Regulation of Frequency and Load Flow Study in a Multi-Area Power System Under Contingencies with the Inclusion of Wind-Generation

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Abstract: **A Sudden loss of a generating station and a sudden switching of heavy loads in the system are the major challenges for a power engineer. Coordinated scheduling of power is necessary to maintain the system parameters under control. In this paper a two-area power system is simulated for contingencies and the frequency deviation is controlled. The load flow studies are also conducted to study the behavior of the system. The results show that the variation of the frequency is within the allowable standards while the system is stable during the period.**

Index Terms: **Frequency Regulation, Wind Generation, Contingency, Multi-area system.**

I. Introduction

A multi area system model has been in practice for a long time [1]. The exchange of power between different areas is based on the balance between the generation and demand in each area. Over the years many advancements happening in the field of renewable energies made it possible to have power generation using sources like wind and solar extensively in MW scales [2-3].

It is a dual problem that the load is not controllable and the power generated by the wind turbines is unpredictable. These two problems are partly addressed in the literature individually [3]. There are advanced topologies available to make the power output of wind to be constant and demand side management makes it easy to control the generation based on generation-scheduling [4].

In each area of power system, the generation should be equal to the load plus the losses incurred in transmission of power [5]. Whenever there is a mismatch, the frequency in the system is varied accordingly. To regulate the frequency, deficit or surplus power should be generated or consumed respectively so that frequency is not deviated out of the limits of ±1%.

The stability of the system is understood when there are contingency studies performed on the system. These include faults, loss of generation units, equipment outages, switching on/off heavy loads etc., which impact the overall system behavior. The stability study includes the frequency deviation, observability and controllability of the system under transient and dynamic states of the system.

In this paper, contingency situation is created like loss of generation during steady state and loss of heavy load on the system, to analyze the system behavior like frequency deviation and load flow study.

The organization of this paper is done as follows: Section II describes the system under investigation. The wind generator model is briefly discussed in section III. Detailed analysis and discussion during contingencies are done with the simulation results in the section IV. The conclusions from the results are given in the section V.

II. System Under Investigation

A two-area power system is considered here in the paper. The description of the two areas considered in the paper is given below.

A. Area-1

Area-1 consists of a synchronous generator connected to a transmission line of 10KM length, which is in turn connected to the distribution system within the area. A wind generator is also connected to a grid via a 25 KM transmission line. The power is generated at a voltage of 575V. This is stepped up to a voltage of 20KV and then to 230KV for transmission. A combination of active and reactive loads is considered and modeled as RLC elements. These loads consume a total active power of 800 MW and a reactive power of 287 MVAR. The total capacity of the synchronous generators is 900MVA, while the rated capacity of the wind generator is 500 MVA. The wind turbine and generators are modeled to have variable wind speeds as input and proportional output can be expected from the stator terminals of the generator.

B. Area-2

The second area considered in the paper consists of a similar system with two generators serving a total active power demand of 100 MW and a total reactive power of 437 MVAR.

Generator-1 having a capacity of 900MVA is connected to the PCC via a step-up transformer (20KV / 230 KV) through a transmission line of 10KM length.

Generator-2 of 900MVA capacity is connected to the PCC through a 25KM line at 230KV using a step-up transformer.

The parameters of the transmission line and the transformer are given in Table-1. The schematic of the

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system considered for area-1 and area-2 are shown in Fig. 1 and Fig. 2.

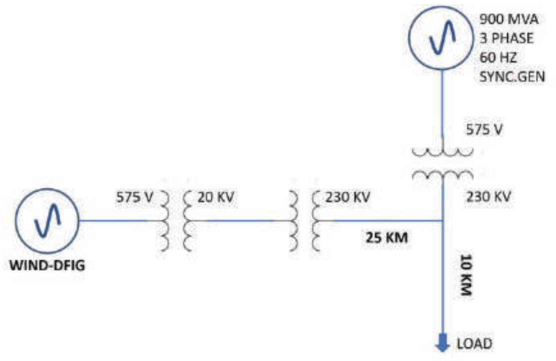

Figure 1. Single line diagram for Area-1.

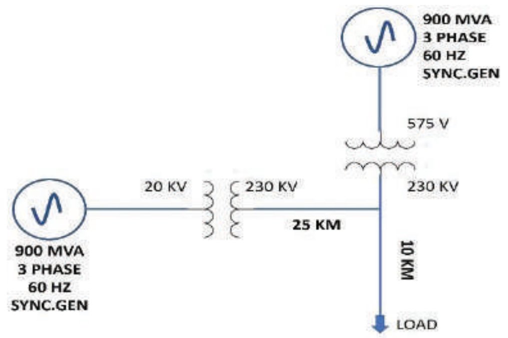

Figure 2. Single line diagram for Area-2.

TABLE I.
TIE LINE TRANSMISSION CONDUCTOR PARAMETERS

Parameter	Value
Resistance per unit length (Ohms/km)	0.0529
Inductance per unit length (H/km)	0.001403
Capacitance per unit length (F/km)	5.014e-9
Line length (km)	220

C. Interconnected System

For power exchange between two neighboring areas, tie-lines are provided [6]. Whenever there is a deficiency of power experienced, a request to buy power can be raised to the neighboring area [7]. Similarly, if there is excess power generation happening in the area, it can be sent to the other areas based on their requests. In this paper a double circuit line is taken between the two areas, separated over 220KM. One of the lines has circuit breakers connected at both ends. The parameters of the tie-line are given in Table II. The overall schematic of the system is shown in Fig. 3.

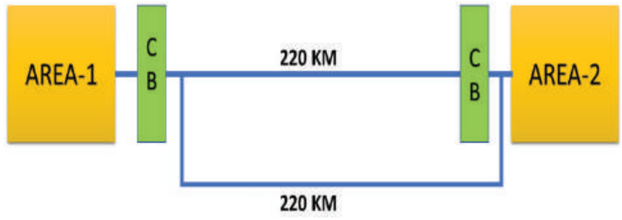

Figure 3. Overall Power System Considered

III. WIND GENERATOR – MODEL CONSIDERED

The wind generator considered in this paper is a doubly fed induction generator suitable for controlling the power output of the generator, as the stator and the rotor are controllable [8]. Here the stator output terminals are tapped and a part of the power generated is used to control the rotor. Maximum energy can be extracted from the varying wind speed energy by electronically interfacing the rotor conductors. The power electronic circuit typically includes AC to DC and DC to AC converters connected back to back. (Less than 25% of the generated power is used for this purpose). The main purpose of this is to convert varying output power to a constant power with controllable frequency and amplitudes. The power factor compensation can also be provided on-board with the electronic circuit with low expenditures. [9-12].

One of these converters is on the grid side and the other is on the machine side. The schematic for voltage control and hence the power factor control is done as shown in the block diagram below. The overall schematic of the doubly-fed induction generator is as shown in Fig. 4. The MATLAB model used in the simulation is considered with the following parameters shown in Table II.

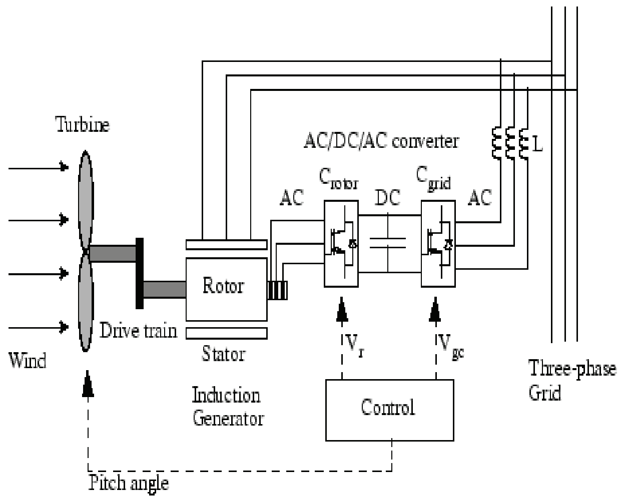

Figure 4. Wind Generator Schematic diagram

IV. Contingency Analysis And Simulation Results

The system described in the Fig. 3 is simulated in MATLAB as shown in Fig. 5.

TABLE II.
WING TURBINE-GENERATOR PARAMETERS

Parameter with units	Value
Nominal power (VA)	6*1.5e6/0.9
line-to-line voltage (Vrms),	575
frequency (Hz)	60
Nominal wind turbine mechanical output power (W):	6*1.5e6
Pitch angle controller gain [Kp]:	500
Converter maximum power (pu):	0.5
Grid-side coupling inductor [L (pu) R (pu)]:	[0.15 0.15/100]
Nominal DC bus voltage (V):	1200
Droop Xs (pu):	0.02
Grid voltage regulator gains: [Kp Ki]	[1.25 300]
Reactive power regulator gains: [Kp Ki]	[0.05 5]
Power regulator gains: [Kp Ki]	[1 100]

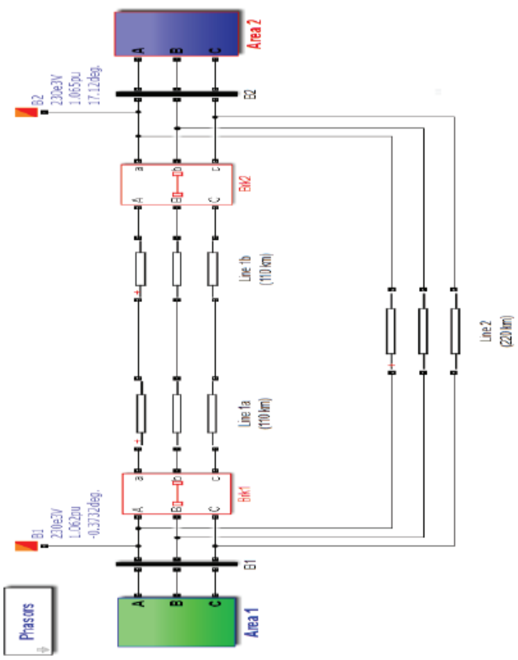

Figure 5. MATLAB model considered for the overall power system

Two different contingency situations are considered here in the paper as discussed in chapter I. They are (i) Loss of heavy load in Area-1, making the generation more than the demand and hence the frequency is expected to shoot up. Secondly, (ii) Loss of generation in Area-1, so that the generation is less than the demand. In this case, the frequency is expected to be less than the nominal.

The behavior of the system under a steady state with no contingencies is analyzed first. The system is simulated from an initial state/zero state. The load flow study is conducted on the system at the buses mentioned in Fig. 5 and the results are given in Table III. The frequency of the system and the power consumption levels are shown in Fig. 6 and 7.

TABLE III .
LOAD FLOW STUDY SCENARIO-1

Appearance		
PARAMETER	P(MW)	Q(Mvar)
Total generation	15.95807	16.40149
Total PQ load	0	0
Total losses	0.538139	15.98149
B1 V= 1.000 pu/230kV -23.67 deg		
PARAMETER	P(MW)	Q(Mvar)
Generation	-134.042	13.06714
PQ Load	0	0
B1	-144.252	12.85714
B2	144.79	3.124345
B2 V= 1.000 pu/230kV 0.00 deg ; Swing bus		
PARAMETER	P(MW)	Q(Mvar)
Generation	-134.042	13.06714
PQ Load	0	0
B1	-144.252	12.85714

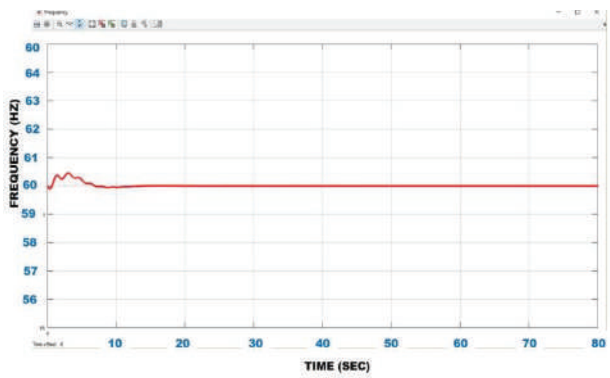

Figure 6. Frequency response under normal conditions

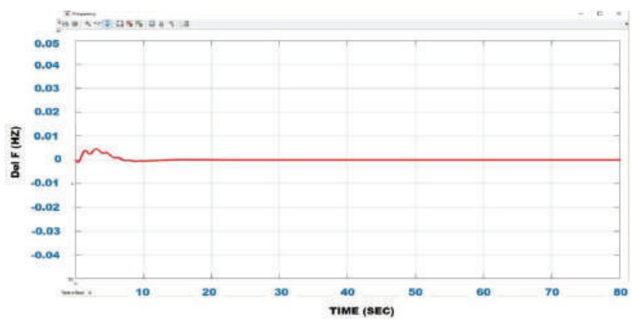

Figure 7. Change in Frequency response under normal conditions

A. Scenario-1 loss of load:

The system is scheduled to expect a loss of heavy load (900 MW) at time t= 40s. Various parameters like frequency, real power and reactive power drawn from the sources, the load sharing at the buses, the voltage profiles at the buses can be analyzed pre and post event using the Table III obtained from the simulation of the system for a time of 80s.

From Fig. 8 and Fig. 9, we can analyze that the system frequency variation after the event has to be controlled and limited to be within the acceptable range of ±1% which is [59.4 60.6]. A maximum excursion of 0.6% is present and it is settled within 10s.

Scenario-2 Loss of Generation:

Due to unexpected lower wind speeds, (speeds less than the cut-in speeds of the turbine), the generator output is not sufficient to be synchronized with the grid. So, there is a loss of generation expected/scheduled at 40s.

Fig. 10 shows the frequency variation in the system during pre and post events. At 40s, there is a disturbance in the frequency, but due to the help of area-2, the frequency is restored. The disturbance caused in the area-2 frequency can also be observed in the figure 10.

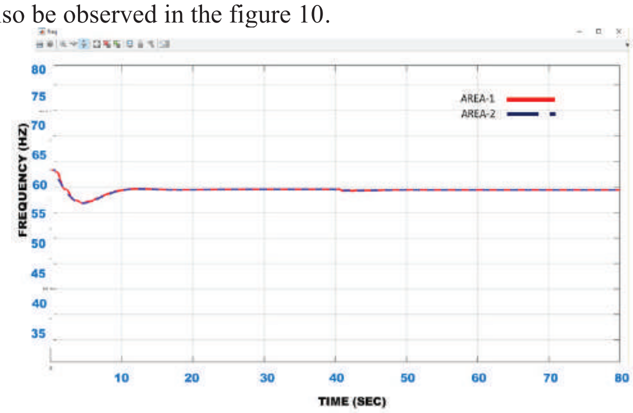

Figure 8. Frequency response under Scenario-1 in Area-1,2

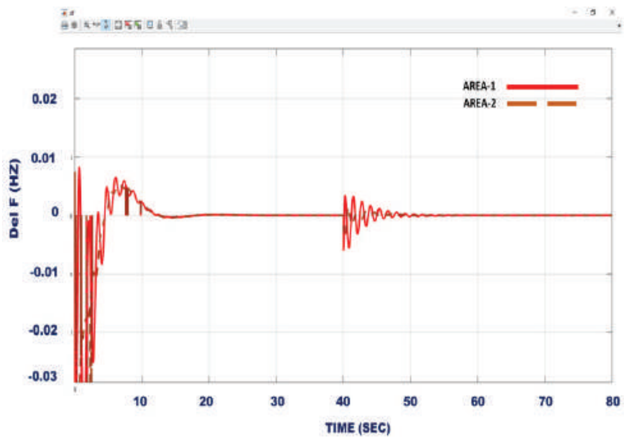

Figure 9. Change in Frequency response under Scenario-1 in Area -1,2

The maximum rate of change of frequency can also be observed from the Fig. 13. The minimum and maximum frequencies during the event are 59.96Hz and 60.04Hz which are limited to the standards of allowable deviation of ±1%.

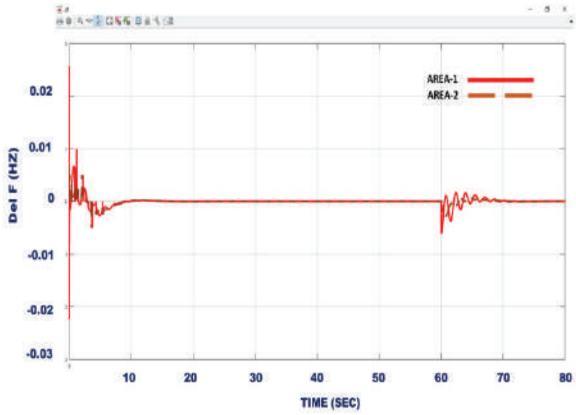

Figure 10. Frequency response under Scenario-2 in Area-1,2

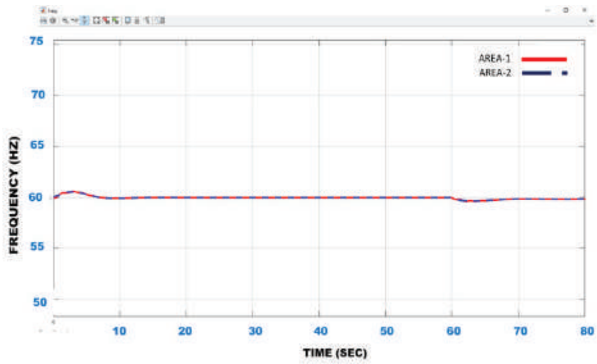

Figure 11. Change in Frequency response under Scenario-2 in Area -1,2

V. Conclusions

A multi-level power system is considered in the paper with wind-energy generation in area-1. The contingency situations of sudden loss of generation and sudden loss of loads are simulated for a two-area system with one of the areas having Wind-turbine generator. The results show that the frequency deviation and the voltage profiles are within the limits in the two situations.

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