IMPACT OF PHOTOVOLTAIC AND WIND ENERGY HYBRID SYSTEMS ON POWER QUALITY IN DISTRIBUTION NETWORK

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ABSTRACT — *Renewable energy resources present a high potential to fulfill the global increasing power demands. However, application of these sources will be fruitful provided their operation is in conjunction with one another, known as hybrid energy networks. Hybrid energy networks provide an inimitable solution to rapid load growth but, the unregulated use of these sources especially photovoltaic networks may cause many significant power quality issues in distributed networks. Power quality is a measure to ensure reliability in a power system. However, the current and voltage distortions caused by the nonlinear converters in photovoltaic systems, are the major cause of poor power quality and a question mark to the integrity of the world saving energy systems. This research work presents the harmonics analysis of a hybrid energy network composed of photovoltaic and wind energy systems. In this paper a hybrid system model to feed a distribution network is simulated and analyzed at different sections of distribution network to monitor power system nonlinearity as a remedial measure to achieve enhanced power quality and designing of efficient harmonic filter.*

Index Terms — Renewable energy, Hybrid energy networks, Photovoltaic, Power quality, Harmonics

I. INTRODUCTION

Electric power system is a network of electrical components which are used to generate, transmit and distribute electrical power. Power quality issues in electrical power system leads to multiple problems that cause power system disturbances. It refers to deterioration in voltage and current waveforms that might results in malfunctioning, inefficient working, or failure of equipment [1]. Power quality problem arises due to malfunctioning of electrical equipment. Main Causes of power quality deterioration are voltage sag, flicker, transients, and harmonics [2,3]. Ideally, the power system is designed to operate with pure sinusoidal wave [4], but most of the loads in the industry are non-linear and they draw non-sinusoidal currents, causing power quality deterioration [5, 6]. Current Harmonics are basically the cause of voltage harmonics [7]. Higher the frequency components drawn by the loads, greater will be the harmonics in the system. Greater harmonics deterioration corresponds to poor power quality [4]. Harmonics also depends upon the impedance of loads. Higher the impedance, higher will be distortion in current than voltage waveforms and vice versa.

Power quality or harmonics distortion must be confined to a permissible range in order to ensure the proper and efficient working of the equipment. Harmonics in the power system may cause unwanted effects. It causes premature tripping of breakers, increases the skin effect in cables, and increases the hysteresis and eddy current losses in transformer, motors and generators. It also causes issues in customer appliances. It can cause overheating and failure of sensitive devices. When harmonic frequency coincides with the natural frequency of the system then the phenomenon of resonance takes place and failure or overheating of device may occur.

In the past decade, advancement in technology has led to produce equipment that is adversely causing power quality deterioration. Incandescent bulbs are replaced by compact fluorescent lamp (CFL) energy savers which is a nonlinear load. Use of variable voltage drive (VVD), variable frequency drive (VFD), static synchronous compensators (STATCOM), switch mode power supplies in industry has also lead to increase in the power quality deterioration[2], [3]. Distributed generation (DG) or on-site generation is a process that refers to power production at the point of consumption. DG system is cost effective and power losses associated with transmission and distribution are less. Distributed generation provides low cost electricity and high power reliability because the system is independent. Distributed generation systems include photovoltaic (PV), wind turbines, small steam turbines and fuel cells. Smart Grids are becoming popular and distributed generation is one of key technologies in it.

Due to problems related to greenhouse effects, depletion of minerals, renewable energy is emerging as an alternative energy source. In the past few years, solar-wind hybrid distributed system has become popular and has taken the attention of energy providers. Solar-wind hybrid system can efficiently feed their loads when operating in normal conditions [8]. Wind generators come out of service when the thrust of air is not enough to drive the blades of the wind turbine. In order to ensure the continuous supply of energy, energy is stored in batteries and capacitors. They provide energy until the solar and wind return to their normal operating conditions [8]. Solar wind hybrid System involves the conversion of power from AC to DC for storing energy in batteries bank and for matching the frequency to the frequency of the system. The DC is again converted into the AC which is then fed to the loads in the distribution system. The inverter in the photovoltaic cell along with this storing mechanism introduces lots of harmonics in the system [2].

Power quality is deviation of voltage waveform from pure sinusoidal waveform. Thus all the concerns are related to the voltage waveform. Main causes of harmonics are described here. Voltage sag is a momentary power interruption that causes a decrease in RMS voltage from (0.1-0.9) per unit. Voltage sag may occur due to heavy load switching, fault in the system. Sag creates under-voltage conditions and these conditions if lasting for 4-5 cycles can cause adverse effects on customer equipment [9]. Currents in the distribution system depend upon load. In a weak distribution system turning on and off of heavy loads may cause large voltage fluctuations. The fast variation in voltage that occurs only for a few seconds is referred as flicker. Motors require large-in-rush current i.e. 5 to 6 times the normal rated current when they start, causing voltage dip for a few seconds. This voltage dip is actually the cause of flicker. Flickers lead to inconstant lights resulting in irritation to person. The critical flicker frequency (CFF) lies in the range 5 to 50 Hz and varies from individual to individual [10]. Residential customers near heavy industry may often experience the problem of flickering. Flickering can cause damage to sensitive electronic equipment. Computer equipment that requires stable voltage for their proper working is most affected by flickering. Flickers are caused by cyclo-convertors, static frequency convertors, electric arc furnaces, rolling mills drives and during motor starting. Situations in power system when instantaneous state changes lead to large amount of energy in system for very short interval of time are known as transients. Transients are actually the abrupt deviation from nominal sinusoidal wave. Transients can be impulsive or oscillatory [11]. Transients that drop below normal voltage are also known as sag. Transients that exceed normal voltage are known as spikes. Transients are caused by capacitor bank switch, tap changer, facility load switches, turning off the energized transmission lines. Transient's voltage range from hundreds of volts to thousands of volts. This large voltage can potentially damage the power system [12], [13].

PV system delivers variable energy to the system due to constantly changing solar irradiance. This inconsistent supply of energy often causes variation in power quality parameters [1]. High Total Harmonic Distortion (THD) and Total Demand Distortion (TDD) have been observed for off grid photovoltaic [14]. Integration of PV system to power system leads to technical problems associated with the stability of the system [15]. Integrating multiple PV sources along with the non-linear load can further increase the power quality distortion in the system [16]. Studies show that for meeting the standard requirements, photovoltaic generation must be equipped with 400kVAR reactive regulation capability [17]. Distortion levels can be sufficiently reduced by forcing the PV to operate at high loading level [4].

Focus of this research paper is on distributed generation because distributed generation is expected to be prominent in future.

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II. MODELING & SIMULATION TESTS ANALYSIS

A. Framework

Consider the single line diagram of the Hybrid power system as shown in Figure 1. There are two sources of power generation, one is from PV panel and second one is from Wind Generator. The power generation from each PV panel is 10.025KW, DC output is 308V (AC 0.4kV) [12] and from each wind generator power is 1.5 MW and output voltage is 0.69 KV, AC. The rating of wind transformers is 40 MVA and step up the voltage from 0.69 KV to 11 KV and then this output is connected with the Load Bay. Some quantity of power generated by PV panels is used for lightning purposes and the rest is sent to the input of PV transformer of rating 50 MVA which step up voltage from 0.4 to 11 KV and then its output is also connected to Load Bay.

Load-A of Load Bay is a network of loads that contains a step down transformer from 11 to 0.4 KV and then output is given to 12 induction machines. Load-B is also a network and consists of two lumped loads. Using the system data, comprehensive load modeling is performed in ETAP. ETAP is modern power system simulation software integrating standard and advanced models present for proper modeling and simulation of different power systems. ETAP is unique in providing wide variety of analysis including Load Flow, Short Circuit, Arc Flash, Harmonic and many more [18]. Our primary concern here is Harmonic Analysis. Harmonic Analysis is carried out on Load Bay, Bus PV, Bus DG including cables, Cable TPV1, Cable TPV2, Cable DG and Cable WG1.

PV array is manufactured by SUNTECH, it is mono-crystalline and has model STP180S-24/Adbt. PV array IV characteristics are given below.

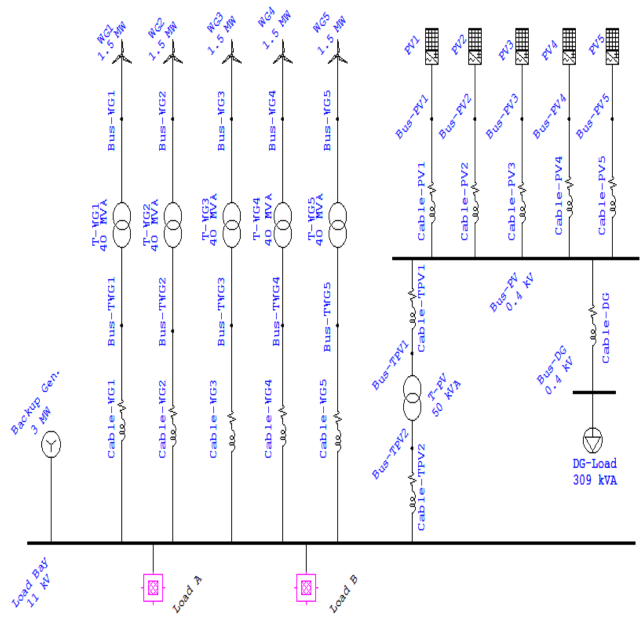

Fig.1. Single Line Diagram of Hybrid System

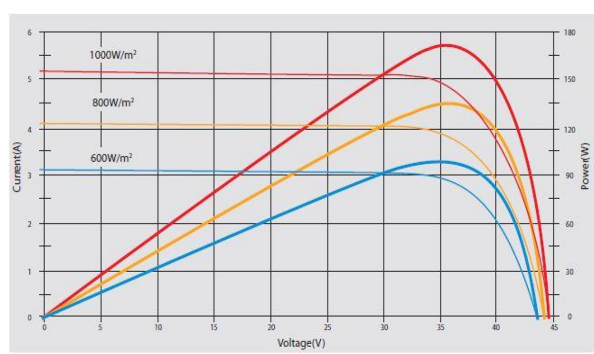

Fig. 2. Current Voltage and power Voltage curve [19]

It is important to know from power quality perspective how much notching is produced in the waveform by inverters. Harmonics generated by inverters are like Typical IEEE 12pulse2 library available in ETAP 12.0. Harmonic spectrum produced by inverter is shown in Figure 3 and corresponding waveform is shown in Figure 4**.**

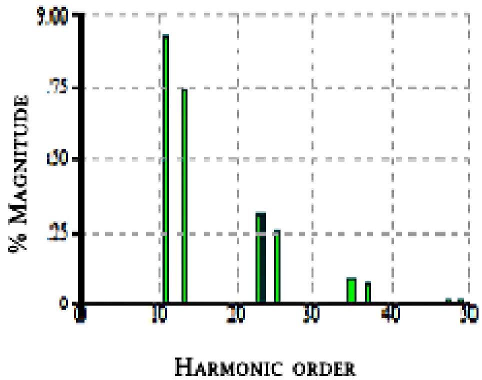

Fig. 3 Harmonic Spectrum of Inverter

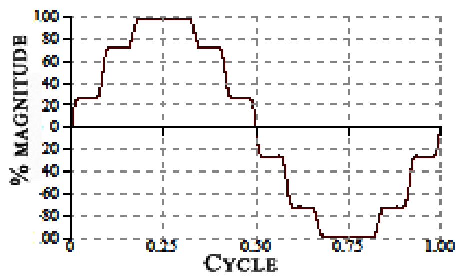

Fig. 4 Waveform produced by inverters

B. Harmonic Analysis

After performing the harmonic analysis of the system under consideration, specific busses and cables are inspected for their voltage waveform, current waveform and their corresponding harmonic spectrum.

Figure 1 shows model of the Power System that contains PV bus where the voltage waveform and corresponding harmonic spectrum is observed. The voltage waveform and harmonic spectrum at PV Bus is shown In Figure 5 and Figure 6. The harmonics produced by the inverter of the PV Array are travelling across the system and cause the voltage waveform to deviate from the normal sinusoidal behavior. The predominant harmonic component that causes the deterioration is 11^{th}, 13^{th} and 23^{rd}. PV Bus is most affected by the harmonics distortion produced by the PV Array Invertor.

The voltage waveform of the DG-Bus shown in the Figure 7 and Figure 8 tends to deviate from the sinusoidal behavior due to the presence of high frequency components.11^{th}, 13th and 23^{rd} harmonic component have high magnitude and contribute significantly in deteriorating the power quality.

The Voltage waveform and harmonics spectrum of the Load Bay is shown in the Figure 9 and Figure 10. The load bay is not much affected by the harmonics produced by the inverter. The magnitude of harmonic component with respect to their fundamental frequency is quite low so the waveform is almost sinusoidal. The harmonics components that are still present in the system are 11^{th} and 13^{th}.

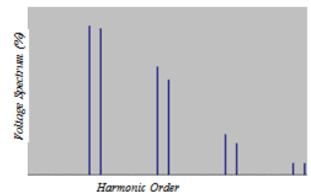

Fig. 5 Harmonic Spectrum at PV Bus

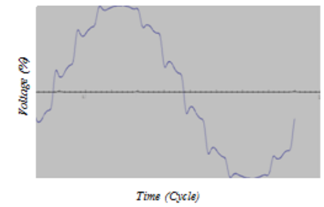

Fig. 6 Voltage Waveform at PV Bus

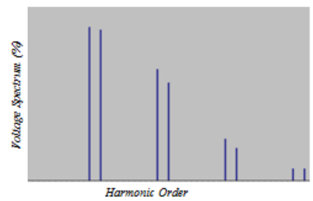

Fig. 7 Harmonic Spectrum of DG Bus

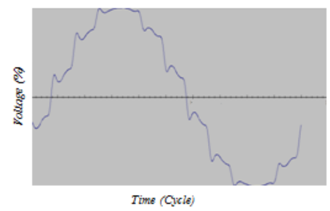

Fig. 8 Voltage Waveform of DG Bus

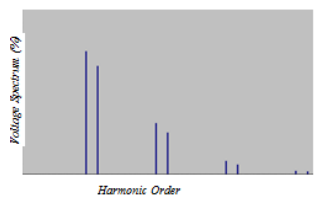

Fig. 9 Harmonic Spectrum of Load Bay

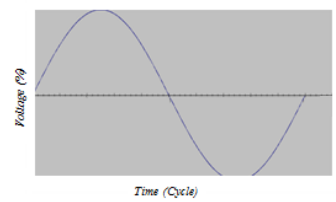

Fig. 10 Voltage Waveform of Load Bay

Fig. 5-10 Voltage **w**aveform with corresponding spectrum

Non-Linear Loads draws the non-sinusoidal current which causes current distortion. Deterioration in the current in turns causes voltage waveform distortion. As the non-sinusoidal current passes the impedance of the line, it produces the distortion in voltage waveform. Figure 11 and Figure 12 show the harmonics distortion in current inspected at DG-Cable.

Current Harmonics are much greater in the Power System as compared to Voltage Harmonics. DG-Cable is most affected by the harmonics distortion and exhibits poor power quality. The large deviation from the sinusoidal behavior is due to the strong harmonics produced by the PV-Array inverter. The current waveform at the PV cable has 11^{th} 15^{th} and 23^{rd} harmonic components

Figure 13 and Figure 14 show the current waveforms at TPV1. Current waveform at TPV-1 cable is significantly affected by the harmonics of the inverter. The 11^{th} and 13^{th} high frequency components majorly contribute in deteriorating the current waveform.

Figure 15 and Figure 16 show the current waveforms at Cable-TPV2. Current waveform at TPV2-Cable also exhibits deviation from sinusoidal waveform. The harmonic spectrum of the Cable-TPV2 shows that 11^{th} and 13^{th} harmonic component is also present in the system. The magnitude of these components is larger as compared to the components observed in Cable-TPV1 due to the non-linear nature of load.

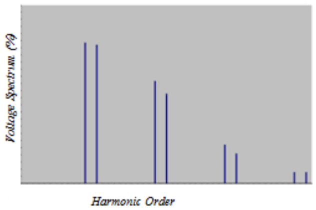

Fig. 11 Harmonic Spectrum at DG Cable

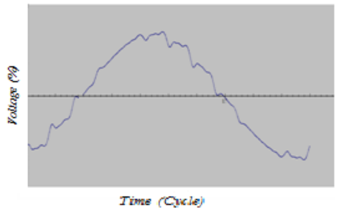

Fig. 12 Current Waveform of DG Cable

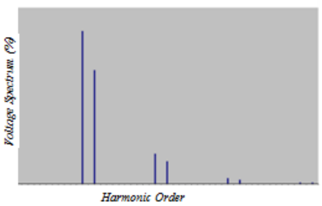

Fig. 13 Harmonic Spectrum of TPV1

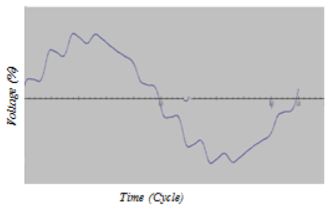

Fig. 14 Current Waveform of TPV1

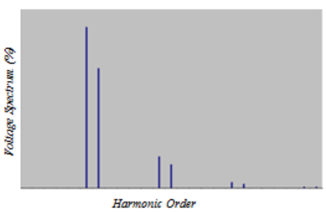

Fig. 15 Harmonic Spectrum of TPV2

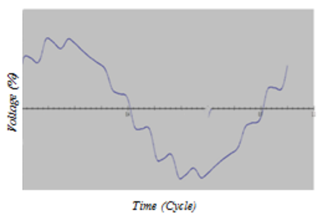

Fig. 16 Current Waveform of TPV2

Fig. 11-16 Current **w**aveform with corresponding spectrum

III. RESULTS AND DISCUSSION

The Power Quality has been the core issue from beginning in maintaining the quality assurance of the system. It has a great impact on every domain related to power system. PV Array produces harmonics that causes power quality deterioration. Poor power quality leads to poor power factor, increased current which in turns causes heating and abnormal behavior in appliances. Power quality problem can be significantly improved by using filters. Deterioration is caused *due to high frequency components, which can be suppressed* by using Single Tuned Filter. Single Tuned filter are highly used in industry to suppress harmonics because of its low cost and simplicity. Single Tuned Filter suppresses a single harmonic component. The Single Tuned Filter is a passive filter consisting of Resistor, Capacitor and Inductor. It is connected in parallel with the load offering a low impedance path to high frequency components.

The Simulation results in ETAP show dominant harmonic component which are 11^{th} and 13^{th}. They greatly affect the power quality. These harmonic components can be suppressed using Single Tuned Filter. Two Single Tuned Filters must be used each for 11^{th} and 13^{th} harmonic component respectively. These filters must be connected in parallel with the load.

IV. CONCLUSION

In this paper, power quality measurements are analyzed for photovoltaic and wind energy hybrid system in distributed generation. The results obtained are providing a wide range of information about non linearity in the form of individual and total harmonics distortion through distorted waveforms and spectrum visualizations. From the results, it is concluded that in distributed hybrid generation, there is high degree of uncertainty in power quality especially with respect to harmonics. It is also noted that such disfigurement in voltage and current waveforms even without taking into account the load characteristics, is not tolerable by any regulatory authority and requires remedial measurements.

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