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Dynamic Study of Grid Connected Hybrid Wind PV System in ETAP

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ABSTRACT

The objective of proposed work is to analyze system load flow study and transient study of 48 bus systems. Renewable source of energy has been proven to be best source of compensating future demand of electricity. In this paper, a hybrid wind PV solar system is designed to feed power to grid. A hybrid doubly fed induction generator (DFIG) based wind turbine and polycrystalline silicon based photovoltaic (PV) module are taken for study. The proposed system is simulated in Electrical Transient Analysis Program (ETAP). Power flows are analyzed for different lengths of cable, for different wind speed and irradiance level. Hybridizing the two or more energy is a new concept and much analysis has been done on the topic in different power system analysis software. It was concluded from the ETAP analysis that hybrid DFIG based wind and solar energy can effectively feed power to grid with a lesser amount of losses. The PV module output for different irradiance was also studied. The transient behavior of system during 3 phase fault and single line to ground fault was studied and the graph indicate the system harm is much more during 3 phase fault. Hybrid wind PV system can compensate demand with additional stability and reliability. Because of additional advantage, this hybrid wind PV system will soon replace the future dependence of generating electricity from coal based plant. The analysis is useful before commissioning of hybrid system in site to study the complete behavior of system under different conditions.

Keywords : Renewable, Hybrid, Electrical transient analysis program (ETAP), doubly fed induction generator (DFIG), Photovoltaic (PV)

I. INTRODUCTION

The rate of production and consumption of energy is escalating day-by-day. Conventional sources of electricity production can damage our environment in many ways. So a clean and green energy is required to match the future need of electricity. Renewable energy is so far the best source of electricity because of its availability. The rising demand of electricity cannot be fulfilled by conventional source of energy alone. As solar and wind which are taken for analysis in proposed work is available in abundant. According to Ministry of New and Renewable Energy (MNRE), as of September 2016, 61% of the renewable power contributed by wind, while around 19% is contributed by solar[1]. Both the sources of energy are contributing major shares in generating power from renewable.

Individually both the sources of energy are not very efficient as both tend to vary due to seasonal variation. However, combining both the sources is better option as both can complement each other during their weak times and increase the energy output when grid connected[2]. Doubly fed induction generator (DFIG) based wind turbine is taken for analysis. There are many advantages of DFIG compared to other type of generators used in wind turbine. The main advantage is the ability to work in synchronous, sub-synchronous and super synchronous speed[3-5] also; additional reactive power compensation is not required. PV modules extract power from solar radiation and convert solar energy directly into direct current (DC). An Inverter is required to convert this direct current (DC) into alternating current (AC) to supply power to utility grid. In the proposed work, a hybrid wind and PV system is taken for study as hybrid system is more reliable and stable compared to individual wind or solar system.

Renewable sources based hybrid system is better option for compensating growing demand of electricity. Figure 1 shows the block diagram of proposed grid connected hybrid wind and solar PV system where the energy harnessed from wind is given to Doubly Fed Induction Generator (DFIG) and power from solar is fed to Inverter. This wind turbine model and solar model are connected to large number of buses, cables and transformers to feed the power to grid. Both Solar PV and DFIG model is available in Electrical Transient Analysis Program (ETAP) software[6-8]. Hence analysis of proposed work is performed in this software.

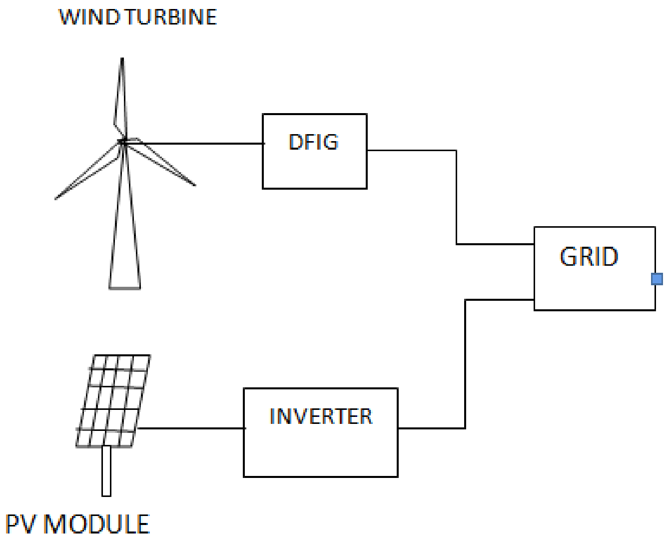

Figure 1. Grid connected hybrid wind and solar system

II. MATHEMATICAL MODELING OF HYBRID WIND PV SYSTEM

A. Solar PV Modeling

Sunlight is never depleting source of energy. In solar PV plant, the power extracted from sun can be used to feed power to grid. The main consideration in installation of solar PV plant is to install it in shade free area to extract maximum solar electricity output. Figure 2 shows the model of solar PV cell where diode in parallel with current source represent solar cell. Shunt and series resistance is added in the circuit since practically the circuit is not ideal. In ETAP, individual panels are connected in series and parallel to represent PV array. Polycrystalline silicon module is taken for analysis.

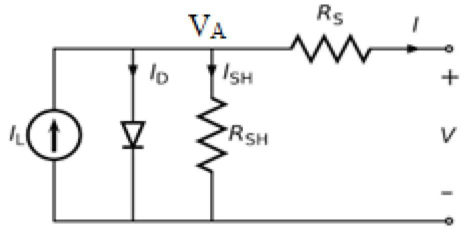

Figure 2. Model of solar PV cell

The output current produced by solar PV cell is given by,

$$I=I_L-I_D-I_{SH} \quad (1)$$

The voltage across these elements is given by,

$$V_A= V+IR_S \quad (2)$$

The current flowing through shunt resistance is given by,

$$I_{SH}=V_A/R_{SH}= V+IR_S/ R_{SH} \quad (3)$$

The current flowing through diode is given by,

$$I_D=Io[exp(q\ V_A / kT) -1] \quad (4)$$

Output current is obtained by substituting values of I_{SH} and I_D in equation (1), we get

$$I=I_L - Io\ [exp (q\ V_A/ kT) -1] - [(V+IR_S)/R_{SH}]$$

Where
I_L=Current Generated from Light in Cell in Amperes
I_D=Diode Current in Amperes
I_{SH}=Current Flowing through Shunt Resistance in Amperes
V=Voltage across Output in Volts
I=Current across Output in Amperes
R_S=Series Resistance in Ohms
R_{SH}=Shunt Resistance in Ohms
Io=Reverse Saturation Current in Amperes
q = Electron Charge (1.6×10^{-19} C)
k= Boltzmann Constant (1.38×10^{-23} J/K)
T= Absolute Temperature of Cell in Kelvin (K)

B. Wind System Model

Wind turbine generator harnesses power from wind energy. The energy present in wind passes through the blades of wind turbine which is connected to gearbox.

The function of gearbox is to increase the rotational speed. The high speed shaft of gearbox is connected to generator and the generated electricity is fed to the grid through transformer and cables.

The power generated from wind is given by equation:-

$$P=0.5C_P\,\rho A V^3$$

Where

C_P=Power Coefficient

ρ=Air Density in kg/m^2

A=Swept Area of Rotor Blade in m^2

V=Velocity of Wind in m/s

There are different types of generator used in wind turbine i.e. Type A, Type B, Type C & Type D. Doubly fed induction generator (DFIG) comes under Type C . Type C generator is advantageous for grid connected system. The main advantage is ability to work under various wind speed from sub-synchronous to super-synchronous. Other advantage is low cost of converter. The working of DFIG is shown in Figure 3.

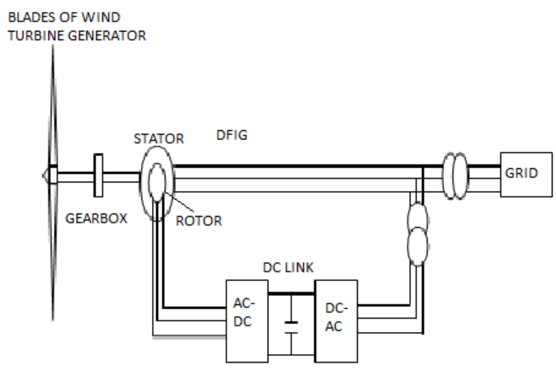

Figure 3. Doubly Fed Induction Generator

The stator is linked directly to grid through transformer and rotor is connected through two back-to-back converters having DC link in common. When slip is negative i.e. rotor speed is greater than synchronous speed of stator, rotor delivers electrical energy to grid and when slip is positive, rotor receives electrical energy from grid while stator continues to deliver power to grid. These abilities of DFIG to export and import reactive power allows machine to support low voltage ride through of wind turbine which is significant for maintaining power system stability.

III. HYBRID SYSTEM CONFIGURATION

In this paper, the hybrid wind PV solar plant of 29.3 MW capacities is designed. Network 1 consists of seven wind turbine generators of 2.1MW each. Network 2 consists of five PV arrays of 252 KW each. Network 3 consists of six wind turbine generators and three PV arrays of 2.1 MW and 252 KW each. Impedance Z1 is connected between Bus 1 & Bus 2 and impedance Z2 is connected between Bus 3 and Bus4. The layout of hybrid wind solar plant shown in Figure 4.

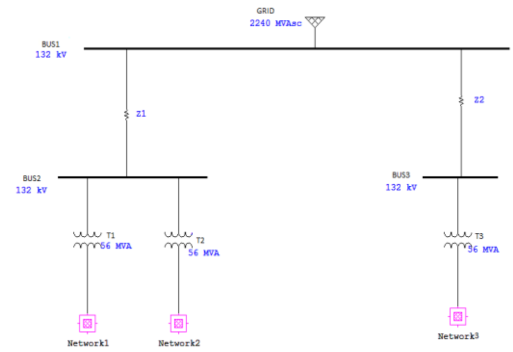

Figure 4. Layout of Hybrid Wind Solar Plant

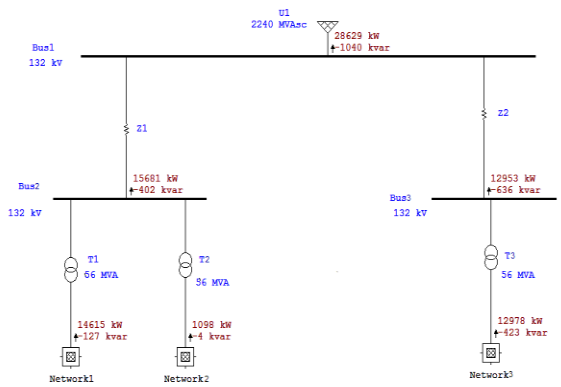

Figure 5. Load Flow of Hybrid Wind And PV Solar Plant

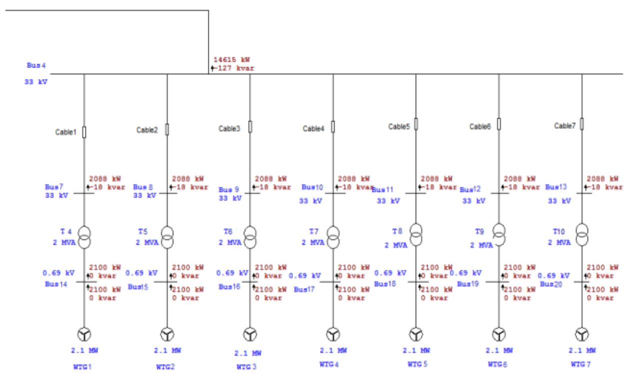

Figure 6. Load Flow of Network 1

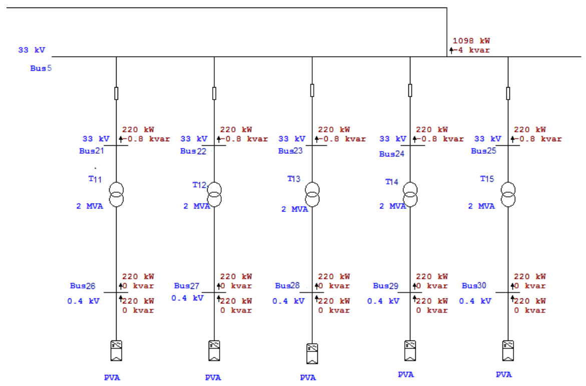

Figure7. Load Flow of Network2

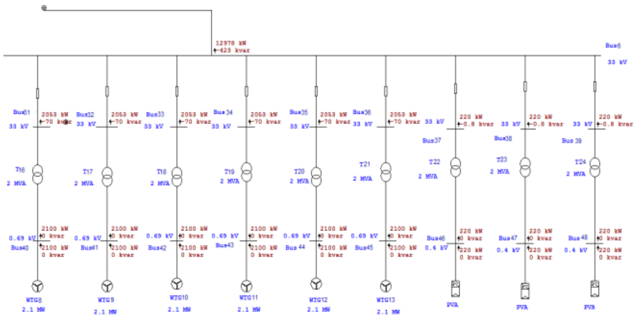

Figure 8. Load Flow of Network3

IV. RESULTS AND DISCUSSION

A. Load Flow Analysis of Designed Plant

Load flow analysis is performed on designed hybrid wind solar plant and real and reactive power flow at each bus[9]. Many methods for load flow are available. In proposed work, the Adaptive Newton Raphson method is used for power flow calculation and results obtained are shown in Figure 5. Figure 6, Figure 7 & Figure 8 shows load flow of network 1, network 2 and network 3.

The loss takes place during transfer of power from generator to grid. The total active power reaching the grid after simulation is 28.5 MW while actual generation 29.316 MW and total loss obtained is 0.716 MW Table 1. These losses can be observed from histogram shown in Figure 9. The elements contributing these losses are transformer, cables and solar inverters.

Table 1-Actual and Simulated Active Power Of Network

NETWORK	ACTUAL (MW)	SIMULATION (MW)	LOSSES (MW)
NETWORK1	14.7	14.6	0.1
NETWORK2	1.26	1.1	0.16
NETWORK3	13.356	12.9	0.456
TOTAL	**29.316**	**28.6**	**0.716**

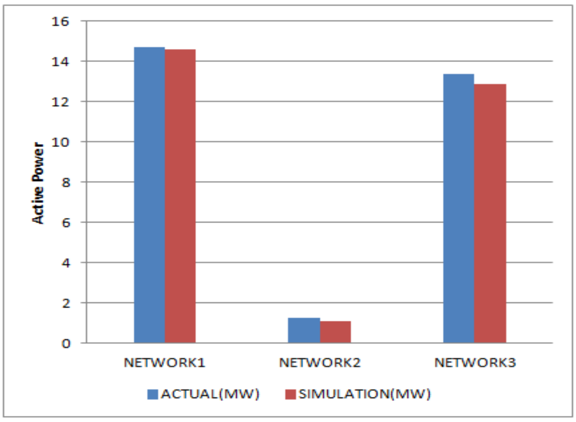

Figure 9. Comparison of Actual and Simulated Active Power

1) Power flow for different Length of Cable

There are losses in the cable in the form of heat while carrying power through cable. This is limiting factor and directly affecting the power transportable through cable. The loss will be greater for large length of the cable. XLPE cable is taken for analysis. The active power at grid is observed for different cable length shown in Table 2 and it was observed from Figure 10 that with the increase in length of cable, flow of electricity to grid is decreasing.

Table2-Active Power corresponding To Cable Length

CABLE LENGTH	ACTIVE POWER AT GRID(MW)
50m	28.5
5km	28.4
10km	27.3
20km	27.1

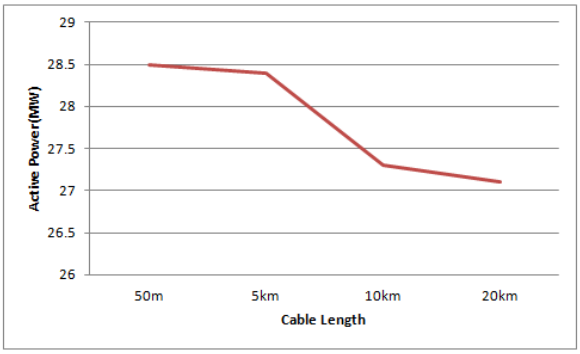

Figure 10. Variation in Active Power with change in Length of Cable

2) Power Output at Different Wind Speed and Irradiance Level

The weather conditions are highly uncertain. The fluctuation in wind speed directly affects the power output of wind turbine generator. It is observed from Figure 11 the wind speed vs. active power graph follows the actual power curve of wind. The maximum power output is at rated wind speed of 14 m/s.

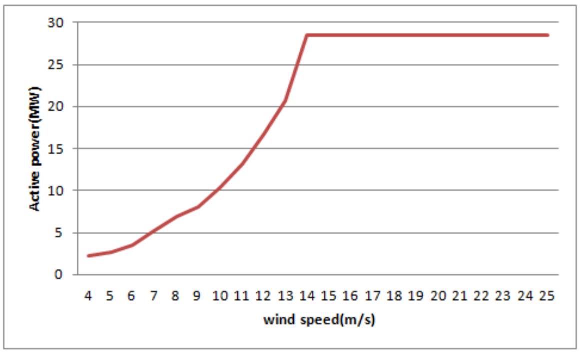

Figure 11. Active power flowing to grid at different wind speed

There is a wide variation lies in solar irradiance on the surface of earth due to local climatic influence. At various irradiance levels, the output of grid is showing a discrepancy[10]. Active power at various irradiance levels is shown in Figure 12. The maximum power is obtained at irradiance of 779 W/m^2 and 970W/m^2i.e output is maximised at lower irradiance due to hybrid configuration.

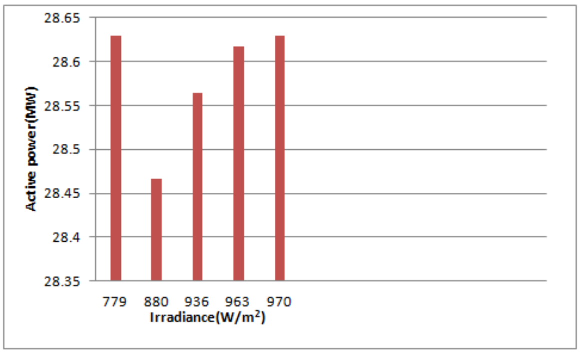

Figure12. Active power flowing to grid at various irradiance levels

B. Transient Analysis of Plant

Unsymmetrical faults are common in power system[11]. For short circuit study, 3 phase fault was initiated at bus 1 and cleared in 0.5 sec. The short circuit current during fault was observed to be 9.8 kA at grid side (bus1) while the short circuit current at generator bus observed was 142 kA(bus 14). The faulted point voltage reduced to zero during short circuit[12]. It is very important to analyze transient stability while designing a plant. In transient state, voltage and current fluctuates i.e. the system is unstable for very short period of time[13-14]. During 3 phase fault at bus 1 of hybrid plant, It is observed from Figure 13 that bus 1 voltage drops to 0 kV after being subjected to fault while the same is not in case of LG fault. In case of LG fault, the voltage drops down to 87.86 kV as shown in Figure 14. Both the system returns back to its original state in 0.521 sec. However the bus voltage angle rise in case of LG fault Figure-16 while during 3 phase fault bus voltage angle drops down to 0 and rises abruptly at 3.5 sec Figure-15. This shows the severity of 3 phase fault.

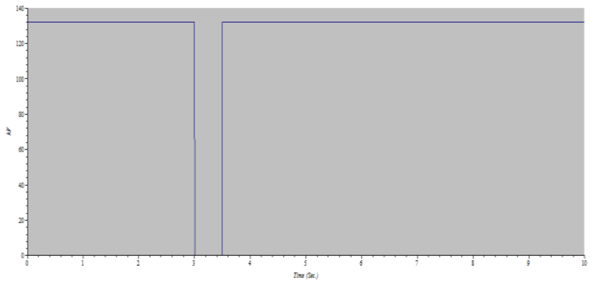

Figure13. Grid bus voltage during 3-phase fault

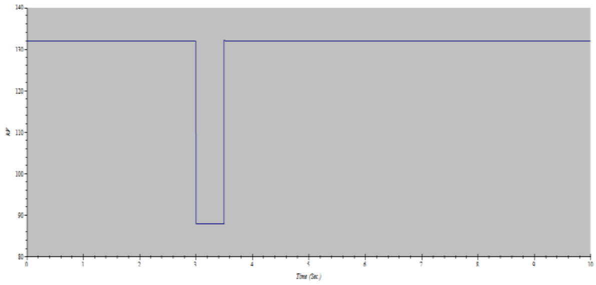

Figure14. Grid bus voltage during L-G fault

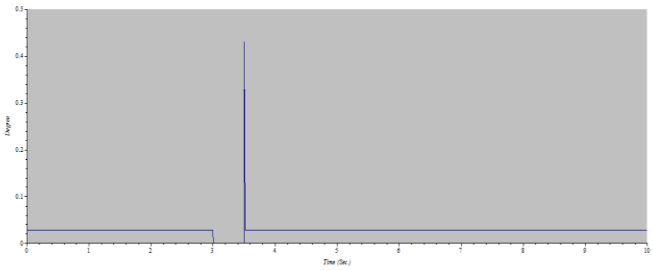

Figure15. Grid bus voltage angle during 3-phase fault

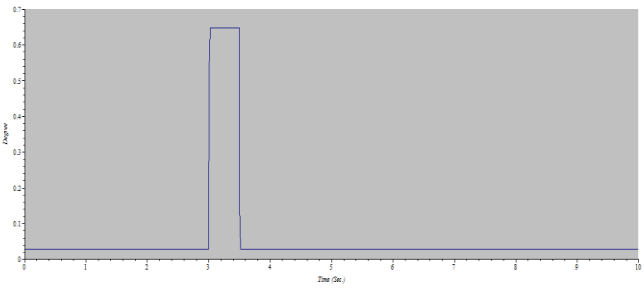

Figure16. Grid bus voltage angle during L-G fault

V. CONCLUSION

While generating power from either wind or solar energy, the continuous supply of power is difficult to maintain which is not suitable for grid connected system. A hybrid system is required while producing power from renewable energy based sources. The analysis of designed wind and PV solar system is very important to find out the power flow at various wind speed, irradiance level and system behavior during transient state. The system transient was studied for LG & 3 phase fault and result shows that 3phase fault damages power system more than LG fault. The analysis of system is performed in ETAP software where the maximum power served to grid at irradiance of 970 W/m2 and at rated wind speed of 14 m/s. So, the hybrid wind solar system can effectively match the demand of electricity in future with its mass usage.

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