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Power Quality Analysis of Hybrid AC/DC Microgrid in Distribution Network

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Abstract*: *Microgrid is a complex structure which is a localized group of electricity generation, storage and load which usually operates connected to a macrogrid. The quality of power delivered to the grid during interconnection is one of the key factors which determine the reliability of the microgrid and is affected due to various reasons which include electronic components that leads to equipment overheating, excessive neutral currents etc., which can cause voltage dip, flicker and unbalance voltage at the end user. The power quality level in microgrid has to be quantized and necessary analysis has to be done to investigate the power quality impact in microgrid network. In this paper the analysis of THD of the hybrid system with PV and DFIG in grid connected and islanded mode is studied using MATLAB/SIMULINK. It is found that the THD is reduced when both PV and wind are connected to the grid and increases when isolated. The major advantage of this analysis emphasizes that this system can be applied for highly nonlinear and variable PV and wind systems connected together with the grid. Simulation results also shows that this system is effective for microgrid with varying inputs.

Index Terms: Microgrid, Power Quality, Grid Connected, Isolated, Photovoltaic Array, DFIG

I. INTRODUCTION

A Microgrid is an integrated system of autonomous small scale power grids which consists of interconnected distributed energy resources and loads and are capable of operating in islanded mode as well as parallel with the grid which makes it highly reliable and flexible. A hybrid AC/DC microgrid consists of AC grid and DC grid which supplies AC load and DC load. The power quality issue in microgrids can occur due to the high penetration of Distributed generators such as PV, wind etc., and also due to harmonics caused by increased load reactive power demands. Hence a technical study about the different power quality effects[1] in microgrid such as voltage and frequency variation, power variation, voltage and current harmonics, unbalance voltage and neutral current level on the utility grid [2] is required to improve the reliability. Among the above mentioned power quality issues, the effect of odd harmonics such as 3rd, 5th, 7th,9th etc., are of more significance in electrical distribution systems [3] [4].

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Current harmonics produced due to nonlinear loads have waveforms that are not sinusoidal due to additional waveforms superimposed on it and produce multiple frequency in addition to the fundamental frequency sine wave. Current distortions are responsible for voltage distortions. Harmonic current measurements indicate the harmonic generation content of the load while voltage measurements define the system response. The design of PI controller for DFIG is given in [5]. Photovoltaic systems usually incorporate power electronic interface to extract maximum power from the PV source and to convert DC to AC for grid connection. Overheating of neutral in three phase system, voltage difference in the secondary of the distribution transformer and hence increase of copper loss and heat loss in electrical equipment are the primary issues following excessive harmonics produced in a system [6] [7].

The summation of higher frequency sinusoidal components which are integer multiple of the fundamental harmonic is called current or voltage harmonics. Current harmonic domination is due to the power electronic converters and non linear loads and this subsequently causes rise in the voltage harmonics due to system impedance. Nonlinear loads are also responsible for harmonics which has a heavy impact on the system reliability and operational efficiency. Current THD analysis should be given more importance than voltage THD analysis especially for grid tied PV system and that operating at variable insolation[8]. Moreover PV with low irradiation produces more current harmonics and appropriate filtering measures have to be taken or disconnected during low irradiation. This paper investigates the harmonic analysis of the DFIG system by connecting the combination of PV-DFIG to the microgrid and is done using MATLAB SIMULINK. Detailed simulation is done for different load conditions by analyzing different system conditions and the effect of the new harmonic sources on the system is studied[9]. PI controller is used for controlling the grid side and rotor side of DFIG. The point of common coupling is taken as the interface between the utility and the consumer. Both the theoretical analysis and simulation are done and the magnitude of harmonics in the system are measured using THD analysis and is done on the inverter output current where the load is connected.

II. PROPOSED METHOD

The proposed system consists of a hybrid combination of DFIG and PV which are intermittent and complementary in nature is shown in fig 1.

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It consists of a DFIG system driven by wind turbine in which the converters used in grid side and rotor side controllers uses only 25 to 30% of the total capacity of output power. The output of DFIG is rectified and tied with the output of PV which uses DC-DC converter to produce constant DC voltage and the input tracked by MPPT controller to track maximum power. This combination is connected to a common DC bus where a battery is also connected which supplements the intermittency and complementary nature of the sources.

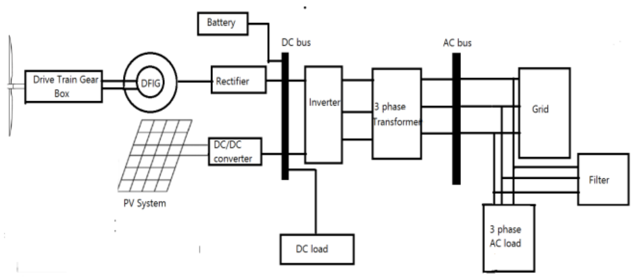

Fig 1. Hybrid Combination of PV and DFIG

The output of DC bus is inverted and then connected to three phase transformer before connecting to AC bus. From there it is connected to the grid where three phase AC load is connected.

III. SYSTEM DESIGN

A. Solar Panel

The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction, and its equivalent circuit is shown in Fig. 2. A photovoltaic source is a current source which depends upon the rate of insolation and is called Photo current, I_{ph}. There is some resistance to the path of flow of electrons which is represented by R_s and is connected in series with the circuit [10]. It is modeled using the following equations.

$$I = I_{ph} - I_D - I_{sh} \quad (1)$$

$$= I_{ph} - \left(I_o\left[e^{\frac{q(V+R_sI)}{mkT}} - 1\right]\right) - I_{sh} \quad (2)$$

$$I_{sh} = \frac{V+IR_s}{R_{sh}} \quad (3)$$

The photo current mainly depends on solar insolation and cell's working temperature which is described in (4).

$$I_{ph} = [I_{sc} + K_1\,(T_c - T_{ref})]H \quad (4)$$

Where I_{sc} = cell short circuit current at 25^0C and 1kW/m^2

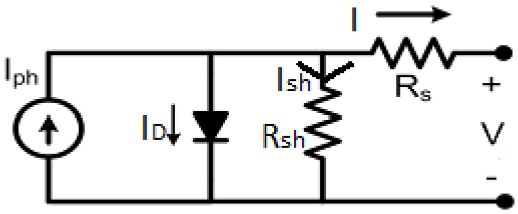

Fig. 2. Equivalent Circuit of Solar Cell

The boost converter is connected to the solar panel in the source side which enhances the output voltage by changing the duty cycle appropriately by matching the source impedance with load impedance. Perturb and Observe(P&O) method is used to track the Maximum Power Point by using a voltage sensor to sense the PV voltage and calculate the reference voltage towards which the PV voltage should move for obtaining the maximum power output.

B. Wind Energy Conversion System

The controller is the brain of the wind system and it is responsible for controlling the speed and torque of the generator and also the power electronic interfaces. The speed and torque can be controlled by regulating the voltage fed from both stator and rotor of the machine. In DFIG the real power and slip depends on voltage magnitude and angle of the rotor[11]. Due to the variable speed operation of DFIG, the maximum operating point of the torque speed curve has to be tracked accurately [12]. When the torque is controlled speed can be adjusted. Thus the desired active power can be obtained by the instantaneous rotor speed value and thus controlling the rotor current in the stator flux oriented reference frame. Thus operating at the desired active power in turn results in desired speed and torque [13]. The grid side controller should also be controlled to keep the DC link voltage fixed and to make the direction of rotor power flow independent.

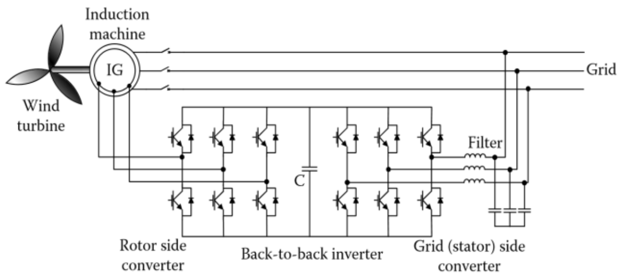

Fig 3: Double Fed Induction Generator

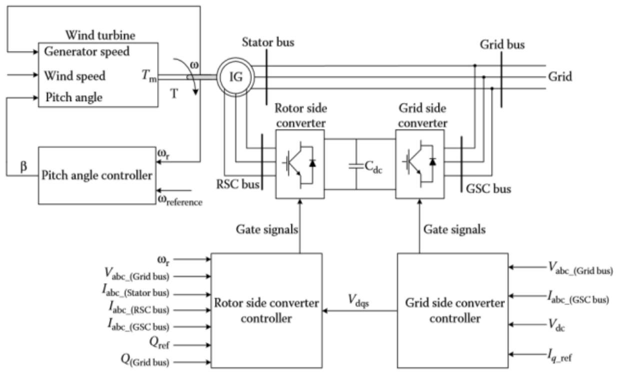

Fig 4: DFIG Topology

The DFIG system and the topology are shown in Fig 3 and Fig 4 respectively. One of the most important advantages of DFIG is that the power flowing through the rotor is only around 25 – 30% of the power through the stator and hence power electronic interface can be designed for 25 – 30% of the total power [14].

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The rotor converter has the capacity to control the slip of the induction generator and when the wind power surpasses the stability limit, then the generator shifts to supersynchonous mode. On the contrary if the input wind power decreases additional power has to be fed through the slip rings into the rotor to prevent the generator operating sub synchronously.

The electrical equivalent circuit of DFIG for steady state is shown in fig 5.

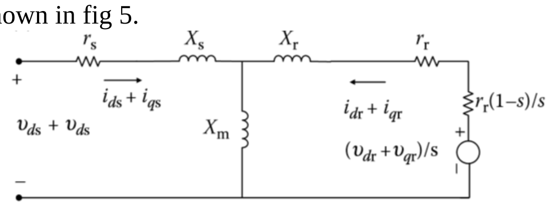

Fig 5: Electrical Equivalent Circuit of DFIG

The direction and magnitude of the power between stator and rotor windings can be controlled by adjusting the switching of the PWM signals of the inverter[15].

The total power of a DFIG is

$$P_e = P_m - P_g = sP_g = P_r + P_{\chi r},$$

Where Pm – total mechanical power from the wind turbine's shaft

Pg – air gap power

Pr – rotor power

$P_{\chi r}$ - power of rotor losses

Hence the power factor can be adjusted by controlling the angle φ_r which is the angle between rotor voltage Vr and rotor current Ir.

$$P_e = sP_g = 3\left[I_r^2 R_r + V_r I_r \cos\varphi_r\right]$$

Here rotor current Ir is

$$I_r = \frac{V\angle 0° - (V_r/s)\angle\theta_r}{(R_s + R_r/s) + j(X_s + X_r)}.$$

C. Rotor Side Controller

The DC signal is inverted by applying previously generated switching signal. The inverter is a Voltage source converter and hence capacitor is used as DC link.

D. Battery System

The time constant of many distributed generators are large and moreover they are intermittent and unstable and hence a battery storage system is essential in microgrid to accommodate variations in power generation and load.The energy is stored in electrochemical form and the main function of energy storage system in microgrid is to maintain stability, to improve power quality and to aid in the integration of distributed generators. Surplus energy produced by the renewable sources wind and solar are stored during high availability and dispatched during power shortage [16].

E. Three phase Inverter

The PV system produces DC output and hence produces only real power and has to depend on inverter for reactive power support. The DC signal is inverted by applying previously generated switching signal. The inverter is a Voltage source converter and hence capacitor is used as DC link.

F. AC Filter

The distortions in the output voltage of the inverter is smoothened using the second order AC filter whose cutoff frequency is 50 Hz.

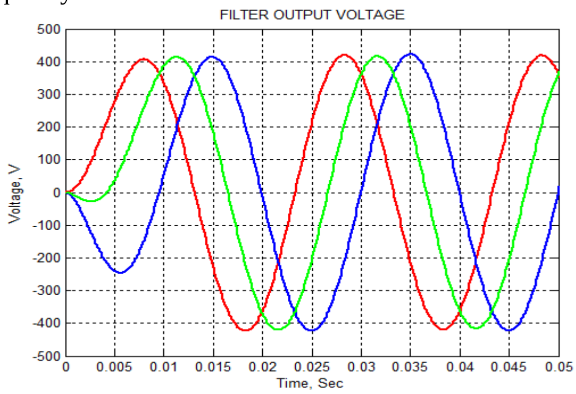

Fig 6. Output of Inverter With Filter

Fig 6 shows the output voltage with filter and the peak voltage is 415V.

G. Transformer

A step up delta-star transformer 0.1 KVA operating at grid frequency of 50Hz is used as galvanic isolation and the low voltage side 250V is connected to the inverter while the high voltage side 400V is connected to the grid. This transformer is connected at the output of the inverter to avoid dc injection and to block the path for dc current into the grid.

H. Utility Grid

The utility grid system is represented as an equivalent 400V and 50 Hz source and this utility grid falls within the low voltage (LV) power system range.

IV. CONTROLLERS

The controllers play a major role in regulating the output voltage in a microgrid and the DC bus voltage in the hybrid microgrid must be regulated by the DC sources and storage devices connected to the DC part during the islanded operation. Meanwhile the ac voltage and frequency must be regulated by the inverter.

1) PV Controllers:

A DC/DC boost converter is used in the Photovoltaic system inorder to change the input resistance of the panel by varying the duty cycle to match the load resistance. The battery is a bidirectional DC/DC converter which charges when abundant radiation is available and discharges during off-peak period and maintains stable DC link voltage during islanded operation. A capacitor is added between PV array and DC/DC converter to suppress the high frequency ripples from the PV output voltage. A PI controller is connected to provide switching pulse to the boost converter by minimizing the error between Vref and measured voltage by varying the duty cycle through the switch before connecting to the DC load inorder to control the input voltage of converter and to maintain constant voltage for load.

2) DFIG Controllers:

The block diagram in Fig 7 shows the rotor control scheme using PI controller for controlling the rotor current. It is used to develop the rotor reference voltages according to reactive power and speed of the rotor.

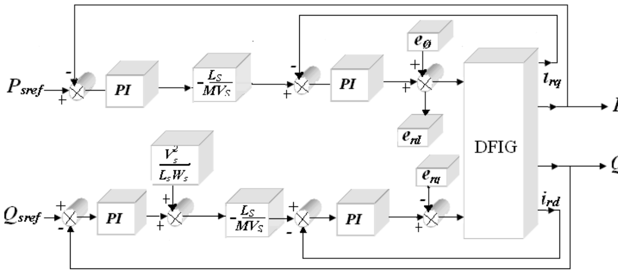

Fig 7: Block Diagram of Rotor Control Scheme

V. RESULTS AND INTERPRETATION

The hybrid system which consists of the distributed generators DFIG and PV under grid connected and isolated system are considered as the test system and developed in MATLAB/SIMULINK.

A harmonic study is done at the point of common coupling (PCC) where the electrical utility and consumers are connected, in order to analyze the performance of the hybrid microgrid with wind, solar and battery connected system. Here the DG is found to absorb the harmonic current from the local load. This condition is checked by connecting a non-linear time varying three phase ac load of 1KW and 0.1KVAR at the inverter side with the speed varied from 10m/s to 8 m/s under two different cases.

Case i) Grid connected mode

In grid connected mode, the converter connects the microsources to the main grid and the power is maintained by the utility grid. The table 1 shows the corresponding values of voltage THD at the load when the system is connected to the grid.

Table 1: Voltage THD Under Grid Connected Mode

	%THD	3rd harmonics	5th harmonics	7th harmonics
Voltage in Phase a	0.66	0.3	0.1	0.05
Voltage in Phase b	4.06	1.75	1.0	0.75
Voltage in Phase c	4.08	1.75	1.0	0.75

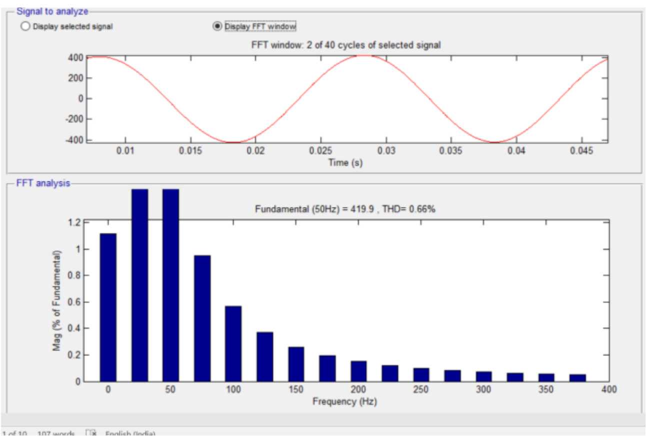

Fig 8: %THD in Phase a Under Grid Connected Mode

From fig 8 it is clear that the %THD is 0.66 when connected to grid.

Case ii) islanded mode

When the grid is disconnected, the converter may have to continue supplying critical load while maintaining the voltage and frequency irrespective of the type of load. Voltage should be provided by the DG unit and the THD at the local load side is shown in Fig 9.

Table 2: Voltage THD Under Islanded Condition

	%THD	3rd harmonics	5th harmonics	7th harmonics
Voltage in Phase a	6.15	0.75	2.0	0.5
Voltage in Phase b	7.35	1.75	1.75	0.25
Voltage in Phase c	6.90	1.0	1.5	0.25

From the Table 2 it is observed that the THD increases during islanded mode. It is due to the fact that under islanded condition, the DG should supply power to the connected loads and the rest of the distribution network which inturn causes some loading changes in microgrid, which produces harmonic voltage and current and contributing to THD.

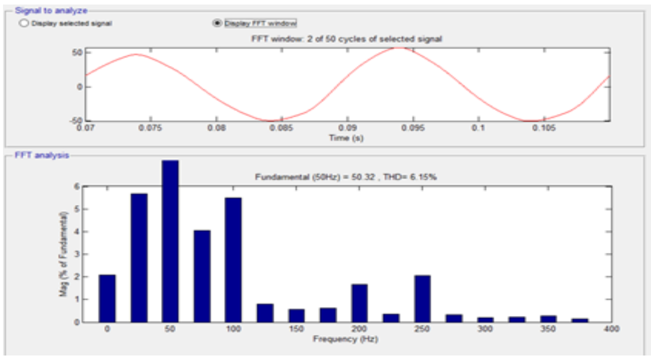

Fig 9: %THD in Phase a Under Islanded Mode

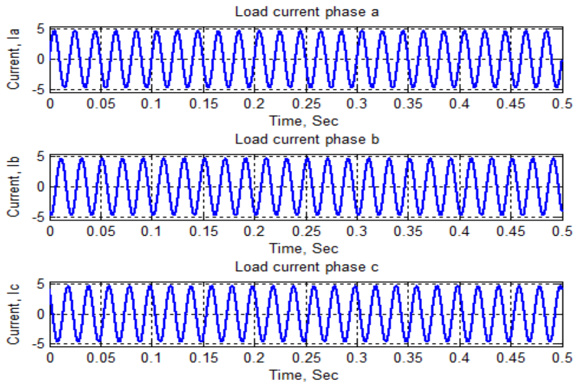

Fig 10: Load Current at Different Phases

The load current at different phases are shown in fig 10. From the analysis of grid connected and islanded modes, it is clear that the system can be applied for highly nonlinear and variable PV and wind systems connected together with the grid.

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VI. CONCLUSION

The microgrid should dispatch power supply of high quality and reliability to sensitive loads. The behavior of microgrid during grid connected and islanded mode is modelled based on Double Fed Induction Generator, Photovoltaic cell, battery and inverter and the THD analysis when connected to AC and DC loads are performed. It is found that the THD is more when microgrid is in islanded mode and less during grid connected mode.

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