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Power Quality Issue in Grid Connected Hybrid System

Padkanthwar Priyanka[1] Prof. Mrs. S. N. Chaphekar[1]
[1]PES's modern college of engineering,
Dept. of Electrical Engineering Shivajinagar, Pune

Abstract: This paper includes analysis of power quality issue (harmonics) of the grid connected hybrid system at distribution level. Four power sources: wind power, solar power, battery storage and diesel engine generator which are connected to the utility grid with the help of circuit breaker. Total harmonic distortion is calculated at end of each source. Also by adding a little modification to the system, harmonics at grid side, micro grid side and both combined can be analysed. The result of this experiment revealed that the renewable energy sources are having higher percentage of harmonics as compared to grid side because of inverter. Also different power sources can be interconnected anywhere on the same power line, which makes system more flexible. Also phases and amplitude of ac output voltage were well synchronized in the proposed hybrid system. This hybrid system will motivate use of renewable energy in rural locations and on isolated islands without depending on any utility grid.

keywords: Power Quality, Solar power, Wind power, Battery storage and Diesel engine generator

INTRODUCTION:

Rural areas are situated away from power generating plant. To provide electricity to such areas is a challenge for the electric power system. It is highly capital intensive to build and maintain long distance transmission lines. Primary power grids deliver electricity from point of generation to the point of consumption via transmission network. Except primary power grids, there is a smaller, independent power grid called "Micro grid". The electrical energy is well utilized by various fields such as industrial, commercial, domestic customers, etc. Technology is developing in all the areas at a faster rate. Power scenario is changing a lot with the increase of size and capacity, power systems have become complex leading to reduced reliability. But, the development in electrical device and other appliances made them so sophisticated that they demands uninterrupted and conditioned power. To maintain the continuity and reliability of the supply, power quality is an important factor to be consider.

In simple words power quality (PQ) can be defined as, "Electrical network's or grid's ability to supply a clean and stable power supply".

A power quality problem can be defined as any deviation of frequency, magnitude, or purity from the ideal sinusoidal voltage waveform. Good power quality is beneficial to the operation of electrical equipment, but poor power quality will produce a great harm to the power system. However, the generated power from the wind energy conversion system is always fluctuating due to unpredictable nature of wind. Therefore injection of wind power into an electric grid affects the power quality. The important factors to be considered in power quality are the active power, reactive power, variation of voltage, flicker, harmonics and electrical behavior of switching operation .

1. Block Schematic Of Praposed Hybrid System

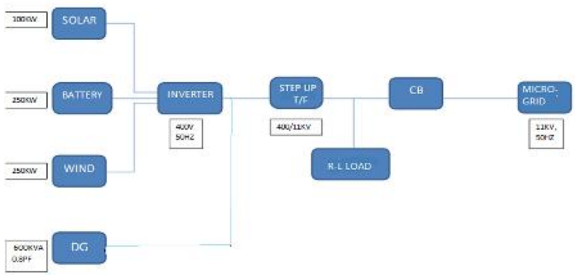

Fig 1. Praposed hybrid system

The Praposed hybrid system consist of four primary energy sources: wind energy system, solar photovoltaic system, battery storage system and diesel engine generator. The inverter voltage is controlled to synchronize them together. The AC output of the inverter is stepped up to 11kV using a three phase transformer. R-L load is connected in between the grid and micro grid. The battery

storage system uses the bi-direction inverter. At starting battery is at charged condition. The main aim to design solar photovoltaic system for 100kW, wind farm for 250kW. Battery storage system for 250kWh and diesel engine generator for 600KVA. 0.8 power factor. The output of the solar photovoltaic system, wind farm are in DC form, so they have to be converted in to AC to integrate with grid. if the renewable energy sources are not generating enough power then 11kV grid is provided for the emergency purpose.

1.1 Modelling Of Solar Photovoltaic System

Now a day, the photovoltaic system is being used frequently. Before studying the working of solar power plant, the equivalent circuit of PV cell should be discussed.

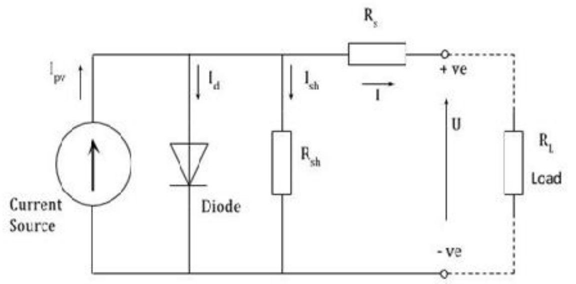

Fig. 2 Equivalent circuit of PVcell

The figure shown above is equivalent circuit of the PV cell. It consist of shunt and series resistance with diode in parallel. When solar cells are linked in parallel and/or series, the structure formed is SOLAR PANEL. If above structure is included with bypass diodes then it forms SOLAR MODULE. When solar modules are connected together in particular manner then it is called as SOLAR ARRAY. When number of solar panels are connected in series it forms SOLAR STRING. And Solar multi string is formed by connecting solar strings in parallel. The principle of solar power plant is quite simple. They consist of a field of solar photovoltaic modules connected them in series and parallel and connected to one or more inverters. Solar energy is directed transformed into electricity.

By using following specifications solar photovoltaic system is designed in software called MATLAB/SIMULINK.

1) Parallel strings=96
2) Series connected module/string=5
3) Module type= Sun Power SPR-305E-WHT-D
4) Voltage at max power point=54.7V
5) Cells per module=96
6) Maximum power=100kW
7) PWM switching frequency=5000Hz

1.2 Modelling Of Wind Farm

Wind is mainly formed due to the difference in temperature of earth's surface. The equator area of earth has high air pressure as compare to the poles. So the air flowing from the equator towards the poles is "Wind". This wind has mass and mass in motion has a momentum. Momentum is a form of energy that can be invested.

The output power of wind energy system is given by,

$P_{wind}=0.5\varrho AV^3{}_{wind}$……………………. (1)

Where, ϱ=air density in 'kg/m'.

A=area swept out by turbine blade in 'm'.

V=wind speed in 'm/s'.

It is impossible to convert all kinetic energy of wind into mechanical power, thus it extract a fraction of power in wind, called power coefficient *Cp* of the wind turbine. And is given by,

$P_{mech}=CpP_{wind}$……………………… (2)

Where, *Cp* is the power coefficient. The power coefficient can be expressed as a function of tip speed ratio λ and β pitch angle.

Following are the parameter specifications for wind farm:

1) Induction generator=3.5kVA
2) Frequency=50Hz
3) Switching resistance (R_s)=0.006Ω
4) Inverter voltage=330V
5) Output power=250kW

1.3 Modelling Of Battery Storage System

Batteries are the group of electrochemical cells which are linked mutually. These electrochemical cells can transfer chemical energy directly into electrical energy in DC form. Batteries can be classified into number of categories depending upon different factors like applications, material used for manufacturing etc. But at basic level batteries can be primary batteries and secondary batteries. Primary batteries are the batteries which are use and through type. These batteries cannot be charged again and again. And secondary batteries can be charged again and again by applying certain voltage in opposite direction.

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Lithium-ion, nickel-cadmium, metal-oxide hydride and lead acid these batteries are available in MATLAB. From which i have used lithium ion battery because of its advantages over other type of batteries.

1.4 Modelling of Diesel Generator (DG)

When micro grid is operating under islanding mode i.e. when grid is not connected, diesel generators are the main power sources. Distributed generating units are small power sources which are located near the point of use. The diesel generator is used as a main distributed energy resource in this proposed system.

II. POWER QUALITY DISTURBANCES

Voltage sag, swell, voltage imbalance, waveform distortion, harmonics, overvoltages, under voltages are some power quality problems which occur in systems. Here the power quality issue which is taken into consideration is Total Harmonic Distortion (THD).

2.1 Total Harmonic Distortion

Consider the power system with AC source and electrical load .Load can be either linear or nonlinear. Home appliances are linear type of load and they draw sinusoidal current and does not have harmonics. Appliances used in house are the linear type of load. The nonlinear type of load may be electronic ballast, PLC, adjustable speed drive or any DC/DC converter. Such type of load gives rise to the distortion in waveform. Mathematically Total harmonic distortion, or THD is measure of harmonics present also it is the ratio of sum of all powers of all harmonic components to the power of fundamental frequency. Mathematical formula for THD is:

$$THD = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2)}}{V_1} * 100\%$$

The formula above gives the THD for voltage signal. If voltage in above formula is replaced by current then the formula gives THD for current signal. The result will give the THD in percentage form. The lower the percentage lesser will be the distortion from its fundamental value.

III. SIMULATION RESULTS AND ANALYSIS

The whole Praposed system is designed as per the specifications in software called MATLAB/SIMULINK.

) Modelling of solar PV system

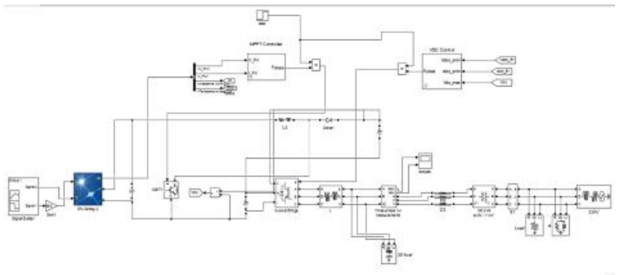

Fig 4. Modelling of solar PV system

Figure 4 shows the solar power generation plant. The system is modeled in software called MATLAB/SIMULINK. By giving the variable temperature and irradiance, at the output signal 'm' we get the voltage and current of the PV cell, the diode current and power. For the maximum power point tracking the MPPT controller is used.

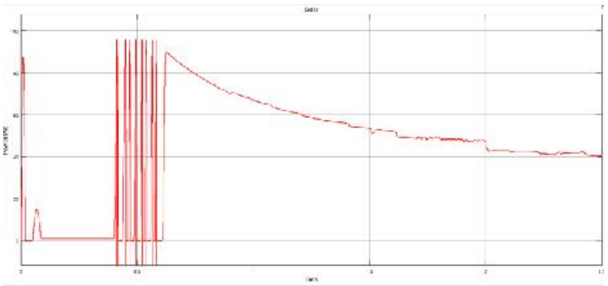

Fig 5. Output of solar PV system

Figure 5 shows the output power for solar system. The nature of the graph is varying due to variable nature of temperature and irradiance. FFT analysis and the Total Harmonic Distortion can be calculated from the tool available in powergui. Total Harmonic Distortion for the solar system is shown in figure 6.3. We can select the portion of the signal for which the THD is needed. Here by keeping the frequency 50 Hz, start time from 0.0 sec, maximum frequency 1000 Hz the magnitude of 3rd, 5th , 7th….. can be calculated. The THD for individual solar power plant is 1.41%.

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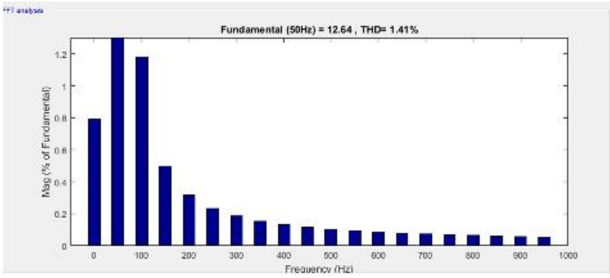

Fig 6. FFT analysis of solar PV system

Modelling of wind farm

Fig 7 shows the SIMULINK model of the wind power generation system. The variable wind speed is given as an input to the wind turbine. We can get pitch angle in degree, per unit values of voltage and current of the stator, grid as output.

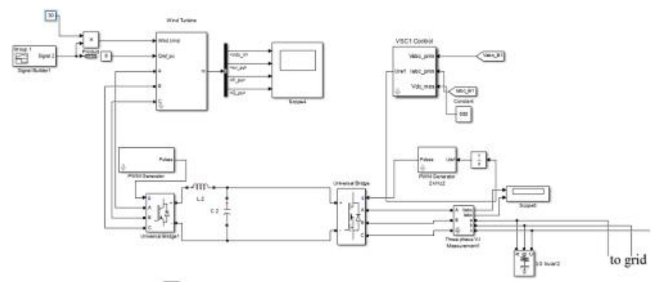

Fig 7. Modelling of wind farm

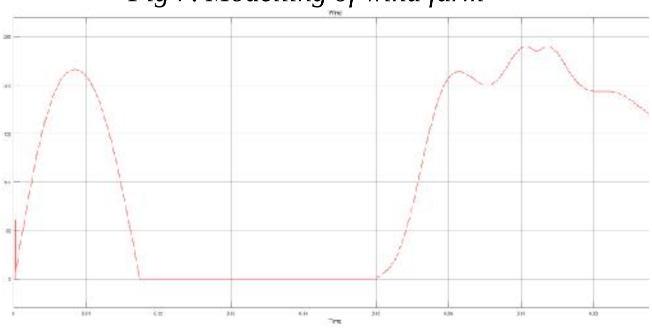

Fig 8. Power output of wind farm

Fig 8 shows the output for the wind power generating unit. Also the total harmonic distortion is shown in fig 9. Fundamental frequency is on X axis up to 1000 Hz and Y axis shows the magnitude of harmonics in percent of fundamental.

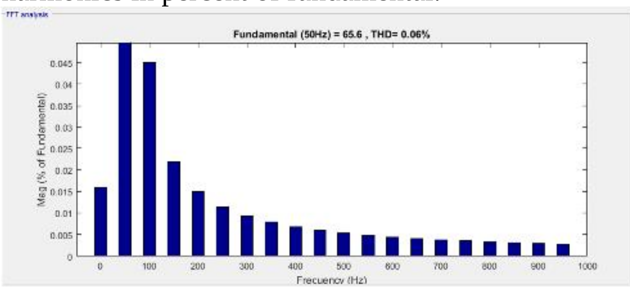

Fig 9. FFT analysis of wind farm

Modelling of DG

Synchronous machine is used in this model having the rating of 50 Hz, 400V, 8.1kVA, 1500rpm. Rotor type is salient type. For controlling the speed of the machine, governor is used. The two inputs actual speed and desired speed are given to the governor and in output we get diesel engine mechanical power.

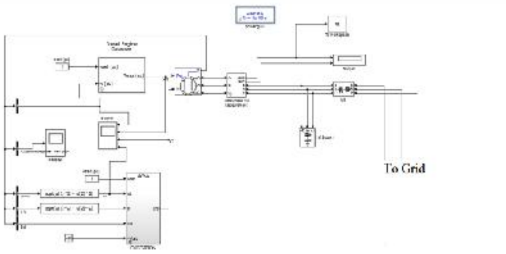

Fig10. Modelling of DG

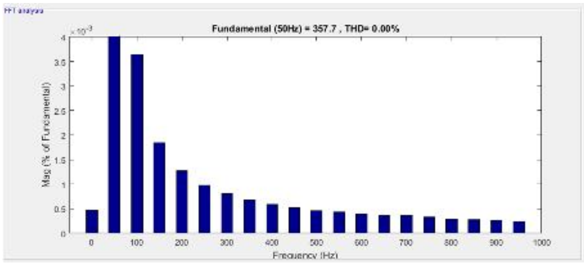

Fig11. FFT analysis of DG

Fig. 10 shows the modelling of the Diesel Generator using synchronous machine and fig 11 shows the FFT analysis and THD percentage.

Modelling of Battery storage system

Nickel-cadmium, Lithium ion, Lead acid and Nickel metal Hydride are batteries which are available in the library for modelling. The lithium-ion battery is used here. Figure 6.8 gives the SIMULINK model for the battery storage system. The output of the battery is a DC output, so it is converted in AC form using a bi-directional inverter. If the generation of solar and wind system is exceeded then the battery will get charged and if generation is less than the demand then battery will get discharged through the load attached to it. This is the purpose of using the bi-directional inverter.

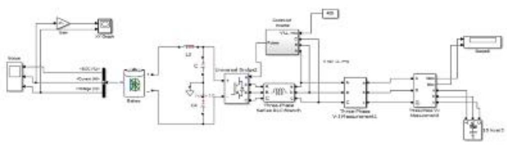

Fig 12. Modelling of battery

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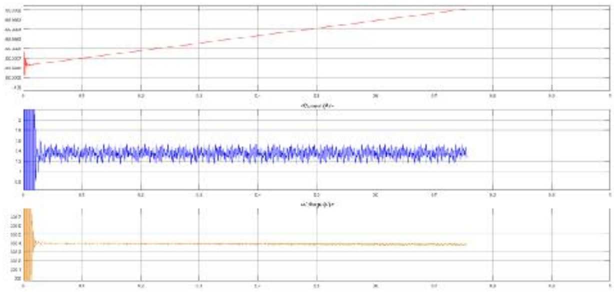

Fig 13. SOC, current and voltage of battery

The state of charge (SOC), Current and voltage graphs and THD for battery are given in fig 12 & fig 13 resp.

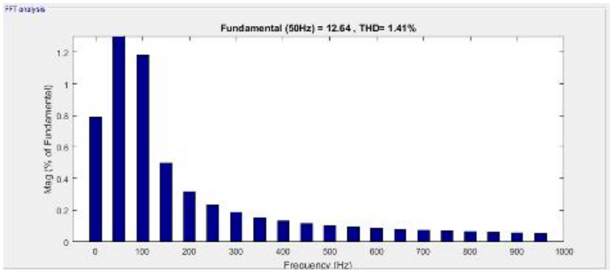

Fig 14. FFT analysis of battery

THD analysis using Circuit breaker

A modification is made into the proposed hybrid system. To calculate the total harmonic distortion at load point, two circuit breakers are inserted in the system. One is placed just after the sources and another one is before the grid.

So that we can observe the THD in following the conditions i.e.

I. When load is linked to the micro grid only i.e. CB1 closed
II. When load is linked to the grid only i.e. CB2 closed
III. When both the circuit breakers are closed i.e. load is fed through both micro grid and grid. i.e. both CB1 and CB2 closed

The THD results are presented in tabular form below.

Table I

THD results using Circuit Breaker

Load is connected to	Voltage THD (%)	Current THD (%)
1. Grid	0.10	3.83
2. Micro-grid	88.82	82.27
3. Both Grid & Micro-grid	0.08	0.01

IV. CONCLUSION:

The solar power generation plant, wind farm, battery storage system and diesel generator are designed individually using MATLAB/SIMULINK. Then all the four sources were integrated with grid using a three phase transformer. THD for solar plant, wind farm and battery storage system is 1.41%, 0.06% and 1.41% respectively.

Then using the two circuit breakers at the load point the THD at load point is calculated. The result are analysed under three conditions

I. When CB1 is closed
II. When CB2 is closed
III. & when CB1 and CB2 is closed

The results revealed that the Harmonic distortion from the renewable energy sources is much more than the grid side. It is may be due to the inverter.

Sources for the power quality problems may be large motor starting, different line faults, lightening etc. The filters, FACTS devices, lightning and Surge Arresters, thyristor based static switches or an energy storage system plays an significant role in power factor improvement.

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