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### **Impact of Renewable Energy Sources on Power Quality of Grid**

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#### **SUMMARY**

The aim of this paper is to share ERDA's experience on power quality issues of wind generating stations and solar power plants when they are in continuous mode of operation. The field measured values are compared with the emission limits set by international standards.

Today's modern and sensitive electronics demand a steady voltage and frequency. So, power quality parameters need to be monitored. These include voltage and current harmonics, sags and swells in voltage, DC current injection, and flicker. This paper focuses on measurement of voltage and current harmonics and flicker.

This work is focused on field measurement as per standards and assessment of power quality parameters at the Point of Common Coupling (PCC). Three case studies for wind power plants and one case study for a solar plant are covered in this paper. Measurements were done as per IEC 61000-4-30:2008. The measurements were done during low and high wind season for the wind plants and during summer season for the solar plant. The results presented in this paper are only for high wind season and hot summers duration.

#### **KEYWORDS**

Flicker emission; voltage harmonics; current harmonics; point of common coupling; solar power plant; wind power plants

## I. INTRODUCTION

Electrical energy is a traded commodity that is becoming more important in day to day life. Today's power environment has increased renewable energy production to meet the continuously increasing electrical power demand to residential, commercial, and industrial sectors. This increases the requirement for continuous and reliable monitoring of the power consumed. Each disturbance that occurs reduces the quality of power. To fulfil power demands at the consumers end, renewable energy sources like solar and wind are installed. Power which is fed into the grid must be of acceptable quality to guarantee the correct behavior of the equipment connected to the power distribution system. Feeding power from renewable sources is creating technical issues due to power quality.

Wind generation is developing in the whole world. Wind turbines connected to grid may affect considerably the supplied power quality because of the fluctuating nature of their output power. The capability of the power system to absorb this perturbation is dependent on the fault level at the point of common coupling. In weak networks or in power systems with high wind generation penetration, the integration of these sources can be limited by the flicker level which must not exceed the standard limit.

Solar power plants also suffer from variable power flow due to the fluctuations of solar irradiance. Temperature fluctuations and selection of power semiconductor devices also affect the power quality parameters.

Central Electricity Authority (CEA) has framed regulations for the wind generating stations and generating stations using inverters.

- Harmonic current injections from generating station shall not exceed the limits as per IEEE Std. 519:2014
  - The generating station shall not introduce flicker beyond the limits specified in IEC 61000-3-7:2008
- CEA also mandates that measurement of parameters shall be done at least once in a year.

## II. UTILITY'S REQUIREMENT

Utilities have made mandatory for wind power generation developers to conduct PQM as per CEA guidelines and state utility guidelines (if applicable). The measured parameters should not exceed the standard limit [6].

Voltage level categorization and flicker evaluation is based on the requirement of the IEC standard IEC-61000-3-7:2008, providing reference for emission limits for fluctuating loads in medium and high voltage networks. For flicker measurement, the instrument used for measurement must measure and record the data for 10 minute cycles. Recorded data is analysed for flicker short term severity (Pst) and long term severity (Plt) on the basis of 10 min. for Pst and 120 min. for Plt, respectively. It must meet the requirements as mentioned in Table I.

Table I. Flicker Planning Levels for Medium voltage (MV) and High Voltage (HV) Networks [1].

Flicker Severity factor	Planning levels	
	MV	HV
Pst	0.9	0.8
Plt	0.7	0.6

As per IEEE-519, the minimum measurement period should be 7 days. However, shorter measurement periods might be needed for assessing emissions under specific conditions.

For current harmonic measurements, instruments must perform a Fast Fourier Transform of the current signal for window width of 10 cycles on 50 Hz systems [5]. The measured data is to be compared with the limits as in [6].

The paper presents the results of an experimental investigation of impact of renewable sources on power quality. The inverters were remain connected to grid during night time also. The voltage fluctuations

and harmonics generated by wind farms are analysed during continuous mode of operation and without the wind farm in operation. The steady state voltage variation at the point of common coupling due to the PV system connection is analysed for sunny days and also analysed during night time in order to get background power quality of grid. The PV system and wind farms are interfaced to main grid with the help of inverter which are injecting harmonics in the 50 Hz grid.

### III. POWER QUALITY SCENARIO IN RENEWABLE GENERATION-ERDA'S

In India, utilities are following CEA guidelines for power quality of wind generation plants. Some state utilities also have their own guidelines for conducting PQ (Power Quality) measurement which is in line with CEA guidelines. The power quality studies are most important for utilities, for ensuring the reliability of power supply to the consumer. Most of the wind plants are connected to 66 kV and 220 kV grids. The entry of these wind plants requires a study of the impact of disturbances produced by wind turbines in the network connection mode.

The detailed field measurements were carried out at three different wind farms in India. The generating capacity of wind plants are as follows.

Table II. Installed capacity of Wind Plants.

Wind Generation Plant details	
Wind Generating Plants	Installed capacity in MW
Wind Plant-1	119.7
Wind Plant-2	226.8
Wind Plant-3	159.5

### IV. WIND GENERATION PLANTS

Measurement was conducted at three different capacity generation plants as mentioned in Table II. Wind plants are located at different locations and plants are connected with the utility grid. Some of the wind plants are connected through a single feeder or double feeder. For PQ measurements, Class-A metering was used. Meters were connected at every feeder at the PCC. Meters are connected to the output of metering CTs & PTs. The measurement was carried out during low & high wind season in the months of December and July, respectively. As per the requirements of the utility and the wind farm developer, the measurement duration is 1 day at the time of low generation & 7 days measurement with full capacity generation to estimate the emission level of the power quality parameters.

Fig.1 shows typical wind generation plant single line diagram.

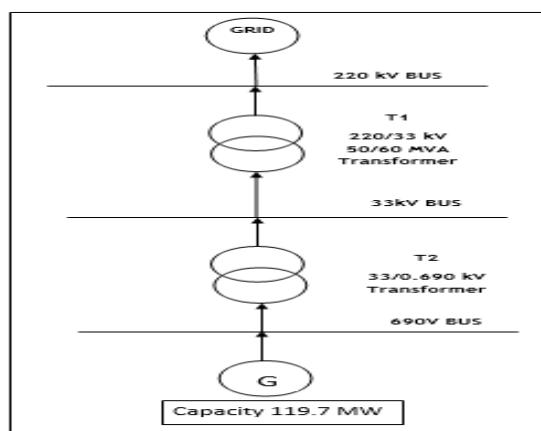


Fig. 1. Simplified Single line Electric Power Flow Diagram of Wind Plant Network.

**a. Flicker**

The standard [1] proposes that 95% probability values of Pst and Plt should not exceed the emission limits Epst and Eplt respectively.

Table III. Shows flicker injection at various power bins compared for different wind farms.

Table III. Comparison of maximum value of short term flicker with active power bins

Active Power bins	Maximum value of Short term Flicker Pst Monitored		
	Wind plant 1	Wind plant 2	Wind plant 3
10-50 %	0.18	0.55	0.67
50-75 %	1.23	1.23	1.00
75-100 %	6.79	1.48	1.88

It is observed from Table III that voltage fluctuations occurred maximum at 75-100 % power bins which in turn generates flicker. The flicker generated at such higher bins will cause major impact on system grid. It is obvious that at higher power generation, wind turbines are running with higher speed which may be nearest to cut-out speed. As soon as the wind turbines reaches the cut-out speed, it will stop generation by putting machines in the off state. This will generate a sag in the power generation, which will cause a change in the voltage of the grid as machines are interconnected with the grid.

Standards [1] & [4] suggest observing the flicker for a minimum period of 7 days. The results should lie within 95% percentile of limit value. For wind plant 1, 2 and 3, the short-term flicker severity results lies within 95 % percentile of limit.

**b. Voltage & Current Harmonics**

Harmonics are defined as current or voltage components with a frequency which is an integer multiple of the fundamental frequency i.e. 50Hz. The emissions have traditionally been dominated by odd frequency components.

The inverters used in wind farms converts DC current into AC in accordance with electrical characteristics of the grid to which they are connected. The standard [6] proposes the limits for the current harmonics as well as voltage harmonics.

The standard [6] proposes a limit for current demand distortion and this current demand distortion (ITDD) is as follows:

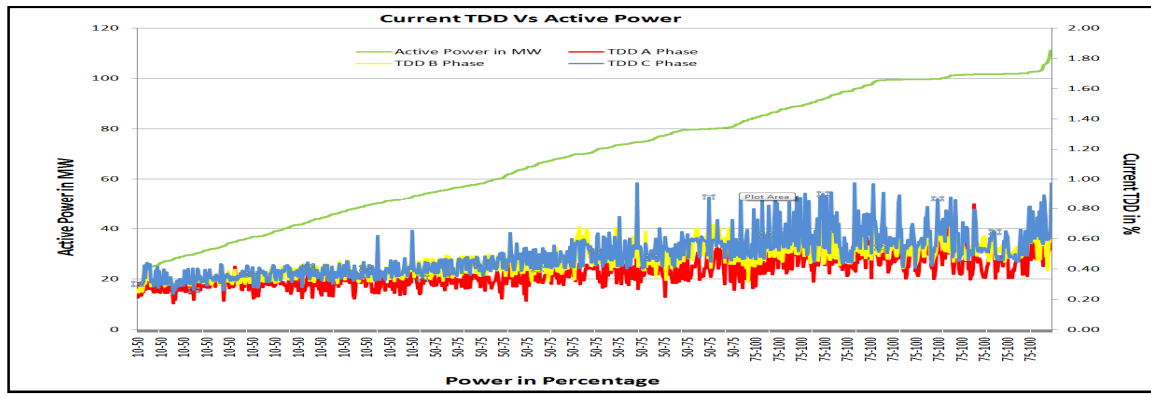
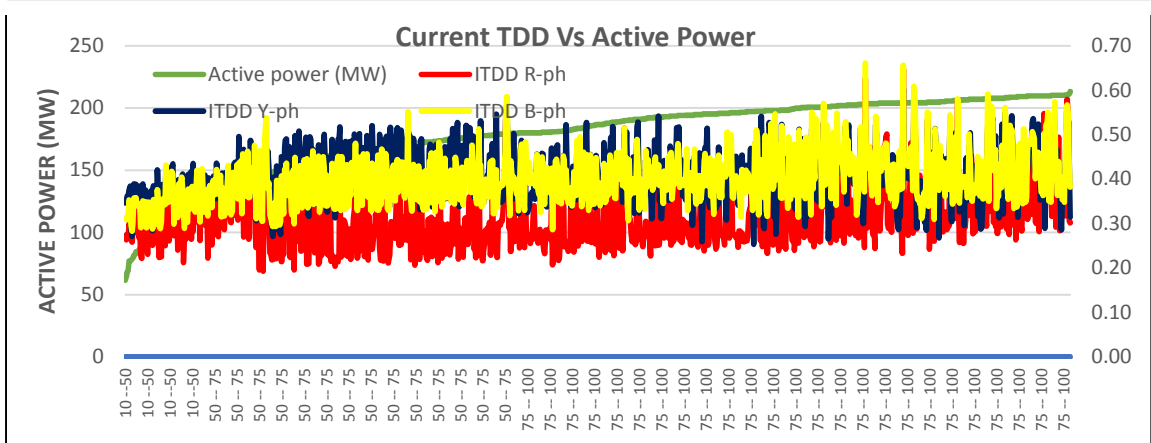
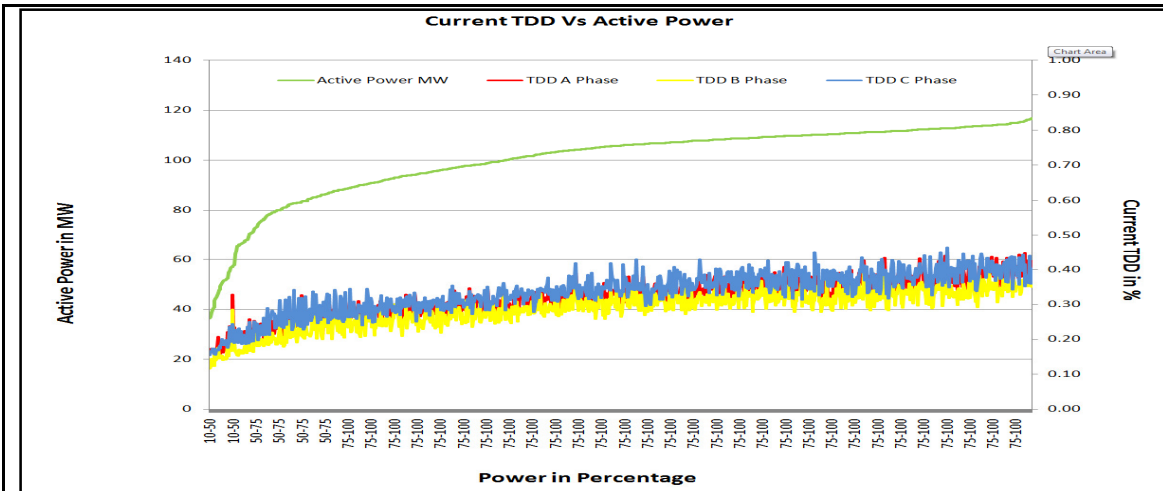
$$I_{TDD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \dots}}{I_L} \times 100\% \quad (1)$$

Where,

I2,I3,I4 are current harmonic orders

IL is the demand load current

The measured current harmonic distortion ITHD was then converted to current demand distortion ITDD by using Eq.(1). The limit set by Eq.(1) for every case is set as per standard.



Graph 1 shows the generation of current TDD with respect to active power bins for wind plant 1, 2 & 3.

From Graph 1, it is observed that the current demand distortion is increasing with an increase in generated power from wind turbine.

For wind plant 1, the maximum power generation observed is 115 MW. Whereas, the current demand distortion increases from 0.15 % to 0.55 %.

For wind plant 2, the maximum power generation observed is 68 MW. Whereas, the current demand distortion increases from 0.3 % to 0.5 %.

For wind plant 3, the maximum power generation observed is 111 MW. Whereas, current demand distortion increases from 0.25 % to 0.98 %.

It is observed that current demand distortion ITDD is below the limit. This shows that inverters used in the wind farm are as per the relevant standard and the current harmonics generated by these inverters are below acceptable limit.

## V. SOLAR PLANT

Photovoltaic converters are semiconductor devices that convert part of the incident solar radiation directly into electrical energy. The output of PV generation is affected by light illumination with the characteristic of instability and periodicity which cause voltage fluctuation and voltage flickering at grid.

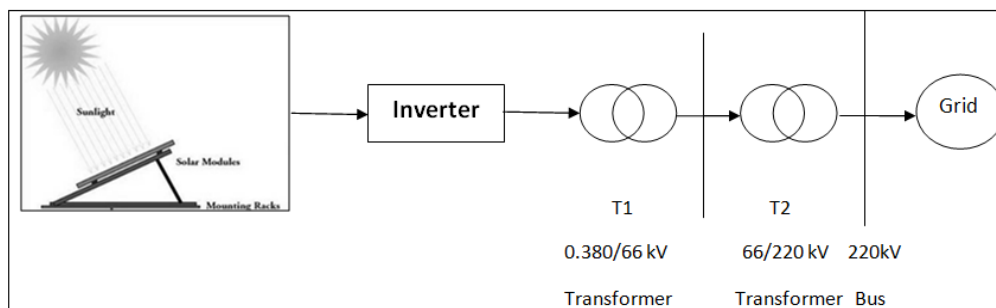


Fig. 2. Simplified Electric Diagram of Solar Network.

### a. Flicker

Table IV shows flicker injection at various power bins for solar plant.

Table IV. Comparison of maximum value of short-term flicker with active power bins

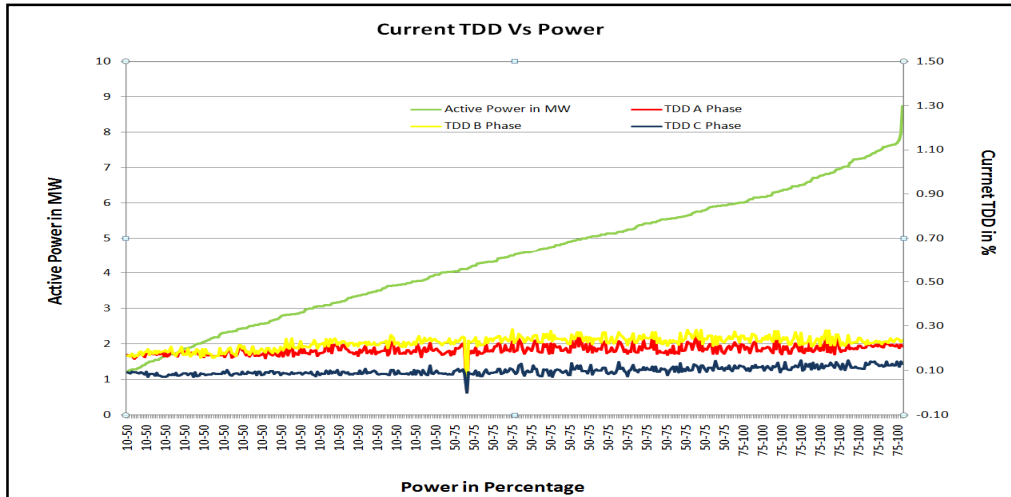
Active Power bins	Maximum value of Short-term Flicker Pst Monitored
10-50 %	0.50
50-75 %	0.55
75-100 %	0.62

It is observed from Table IV, that the flicker value remains almost constant at 0.55 between 10 to 100 % of Active power bins. The drop down of generation from its peak will not occur with the solar plant as it follows a bell curve. So, the generation of flicker at a solar plant is almost not possible. After comparing the 95th percentile data of flicker for the measurement duration of a week, it was observed that flicker values are within limits specified by [1].

### b. Voltage & Current Harmonics

The inverters used in solar plants contribute to harmonic generation. The inverter converts the DC voltage of the photovoltaic module into AC. The inverting action generates harmonics which will get added to the PCC. The study was carried out to identify the amount of current harmonics generated by the developers and their combined effect at the PCC.

Measuring instruments were connected at the 66 kV side of 66 kV /220 kV transformer for the period of one week to observe the combined effect of the inverters used in the solar park. The measurement was carried out during the peak summer period i.e. in the month of April. The generated harmonics with Active power bins are shown in Graph 2.



Graph 2. shows the generation of current TDD with respect to active power bins for Solar plant.

From Graph 2, it is observed that maximum generation of solar plant reached 8.75 MW. During analysis of active power bins, it is found that current demand distortion remains constant between 0.10 to 0.30 %. This value is below the acceptable limit which is 5 %. This shows that inverter used in the solar plant filters out the harmonics generation.

## VI. RESULTS & CONCLUSION

In this paper, power quality evaluation for three wind plants and a solar plant of renewable generators is discussed.

The voltage flicker due to output power variations for continuous operation of wind turbine at a wind plant is analysed. From case studies of the three different wind plants, it is seen that flicker generation varies with active power bins. The same is the case with current harmonics generation. The current demand distortion increases with increase in active power.

In the case of the solar plant, it was observed that flicker generation is almost constant regardless of the active power. The current demand distortion is in the range of 0.10 to 0.30% with increase in active power bins from 10 to 100 %.

In this study, it is found that wind plants and solar plants are meeting the requirements for flicker and harmonics as per CEA guidelines.

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