality Indices (PQIs) based on flicker and faults are defined. Two major parameters are considered to arrive at suitable control actions needed for monitoring and control of DGs. These parameters include PQ distortions due to environmental factors, such as change in wind speed and solar irradiations. The flickers produced are mitigated through Volt-VAr control mechanism implemented in MatLab. PQIs under different fault conditions on the EDS are also carried out, which are used further to estimate the performance of a system. A 17-bus test system is modeled using the open source software, Open Distribution System Simulator (OpenDSS). Smart converter control is realized through Volt-VAr control mechanism, so as to initiate proper grid-support functions.***

Keywords: Power Quality, Distributed Generation, Flicker, system faults, Voltage Dip Amplitude

1. Introduction

Distributed Generation Systems (DGs) are becoming promising option for effective generation of electrical power. As a result, renewable energy source based DGs, such as, solar and wind are being deployed for power sustenance. However, based on the performance of different DGs as per the various environmental operating conditions such as, solar irradiation, cell temperature, partial/ full shading and variation in wind speed, it is observed that high penetration of Solar Photovoltaic (SPV) and wind units can cause various Power Quality (PQ) disturbances [1-3].

In a system with wind turbines, flickers are produced by sudden change in wind speed. Modern Doubly Fed Induction Generator (DFIG) wind turbines equipped with Power Electronics (PE) converters have the ability to mitigate such flickers. Approaches to reduce the effect of flicker are, use of DFIG [4], installation of STATCOM for dispatching reactive power, integrating intelligent control functions with PE converter (volt-VAr) [5], reinforcement of distribution feeder and active power curtailment. Some of these techniques are not found to be cost-effective, For e.g. power curtailment is limited since the active power sent to the grid is reduced, with an economical impact. Similarly, the use of STACTOM or SVC would involve additional cost of accessories. However, the utilization of the capabilities of DFIG is widely preferred due to their inherent capability to control reactive power. Also, it is possible to integrate the capabilities of compensating devise within the converter itself by employing volt/VAr control mechanism, which helps in flicker-mitigation through reactive power dispatch. Similarly, flickers produced by the SPV systems from different scenario of solar radiations can also be addressed by employing smart converter control mechanisms such as Volt/VAr within the inverter [6-7].

In this article, a 17-bus test system is considered and modelled using Open Distribution System Simulator (OpenDSS). Algorithm for Volt-VAr control mechanism is implemented by using MatLab-OpenDSS Component Object Model (COM) interface. Flicker related PQ indices, Pst and Plt are obtained for base case and with Volt-VAr control strategy. The article also focuses on the performance of the system under short circuit faults, by finding the voltage dips, the most common PQ problem. The PQ Indices (PQIs) calculated based on voltage-dip magnitudes are useful to estimate the system performance [8-10]. The contents are presented in four sections next. Methodology adopted to mitigate flicker is discussed in section 2. Mathematical formulation of PQIs for voltage dips is discussed in section 3. The results are presented in section 4, with the section 5 summarizing the findings and observations.

2. Flicker Mitigation by Volt-VAr Technique

IEC 641000-4-15 is also referred to as the IEC flicker meter. The IEC flicker meter essentially processes the input voltage measurement at the node under study and outputs two main indices, notably, the short-term flicker severity (Pst) and the long-term flicker severity (Plt). These two main indices are derived statistically from the level of perceptible flicker over periods of 10 minute and 2 hour. The relative change in voltage at the point of measurement due to power fluctuations is given by [5]:

$$\Delta V = \frac{R_L \, \Delta P + X_L \, \Delta Q}{V_{PCC}} \qquad (1)$$

where,
ΔV= Change in voltage at the PCC
ΔP= Change in active power injection from wind turbine
ΔQ= Change in active reactive power injection from wind turbine
R_L= Distribution feeder-line resistance

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X_L= Distribution feeder-line reactance
V_{pcc}= voltage at PCC

Modeling of wind resource simulation in the study pertains to flicker emission, in this context, OpenDSS load objects are properly configured to simulate flickers due to stochastic variations of wind speed. As a consequence of the initiation of such control action, a Volt-VAr curve is shown in Fig. 2, that could be useful to regulate the voltage according to the requirement.

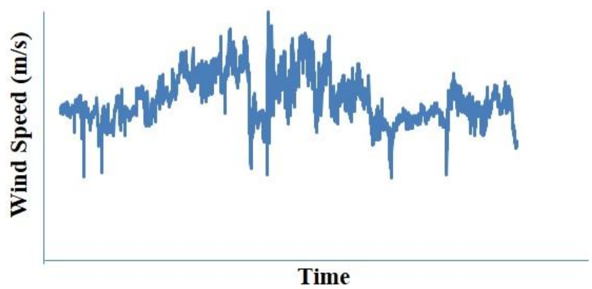

Figure 1: Typical wind variation pattern

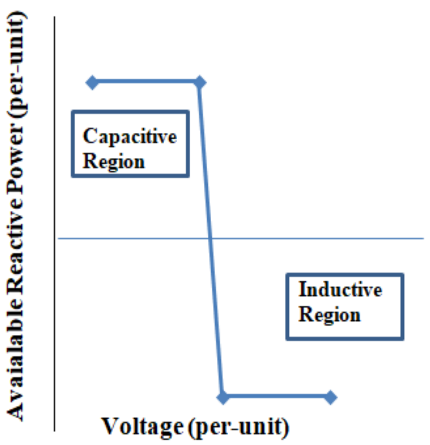

Figure 2: Typical Volt-VAr curve

3. Fault Studies

Different PQIs useful for quantification of distribution system behavior are reported in [8-9]. The rms variation of voltage related PQ attributes corresponding to either a single bus-i or for the whole system (S), can be characterized by an index, x, in terms of bus-voltages (V). In general, for a given n- bus system, the PQ index, xi, at the bus-i, when expressed in normalized form, in terms of the index values corresponding to the pre-installation and post -installation stages of DG, is given by:

$$xi= \frac{X_i - X_{i_{DG}}}{X_i} \quad \forall i=1 \text{ to } n \qquad (2)$$

where, this index can either be positive or negative, depending on the attribute considered. Accordingly, the various power quality indices considered for the proposed PQ assessment studies are defined [for xi of (1)] as per the following equations:

$$VDA95\_{V_i} = \frac{VDA - VDA_{DG}}{VDA} \times 100 \qquad (3)$$

$$SAVDA\_V = \frac{SAVDA - SAVDA_{DG}}{SAVDA} \times 100 \qquad (4)$$

where,
VDA= Voltage Dip Amplitude
SAVDA= System Voltage Dip Amplitude

Thus, the equations (3) give the site index relative to bus-i, whereas equations (4) give the system index corresponding to the complete system. The number 95 used in the PQ indices defined above refers to the 95^{th} percentile Cumulative Probability (CP) value of distribution, which is better than the maximum value, being less sensitive to spurious measurements [10]. The indices are calculated from data obtained through short circuit simulation of the test system.

4. Results and Discussions

An example distribution system including DGs, as shown in Fig. 3 is considered for analysis [11]. By using all the relevant data available in literature with respect to the selected system, the load flow analysis is carried out using the OpenDSS software tool. The results obtained are presented in this section.

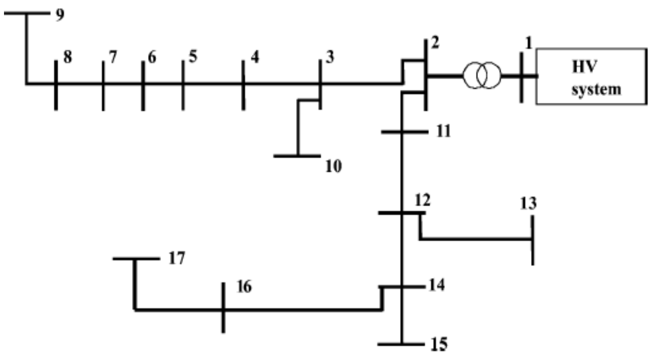

Figure 3: Sample test System

4.1 Flicker Mitigation

For the sample system considered, at bus 17, the highest PQ improvements are realized irrespective of the size of the DG [12]. In this context, bus 17 is considered as installation bus with DG capacity of 4.95 MW. Wind speed is simulated for 8460 (one day) points, each with a duration of 10 seconds using loadshape objects in OpenDSS. Variations in wind speed considered for study is shown in Fig. 4. Loads are modeled as constant impedance and does not contributes towards flicker. Reactive power is properly dispatched to reduce the effect of voltage flicker. This is done as per the Volt-VAR curve. This control function is embedded within the PE converter control strategies. As a consequence of the initiation of such control action, a Volt-VAr curve is shown in Fig. 5.

At the DG installation bus, voltage flickers are observed as shown in Fig. 6. As a consequence of control action, as per the Volt-VAr curve, the control action is realized to mitigate the effect of voltage flicker due to variations in wind power. Fig. 7 shows the voltage at installation bus after applying Volt-VAr control. It is observed that, the control strategy is successfully mitigating the voltage flicker, as the magnitude of the voltage during flickering is restoring near to 1 p. u. However, at some extreme cases, as evident from Fig. 4, the control action initiated is not able to regulate the voltage. This is observed at rare intervals, which is due to the power

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limitation capability of the inverter and wind flicker being very high. Further, flicker severity factors are obtained for the voltages in Fig. 4 and Fig. 5 as per IEC 641000-4-15 [12]. Table 1 gives the comparison of flicker severity factors calculated for sample values. The values reported in Table 1 are in close agreement with the IEC 61400-4 standard.

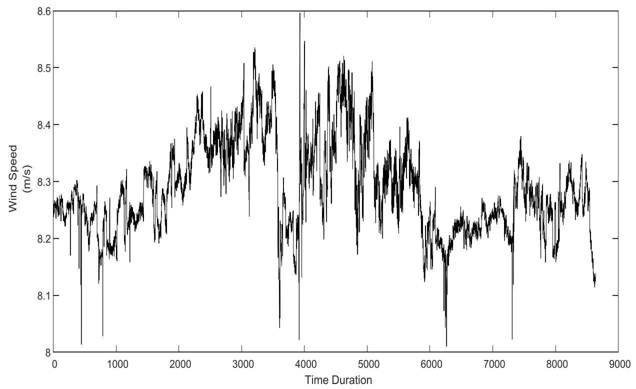

Figure 4: Typical wind variation pattern

Table 1: Flicker severity factors for different cases

Type of DG considered	*Flicker severity factor*	*Without Volt-VAr control*	*With Volt-VAr control*	*Emission levels specified (IEEE Guide) [13]*
Wind	Pst	0.38	0.32	0.35
	Plt	0.26	0.21	0.25
Solar	Pst	0.41	0.34	0.35
	Plt	0.29	0.26	0.25

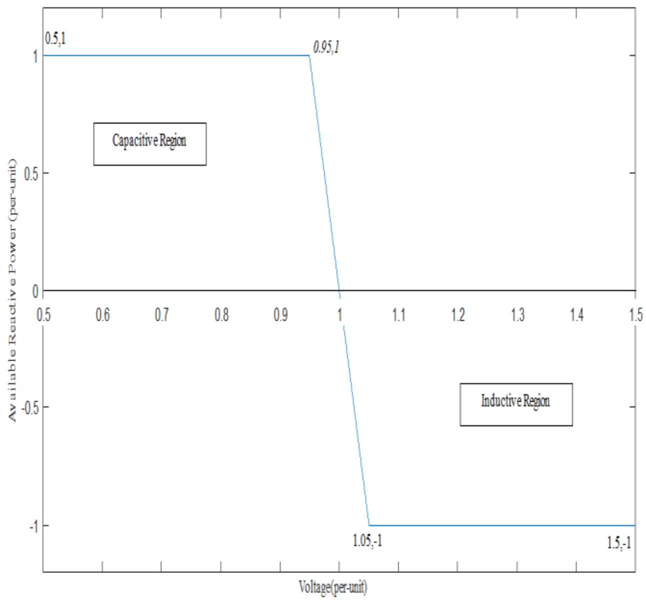

Figure 5: Typical Volt-VAr curve

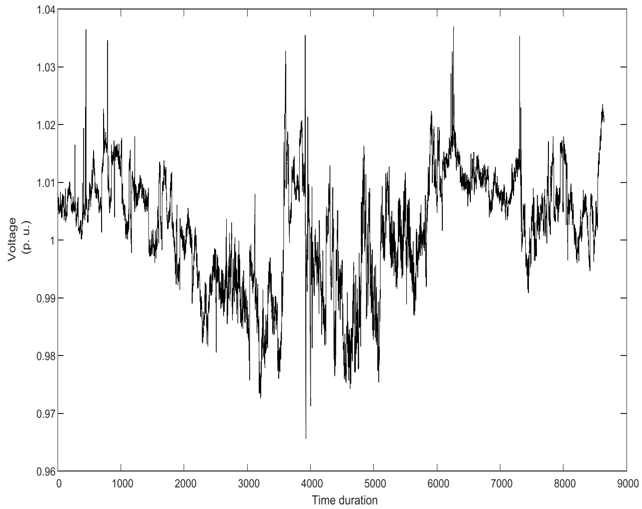

Figure 6: Voltage at bus-17 before control action

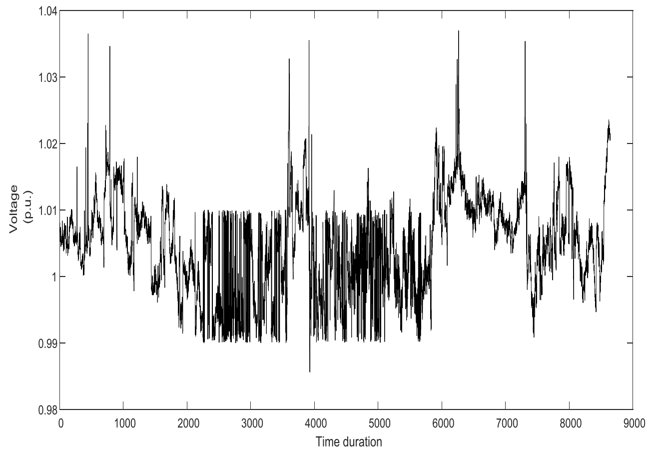

Figure 7: Voltage at bus-17 after control action

4.2 Voltage Dip Amplitude

Since the objective of the proposed work is to verify the behavior of the distribution network with DGs. Hence, the size and location of DGs are selected based on available literature corresponding to the selected 17-bus test system. Accordingly, the studies have been conducted by varying the installation buses as 9, 12 & 17 respectively and sizes of DGs as 1.65 MW, 3.3 MW and 4.95 MW. PQI w.r.t voltage dip variation is obtained as discussed in section 2.2. The contribution of DG is examined by performing fault studies on the distribution network. The DGs are modeled as an impedance. Fig. 8 shows the $VDA95_{\_V_i}$ given by (3) at each bus in the presence of 3.3 MW DG at 3 different installation locations. From the results obtained through Fig. 6, it is evident that with reference to voltage dip disturbances, overall improvement is observed during the presence of DG. All the values reported are negative, indicating a greater voltage availability during faults, in accordance with (3).

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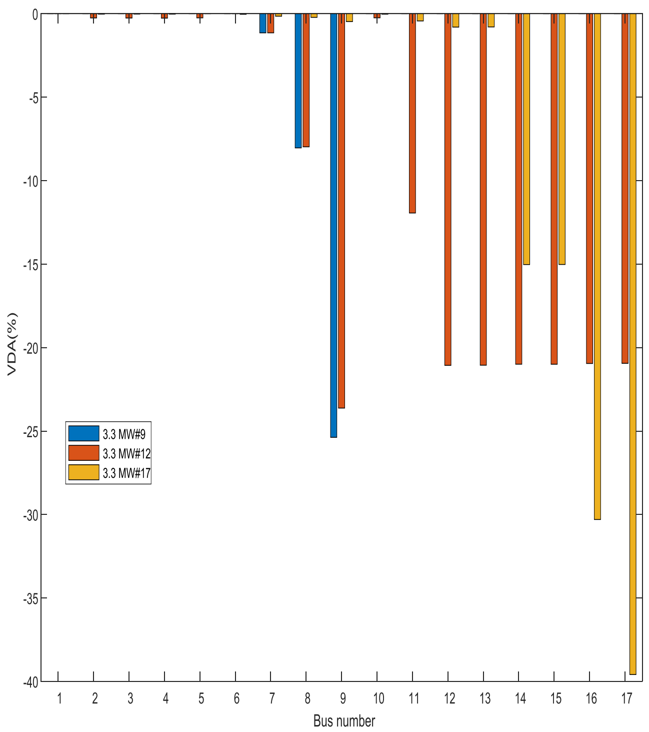

Figure 8: Voltage dip variation with 3.3 MW DG at 3 different locations.

5. Conclusions

In this paper, a given Electrical Distribution System is analyzed for power quality assessment through useful set of Power Quality Indices based on flicker and faults. This assessment helps in initiating suitable control actions so as to realize the better power quality operation of the EDS. In this context, the strategy to utilize the DFIG-PE converter to inject reactive power is useful in mitigating the effect of flicker. Further, the fault analysis on the selected system reveals that the installation of DGs provide PQ benefit in terms of improved voltage profile even under short circuit conditions.

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