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"Frequency Control of Smart Grid **- A** MATLAB/SIMULINK Approach"

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Abstract

In this paper, a Smart Grid has been designed using MATLAB/SIMULINK approach for synchronization of Thermal and Wind power plant. The Smart Grid is regarded as the next generation power grid, uses two-way flow of electricity and information to create a widely distributed automated energy delivery network. Output Voltage and frequency of these power plants must be same to avoid circulating current in existing power system network in the synchronization process. The maximum and minimum frequency deviation calculated for this smart power system network explains about the permissible range of active and inductive load applied at different load bus , from which stable working condition of the system has been deduced in order to satisfy the frequency deviation of ± 3%.

***Index*: SIMULINK, Smart Grid, Frequency Deviation, DFIG, Load Analysis**

I. INRTODUCTION

A Smart Grid is an electrical grid that uses information and communication technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity [1]. Smart grid is technically classified in three categories namely Smart Infrastructure System, Smart Management System and Smart Protection System [2]. The design & simulation work of this paper has been done under the Smart Power generation [3] technique which is a part of Smart Infrastructure System.

Frequency is the main parameter to show the stability of any power system network like conventional power grid, micro grid or any virtual power plant. These distributed generators along with local loads and storage constitute micro grids [4]. The analysis of frequency control has already been done in Isolated Micro grids [5]. Micro grid is designed to operate in grid connected and isolated mode [6]. In the case of grid connected system, the supply and demand gap shall be taken care by main grid and hence the system is more stable i.e., voltage and frequency are maintained within the limits [7]. To control the frequency in isolated micro grid, storage element is necessary [8]. Different rating of storage and integrating devices are used to control the frequency which can create a very complex situation. Since micro grids are a low voltage network which is generally not the case of modern power system network [9].

In present scenario of power system network, conventional and distributed generation are used together to control the power flow in order to get a highly stable network. The proposed smart grid model includes four units of Thermal power plant (conventional generation) and six units of Wind power plant (distributed generation). Wind power plant has been connected to the side of major load. In Thermal power plant power generation is done by Synchronous generator and in Wind power plant by Doubly Feded induction generator (DFIG) [10]. The rating of each thermal power plant is 900 MW where as wind power plant rating is 12 MW. 13.8 KV is generated by synchronous generator which is then step-up to 230 KV of voltage level and 575 V is generated by DFIG which is again step-up to 230 KV to maintain the transmission voltage at 230 KV. The overall Frequency of system has been controlled by controlling the frequency of both synchronous generator and DFIG independently.

II. FREQUENCY CONTROL SCHEME

Frequency control of the proposed power system model has been done by two processes:

(i) Automatic load frequency control (ALFC) loops of synchronous generator.
(ii) Automatic frequency control of doubly fed induction generator.

A. *Frequency control of synchronous generator*

When loads increase or decrease the frequency decreases or increases accordingly. For automatic frequency control, ALFC has been used in both single and double area loop.

Block diagram of Synchronous Generator:

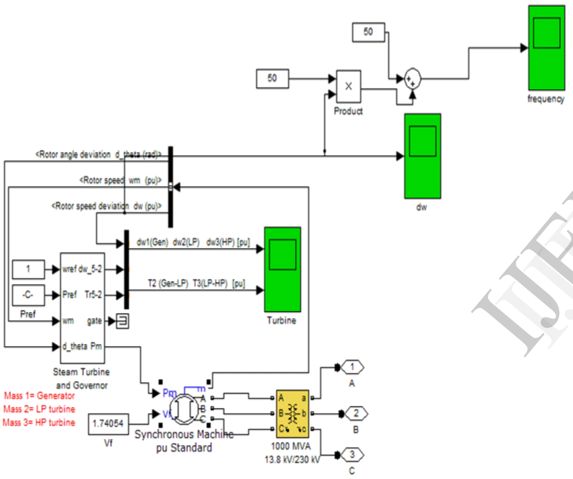

Fig 1. Block Diagram of Synchronous Generator

In thermal power plant, frequency can be controlled by automatic frequency control loop (ALFC) which comprises generator, load, prime mover and governor.

The steam input of governor system is adjusted with respect to turbine speed which is directly proportional to load variation. As the change in the value of speed diminishes, the error signal becomes smaller and the position of the governor and fly balls get closer to the point, required to maintain the constant speed. One way to restore the speed or frequency to its nominal value is to add an integrator on the way. The integrator unit shall monitor the average error over a period of time and will overcome the offset. Thus as the load of the system changes continuously, the generation is adjusted automatically to restore the frequency to the normal value. This scheme is known as Automatic Generation Control. In an interconnected system consisting of several pools, the role of the AGC is to divide the load among the system, stations and generators so as to achieve maximum economy and reasonable uniform frequency.

When a group of generators are closely coupled internally and swing in unison, the generator turbines tend to have the same response characteristics. Such a group of generators are said to be coherent. It is assumed that the LFC loop represent the whole system and the group is called the control group. For a two area system, during normal operation the real power transferred over the tie line is given by:

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin \delta_{12}$$

Where $X_{12} = X_1 + X_{tie} + X_2$

and $\delta_{12} = \delta_1 - \delta_2$

For a small deviation in the tie-line flow

$$\Delta P_{12} = \left.\frac{dP_{12}}{d\delta_{12}}\right|_{\delta_{12}} \Delta\delta_{12} = P_s \Delta\delta_{12}$$

$$\Delta P_{12} = P_s\left(\Delta\delta_1 - \Delta\delta_2\right)$$

Where

$P_{12} =$ power flow between area 1 and area 2.

$E_1 =$ generated voltage of area 1.

$E_2 =$ generated voltage of area 2.

$X_{12} =$ reactance between area 1 & area 2.

$X_1 =$ reactance of area 1.

$X_2 =$ reactance of area 2.

$\delta_1 =$ load angle of area 1.

$\delta_2 =$ load angle of area 2.

$\delta_{12} =$ load angle between area 1 & area 2.

The tie-line power deviation then takes on the form

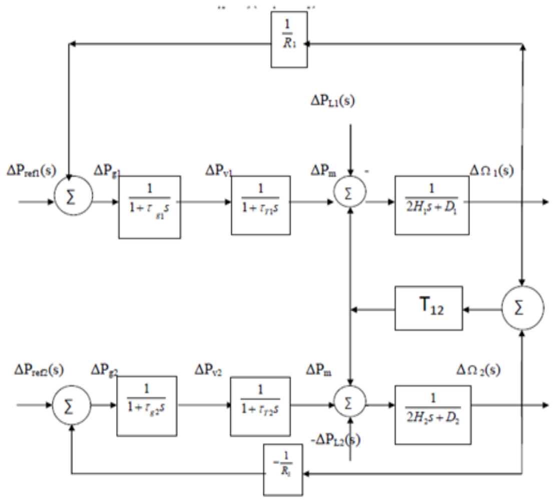

Fig.2 Tie Line Power Representation

B. *Frequency Control of DFIG:*

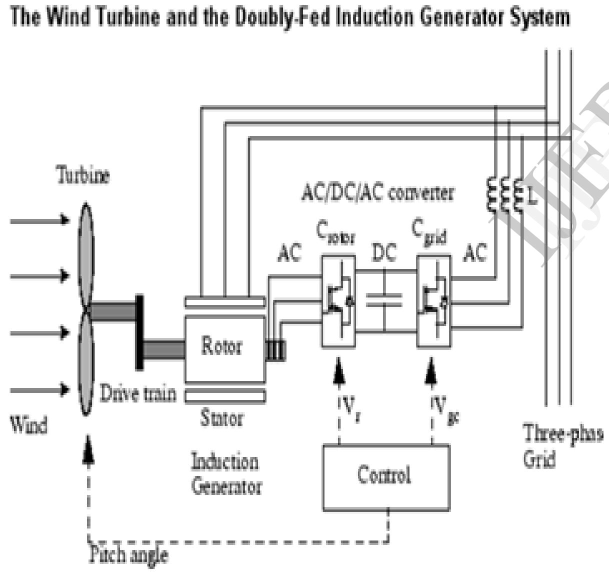

Fig.3 Wind Turbine and Doubly-fed Induction Generator System

In doubly feded electric machines, ac current is fed into both stator and rotor windings. Doubly-fed induction generators work on the doubly fed machines principle which is used in wind turbines to get the constant voltage and constant frequency irrespective of variation in wind speed. Due to this great feature of DFIG , doubly-fed induction generators can be directly connected to the ac power network and remain synchronized with the ac power network.

When the magnetic field at the rotor rotates in the same direction as the generator rotor, the rotor speed n_{Rotor} and the speed $n_{\phi,rotor}$ of the rotor magnetic field (proportional to f_{Stator}) add up. The frequency of the voltages induced across the stator windings of the generator can thus be calculated using the following equation:

$$f_{Stator} = \frac{n_{Rotor} \times N_{Poles}}{120} + f_{Rotor}$$

Where

f_{Stator} is the frequency of the voltage induced across the stator winding

and

f_{Rotor} is the frequency of the ac currents fed into the doubly-fed induction generator rotor windings, expressed in hertz (Hz).

Conversely, when the magnetic field at the rotor rotates in the direction opposite to that of the generator rotor, the rotor speed n_{Rotor} and the speed $n_{\phi,rotor}$ of the rotor magnetic field subtract from each other. The frequency f_{Stator} of the voltages induced across the stator windings of the generator can thus be calculated using the following equation:

$$f_{Stator} = \frac{n_{Rotor} \times N_{Poles}}{120} - f_{Rotor}$$

The SIMULATION model of frequency control scheme is shown below in fig.4.

The smart grid simulation model comprises of four units of thermal power plant i.e. P1, P2, P3 and P4, each having 900 MW capacity. Six units of wind power plant are added to this power system network having the total capacity of 12 MW.

Two different set of loads are used at bus bar B3 ant at bus bar B6. Magnitude of inductive and active loads are varied keeping the capacitive load constants to get the frequency of the system.

SIMULATION MODEL

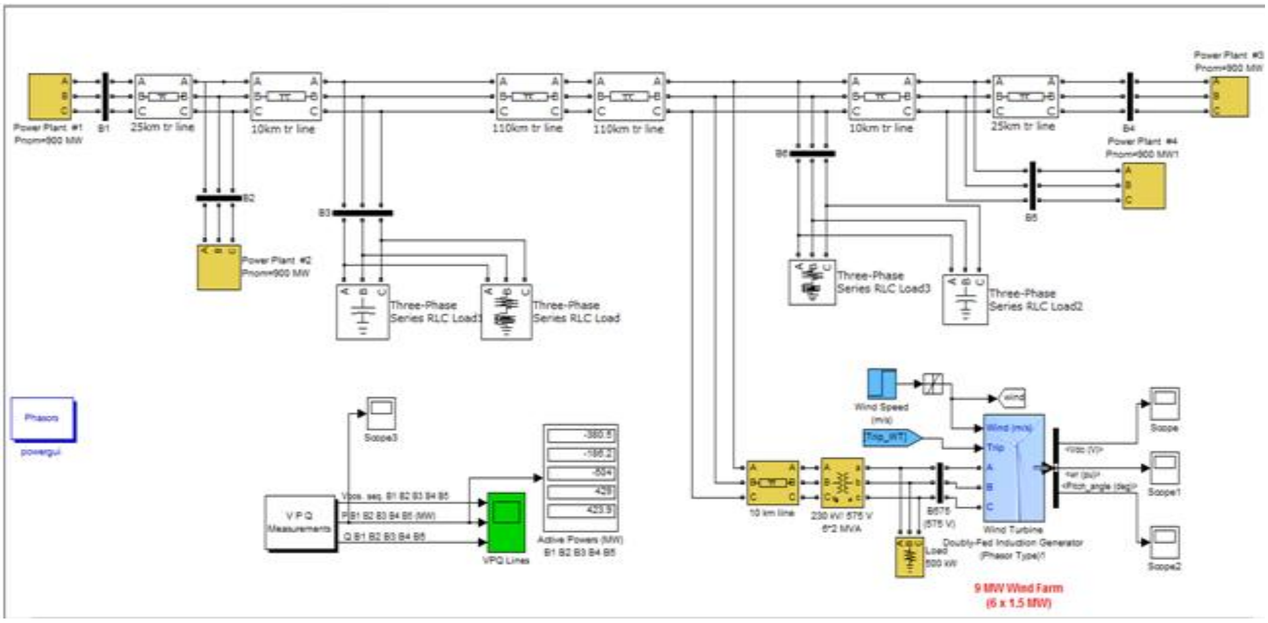

Fig 4. Frequency Control Scheme

The effect of load variation has been studied,which is as follows:

Sl No	Load at Bus 3			Load at Bus 6			Frequencies(In Hz)		% Frequency Deviation	
	Inductive (MVAr)	Active (MW)	Capacitive (MVAr)	Inductive (MVAr)	Active (MW)	capacitive (MVAr)	Minimum	Maximum	Negative deviation	Positive deviation
1.	150	1100	200	120	1900	350	49.90	50.292	-0.584%	0.20%
2.	180	1030	200	190	1950	350	49.72	50.105	-0.21%	0.56%
3.	190	1200	200	210	2100	350	49.81	50.06	-0.12%	0.38%
4.	130	1050	200	140	1850	350	49.87	50.03	-0.06%	0.26%
5.	120	1000	200	120	1800	350	49.96	50.33	-0.66%	0.08%
6.	100	960	200	100	1760	350	49.78	51.23	-2.46%	0.44%
7.	80	900	200	80	1700	350	49.72	50.24	-0.48%	0.56%
8.	70	800	200	65	1600	350	49.70	50.34	-0.68%	0.60%
9.	60	700	200	50	1500	350	49.63	50.55	-1.10%	0.74%
10.	50	650	200	40	1400	350	49.20	50.8	-1.60%	1.60%

III. RESULT AND DISCUSSION:

Four cases of different loads has been taken to check the stability of system:

A. CASE I

Load at BUS 3		
Inductive (MVAr)	Active (MW)	Capacitive (MVAr)
150	1100	200
Load at BUS 6		
Inductive (MVAr)	Active (MW)	Capacitive (MVAr)
120	1900	350

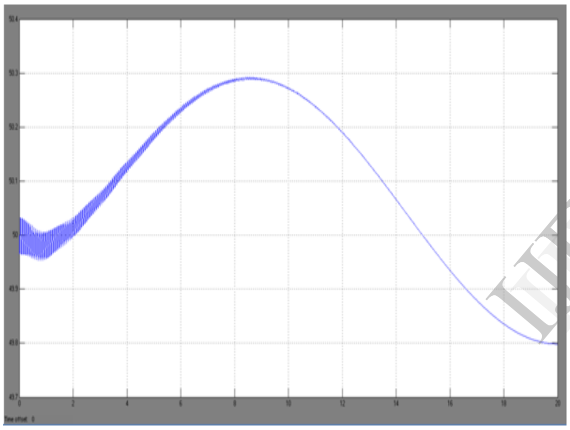

Fig. 5 Frequency of Thermal power plant for case-I.

It is observed that the f_{max}=50.29 Hz AND f_{min}=49.9 Hz. This is a stable working region of a power system network.

B. CASE II

Load at BUS 3		
Inductive(MVAr)	Active(MW)	Capacitive(MVAr)
190	1200	200
Load at BUS 6		
Inductive(MVAr)	Active(MW)	Capacitive(MVAr)
210	2100	350

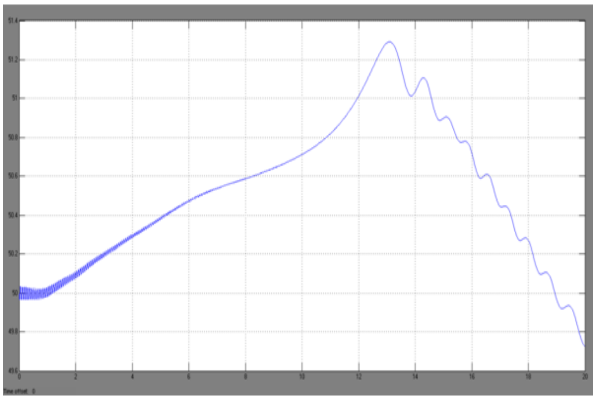

Fig.6 Frequency of Thermal power plant for case-II

It is observed that the f_{max}=50.06 Hz AND f_{min}=49.81 Hz. This is a stable working region of a power system network.

C. CASE III

Load at BUS 3		
Inductive (MVAr)	Active (MW)	Capacitive (MVAr)
100	960	200
Load at BUS 6		
Inductive (MVAr)	Active (MW)	Capacitive (MVAr)
100	1760	350

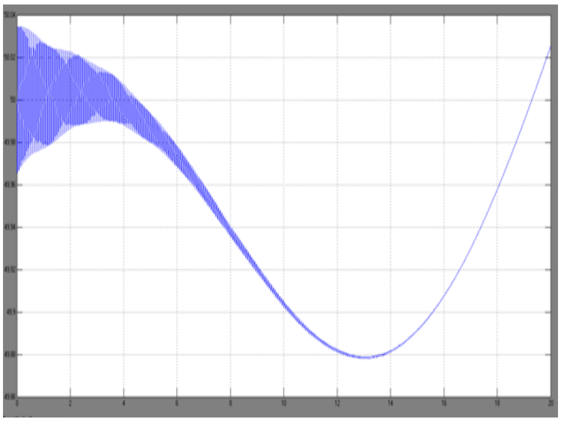

Fig.7 Frequency of Thermal power plant for case-III

It is observed that the f_{max}=51.23 Hz AND f_{min}=49.78 Hz. This is a stable working region of a power system network.

D. CASE IV

Load at BUS 3		
Inductive (MVAr)	Active (MW)	Capacitive (MVAr)
50	650	200

Load at BUS 6		
Inductive (MVAr)	Active (MW)	Capacitive (MVAr)
40	1400	350

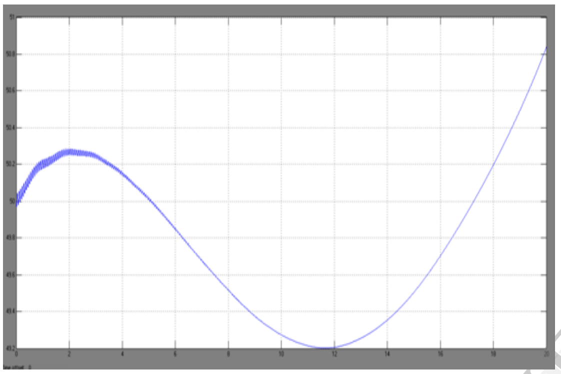

Fig.8 Frequency of Thermal power plant for case-4

It is observed that the f_{max}=50.80 Hz AND f_{min}=49.2 Hz. This is a stable working region of a power system network.

In load analysis of above simulation model, Inductive and Active loads are varied in RL series load which is taken at both load buses i.e. B3 and B6, whereas capacitive load is kept as it is with the initial value taken in series load. The value of capacitive load at bus bar B3 is 200 MVAr where as 350 MVAr of capacitive value is taken at bus bar B6. Initially active and inductive load at B3 is taken as 1100MW and 150 MVAr respectively and at B6 the value of active load is 1900 MW and the value of inductive load is 120 MVAr. The maximum and minimum frequency measured at these loads is 50.252 Hz and 49.90 Hz respectively. The positive frequency deviation is calculated to be 0.20% and the calculated value of negative frequency deviation is 0.584%. Since both the positive and negative frequency deviation result comes under the defined stable frequency deviation range which is ± 3%. This result shows that this smart grid power system is stable on these load values.

Inductive and Active loads at both buses has increased simultaneously and this is found that when inductive and active load values at bus B3 is 190 MVAr and 1200MW and load value at bus B6 is 210 MVAr and 2100 MW then active power measured at all buses namely B1, B2, B3, B4 and B5 are not constant throughout the process and it is varying time to time which is an undesirable result for a stable power system network. Although frequencies measured are within the stable range. Minimum and maximum frequencies measured at these load values are 49.81 Hz and 50.06 Hz respectively. The positive frequency deviation is 0.12% and 0.38% which is within ± 3%.

The maximum values of load has been taken to check the maximum load limit of this smart grid network and it has seen that at that maximum values of load, frequency is under stable range but nature of active power is no more compatible for applied load to their corresponding buses. So in another case, magnitude of both active and inductive loads has been decreased on both load buses to know the range of loads that can be attached to the power system network for a stable operation. To know these load ranges, value of inductive load on bus bar B3 is decreased to 50MVAr from their initial value which is 150MVAr and value of active load is decreased to 650MW from their initial value of 1100MW where as at bus bar B6, inductive load is decreased from 120MVAr to 40MVAr and active load is decreased from 1900MW to 1400MW. At these lowest load values, the values of maximum and minimum frequencies are measured to be 50.80 Hz and 49.20

Hz. The positive and negative frequency deviation is calculated to the same value of 1.60%. Although this frequency deviation comes under the defined frequency deviation range i.e. ±3% but it is seen that the worst power blackout which happened on July ’2013 in India occurred at 49.20 Hz only. So to take the standard of 49.20Hz, the load is varied to get the frequency value of 49.20Hz. So final range of inductive load on bus bar B3 is from 190 MVAr to 50 MVAr and final range of active load is from 1200 MW to 650 MW where as maximum variation of active load on bus bar B6 is from 2100 MW to 1400 MW and for inductive load the range is from 210 MVAr to 40 MVAr.

IV.CONCLUSION

In this paper, load analysis has been done on the designed smart grid to check the stability in terms of frequency deviation. Since the standard frequency deviation is defined in ± 3% range. Synchronization of the proposed system consists of both wind and thermal power plant has been considered to get a constant frequency output of the system. Constant frequency system is the combined effect of DFIG in wind power plant and ALFC loop in thermal power plant. Load Analysis has been done to know the maximum capacity of whole power system network by maximum positive and negative frequency deviation. The base frequency of the system is taken as 49.2 Hz considering the case of 2012 power blackout of India making the permissible limit to be ± 1.6% in place of ±3%.

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