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Automatic Generation Control in a Smart Grid using Electrical vehicle as a Battery Energy Storage System

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Abstract*: *The Load Frequency Control (LFC) problem in a smart grid is presented in this paper. For the visualization of the problem, an isolated two area restructured power system contains thermal-thermal non-reheat unit with distributed wind energy system considered. In the study presented here efforts have been put to visualize and realize the LFC problem because of sudden load variation and uneven wind power in the smart grid. The generators are assumed working in Automatic Generation Control (AGC) mode under the bilateral market contract to meet the load demand. For visualization of load frequency control problem with local load variation of +20% and wind power which further add in sudden load deviation has been considered. Generators running under AGC mode are facing the cyclic and random load frequency fluctuations due to this sudden load variation and grid-connected wind power. In this way to enhance the solution the grid-connected aggregated EV batteries are used in distribution areas in the simulation with charging and discharging mode as distributed battery energy storage. The effect of grid-connected EV has studied for the improvement in stability as well as system dynamic response. From the results it is observed that the peak overshoots and settling time in load frequency fluctuations have minimized during the sudden load variation and wind power fluctuations.

Keywords: AGC, Wind Power, restructured power system, Electrical Vehicles.

I. INTRODUCTION

Worldwide an electric power system is under restructuring and has adopted deregulated market practice [1]. Today, after installation of Renewable Energy Sources (RESs) at many places in the existing grid, the grid becomes a smart grid. The nature of these renewable sources is also unpredictable under weather conditions. Due to the environmental problem throughout the world like greenhouse gas emission, the power generation from wind energy source has become most popular RES.If generator is taking part in AGC operation repeatedly, will increase in the wear and tear of generator, high maintenance costs and thus operational effectiveness of generator will diminish. Also, it leads to enlarging in generation cost. So, due to deliberate response of the governor which is not competent to pay off sudden load changes for a stretched time [3]. So it may be better option to regulate grid frequency from demand side, so generators will not disturb [4]. Also, because of uneven wind velocity the power generation from wind cannot be kept constant and occasionally cause the mismatch between generation and demand. To enhance the problem of LFC, a large capacity of Battery Energy Storage System (BESS) considered, but becomes significantly expensive [5]. Recently in the smart grid, ability of the technologies such as distributed generation and controllable loads are point out. So, the detailed study has been carried out from the contribution of many researchers worldwide in the controllable loads such as heat pumps, water heaters and electric vehicles for the reduction of the BESS installation. It has found that because of advance lithium iron battery and development in charging infrastructure, a large amount of Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs) expected in the future as low carbon energy system .It indicates a large potential in grid-connected PHEVs and EVs. An aggregated EVs become virtual power pool of MW class, which can contribute in the LFC problem by information exchange to the Load Dispatching Centre (LDC) or Independent System Operator (ISO) [6]. LDC or ISO dispatches the LFC signal to all EVs. The batteries of EVs in a two-way power converter can be charged and discharged, and the EVs can be controlled like BESS. The problems caused by integration of renewable energy sources such as frequency deviations can also be solved. An EVs having an electric motor instead of engine have gained many attractions in the next-generation vehicles. The EVs batteries can work in both the ways of charged and discharged through bidirectional converter/charger, so in the grid EVs can operate and control like BESS [7]. In this paper for the solution of LFC problem, a fleet of EV model is with an integration of wind energy source. Moreover, a load frequency control method based on the dispatching of the LFC signal proposed, which enables the State of Charge (SOCs) of all the EVs to be synchronized.

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II. Description of Smart Grid

The smart grid of two area power system with thermal – thermal non-heat unit incorporation with the wind energy system and Electrical Vehicles presented in Figure 1.Two area restructured power system is considered for the simulation as presented in [1].

In which, Area 1 presented with 2 numbers of Generating Companies GENCO1 and GENCO2 with 2 numbers of distribution companies DISCO1 and DISCO2. Similarly, Area 2 presented with 2 numbers of Generating Companies GENCO3) and GENCO4 with 2 numbers of distribution companies DISCO3 and DISCO4. To visualize the load frequency control problem local load represented in the area1 and area2. Wind power also represented in grid-connected to the common coupling. To normalize the load frequency and enhance the AGC problem BESS as an aggregated EVs battery considered and connected locally in both areas.

Figure 2 represents the block diagram of wind turbine operated by pitch control [14] including transducer to measure power, set point to control power, a proportional plus integral close-loop function and a hydraulic actuator to vary the pitch of the blades. Pitch control of wind turbine having a significant impact on dynamic system behavior. This type of variable pitch turbines as compared to fixed pitch machine operates efficiently over a wide wind speed range.

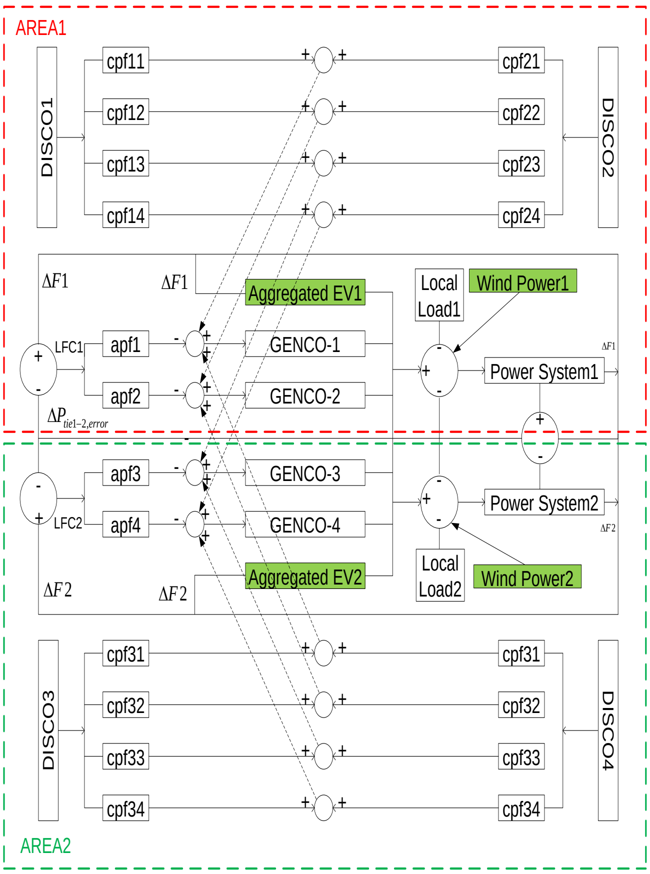

Fig. 1 Block diagram representation two area restructured smart grid.

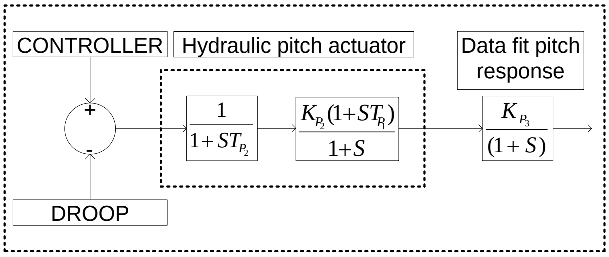

Fig. 2. Block diagram representation of wind turbine with pitch control

III. Mathematical Modelling of the Restructured Model of Power System Under the Bilateral Contract.

The mathematical models of thermal-thermal non-reheat unit [10], EV modelling [11] and wind turbine modelling used for the simulation, which is based on the small-signal analysis. The thermal power plant with various components such as speed governor, steam turbine and generator are modeled and furnished in IEEE Committee Report (1973) and the same model used in this work. The transfer function for wind turbine with blade pitch control mechanism is considered and presented in 150 KW MOD-OA- horizontal axis machines installed on Block and Rhode Island, USA [12][13]. A first order system describes the wind power generating unit dynamics model. Any mismatch between supply and load results in frequency deviations, which generates area control error (ACE) and it is sent to the PI integral controller to establish the frequency control. The controller is tuned using internal mechanism inbuild in the MATLAB/SIMULINK. Following the PI controller signal the governor will respond to match the supply and load by moving the steam valve. Thus turbine torque mechanical power will control and finally electrical power will control through generator.

To represent the contract among the generating and distribution companies, a DISCO participation matrix (DPM) is presented eq. 1. In DPM matrix the number of rows equal to the number of GENCOs and the number of columns equal to the number of DISCOs in the system. Matrix shows the total load side power contracted by DISCOs with respective GENCOs. Hence are the names a “DISCO Participation Matrix”. The DISCO participation matrix (DPM) represents the contract of any DISCO with any GENCO under the supervision and approved by Independent System Operator (ISO) [8].

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \quad (1)$$

Where, $\sum_i cpf_{ij} = 1$,”cpf” is known as “Contract Participation Factor”. CFD information is transmitted to respective GENCO to follow the demanded load by the DISCO.

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The"apf" refers to "Area participation factor represents the participation of respective area generator in AGC.Here, the diagonal elements represent the local demand and off diagonal elements corresponds to the DISCOs demand in one area to another area GENCOs. Suppose, total 150 MW power demanded toGENCO3.From 150 MW DISCO1 is demanding 30 MW, DISCO2 is demanding 45 MW, DISCO3 is demanding 60 MW, and DISCO4 is demanding 15 MW. Then column 3 entries in (1) are easily defined as in (2). The following mathematical formulas used for the simulation of two area power system [8].

$$cpf_{13}=\frac{30}{150}=0.2,\quad cpf_{23}=\frac{45}{150}=0.3,$$
$$cpf_{33}=\frac{60}{150}=0.4,\quad cpf_{43}=\frac{15}{150}=0.1. \tag{2}$$

The contracted power supplied by i[th] GENCO given as

$$\Delta P_{gi}=\sum_{j=1}^{DISCO4} cpf_{ij}\Delta P_{Lj} \tag{3}$$

$$\Delta P_{L1,LOC}=\Delta P_1+\Delta P_2$$
$$\Delta P_{L2,LOC}=\Delta P_3+\Delta P_4 \tag{4}$$

Where ΔP_{Lj} is the total demand for DISCO$_j$. $\Delta P_{L1,LOC}$ and $\Delta P_{L2,LOC}$ are local load variation in area 1 ($\Delta P_1+\Delta P$) and area 2 ($\Delta P_3+\Delta P_4$).

The tie-line power flow is given as,

$$\Delta P_{tie1-2,scheduled}=(denad\ of\ DISCOs in\ area\ II\ \ from\ GENCOs\ in\ area1)-(denand of\ DISCOs in\ area\ I\ \ from\ GENCOs in\ area\ II)$$

$$\Delta P_{tie,12,schedule}=\sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj}-\sum_{j=3}^{4}\sum_{i=1}^{2} cpf_{ij}\Delta P_{Lj} \tag{5}$$

$$\Delta P_{tie1-2,actual}=\left(\frac{2\pi T_{12}}{s}\right)(\Delta F_1-\Delta F_2) \tag{6}$$

$$\Delta P_{tie1-2,error}=\Delta P_{tie1-2,actual}-\Delta P_{tie1-2,scheduled} \tag{7}$$

The error signal is used to generate the Area Control Error (ACE) signal of the particular area as in the traditional scenario [2], [3], [9].

$$ACE_1=B_1\Delta f_1+\Delta P_{tie1-2,error}$$
$$ACE_2=B_2\Delta f_2+a_{12}\Delta P_{tie1-2,error} \tag{8}$$

$$a_{12}=-\frac{P_{r1}}{P_{r2}} \tag{9}$$

Where, P_{r1} and P_{r2} (Rated capacities of area 1 and area 2.)

Through the DPM matrix, GENCO feeds power to respective DISCO as per the contract. The effects of actual loads on the system dynamics shown through the input $\Delta P_{L,LOC}$. The load frequency control signal (LFC) generated due to any mismatch between GENCOs and DISCOs because of contracted or uncontracted load will dispatch to the GENCOs according to ACE participation factors, i.e. apf_1, apf_2, apf_3 and apf_4 .As per the AGC integral control law is shown in (10) the gain is optimized.

$$U_i=-K_{1i}\int ACE_i dt \tag{10}$$

A. Electrical Vehicle Control Scheme

The conventional control methodology could not absorb the frequency deviation completely because of slow dynamic response against load fluctuation. By considering the dynamic response, the EVs are faster than the turbine and governor of thermal generator [17]. So, EVs are liable for the reduction in the peak value of frequency oscillations and the turbine-generator are used for the steady-state error of frequency deviations. As a job of transmission system operator (TSO) to balance generation and load the LFC signal followed by Area Control Error (ACE) signal is sent to all the EVs. The frequency deviations due to generation and demand imbalance can be observed at from home outlet too [17]-[18]. So, EVs can work from the home outlet. So, EVs can keep the regional balance [2] and restore the frequency to the nominal value and the tie-line flow to their desired value [8]. It can calculated from (12). These controls are equivalent to the LFC operation of thermal or hydropower generators. Based on LFC an EVs can control the charging power as shown in Figure 3, which handle the fluctuation caused by sudden load variation. The delay calculation function T_{V2Gi} for the aggregated EV fleet represented by the first-order transfer function [2],[14],[15].

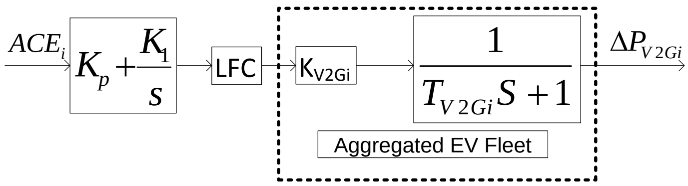

Fig. 3 V2G Model

$$LFC=-\frac{ACE_i}{K_{V2Gi}} \tag{11}$$

The power output of EV control methodology created on Area Control Error (ACE) and droop characteristics (MW/Hz)against frequency deviations of Electrical Vehicle (EV), which is a change in power divided by a change in frequency as shown in Figure 4. Linear characteristics between 49.7 to 50.04 Hz (CERC, 2016) is considered [8].

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The ACE signal dispatched is in proportional to the magnitude of a gradient. Due to positive ACE, a LFC signal becomes negative it means battery charging power for EV will be increased, when negative ACE will be there LFC signal delivered to EVs is positive, means increases in discharging power. The PI gain controller is used, which is the MATLAB/SIMULINK inbuilt function.

Following the area requirement, the aggregators receive the signal of power set point from the control centre and LFC signals allocated to disperse EVs. The bidirectional power electronics devices allow EVs to pump/absorb energy in to/from the grid and their power capacity can be contributed to the LFC control as power plant.

B. V2G Power Control

The decentralized V2G control method is used to maintain the power output (P_{V2G}) / (P_{G2V}) by the charging/discharging characteristics followed by fig.4. The battery power can control as follows

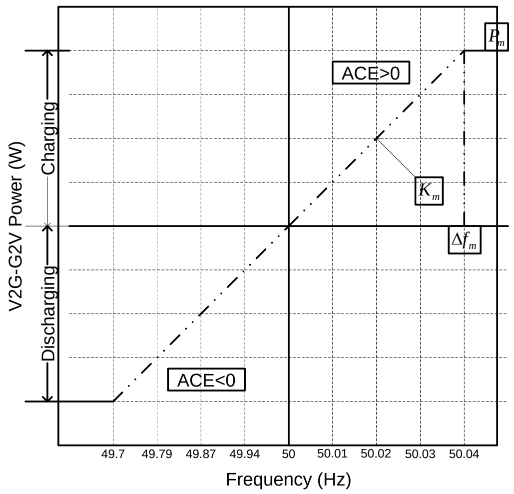

Fig. 4 V2G power Charging/Discharging control

$$P_{V2G} = \begin{cases} K_{V2G}\Delta f & (\Delta f \geq 0) \\ Pm & \left(\left|K_{V2G}\Delta f\right| \geq P_m\right) \end{cases} \tag{12}$$

$$P_{G2V} = \begin{cases} K_{G2V}\Delta f & (\Delta f < 0)) \\ -Pm & \left(\left|K_{G2V}\Delta f\right| \leq -P_m\right) \end{cases} \tag{13}$$

Where, K_{V2G} and K_{G2V} are charging and discharging droop. These are the gain tuned by taking a tradeoff between the V2G/G2V effect according to the battery state of charge (SOC) deviation range into consideration. P_m is the maximum V2G/G2V power defined by EV. The gain K_{V2G} and K_{G2V} can be computed by

$$K_{V2G} = K_m\left[1-\left(\frac{SOC - SOC_{low(high)}}{SOC_{\max(\min)} - SOC_{low(high)}}\right)^n\right] \tag{14}$$

$$K_{G2V} = K_m\left[1-\left(\frac{SOC - SOC_{high(low)}}{SOC_{\min(\max)} - SOC_{high(low)}}\right)^n\right] \tag{15}$$

Where $SOC_{\min}, SOC_{low}, SOC_{high}, SOC_{\max}$ and n are the minimum battery SOC, Low battery SOC, High battery SOC, maximum battery SOC and design parameters, respectively. To predict the SOC level, V2G control and plug-in time, it is required to develop an algorithm.

C. Battery SOC deviation control

The charging power (P_{V2G}) and discharging power (P_{G2V}) can be controlled by tuning the gain K_{V2G} and K_{G2V} against frequency deviations by LFC based PI controller. For the optimal performance to track the changes in the power system PI controller is used. Value of K_{V2G} and K_{G2V} depends on the maximum and minimum state of a charge state of charge (SOC=Actual capacity/ Rated capacity) value. Here, the range maximum (90%) and minimum (30%) for SOC in both the area1 and area2 considered. A battery of EV will charge in the range of inverter capacity. For maximum and minimum value of SOC, the integral absolute error (IAE) values of the SOC deviation in area 1 and area 2 are applied in the problem as follows [16].

$$IAE\ of\ \Delta SOC_{Area1} = \int_0^\infty \left|\Delta SOC_{Area1}\right| dt \tag{16}$$

$$IAE\ of\ \Delta SOC_{Area2} = \int_0^\infty \left|\Delta SOC_{Area2}\right| dt \tag{17}$$

IAE values of the SOC deviations can be calculated for multiple EVs from (14) and (15) by multiplying the total number of EVs in respective areas [24], [28]. The value of IAE subjected to,

$$\begin{aligned} K_{pi,\min} &< K_{pi} < K_{pi,\max} \\ K_{Ii,\min} &< K_{Ii} < K_{Ii,\max} \end{aligned} \tag{18}$$

Where, i= area1 and area2, $K_{pi,\min}$ and $K_{Ii,\min}$ are the minimum value of proportional and integral gain values for the controller $K_{pi,\max}$ and $K_{Ii,\max}$ are the maximum values of proportional and integral gain values for the controller.

IV. CASE STUDY:

In the bilateral contract, all the DISCOs can contract with any GENCOs for power as per the DPM gave in (12). It has assumed that each DISCO demands same power from GENCOs and each GENCO participates followed by an AGC as per $apfs$ given below,

$$apf_1 = 0.75, apf_2 = 1 - apf_1 = 0.25, \; apf_3 = 0.5, apf_4 = 1 - apf_3 = 0.5$$

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix} \tag{19}$$

The total load variation of 200 MW in each area1 and area2 ha taken into consideration. The comparative results of with and without grid-connected EVs has represented in Fig. 4(a) to (d). It observed that the peak overshoots and deviations in power, tie line and frequency are reduced in case of grid-connected EVs. Fig. 4(a) to (b) shows the simulated results of the generated powers of four GENCOs. Fig. 4(c) shows the results of frequency deviations and Fig. 4(d) shows the actual flow on the tie line. Calculated values of generated power have shown in Table III.

A. Results:

Figure 5describes the deviations in the power system due to the sudden load of variation of 20% (200MW) in area 1 and area2 each. The calculated and simulated GENCOs power are 150 Mw, 45 Mw, 195 Mw and 55 Mw in GENCO1, GENCO2, GENCO3 and GENCO4 respectively. The tie-line power is -50 Mw presented in table 1 and figure 7. Similarly, Figure 6 and 8 represents the frequency deviations in area 1 and area 2.From the results it can be visualized that the power and frequency deviations result it can be normalized by integration of Battery Energy Storage.

Table 1 Calculate Power

	Change in Generation				Tie Line
Unit	G-1	G-2	G-3	G-4	
MW	105	45	195	55	-50

V. Conclusion

Sudden load variation and cyclic fluctuation in wind power create an imbalance between generation and load, which increases the deviations of the grid frequency. Presently, to compensate the frequency deviations, generators running under the AGC control loop having slow response. Frequent participation of the generators in AGC operation increases maintenance cost due to wear and tear of generators, reduces the life of the generator and its performance. Also, sometimes generators are tripped too. From the simulated results can be observed that due to the fast damping response of battery against frequency deviations, the peak overshoots and time-period to settle down the frequency reduced. Also, tie-line power flow error can reduce. There is a tremendous scope in the area of coordination of EVs to plug in and plug out.

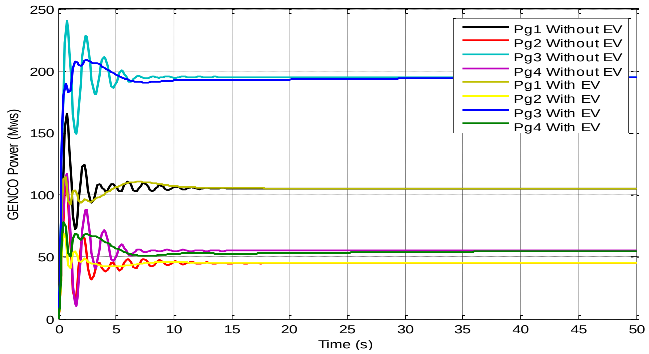

Fig. 5 GENCO power deviations

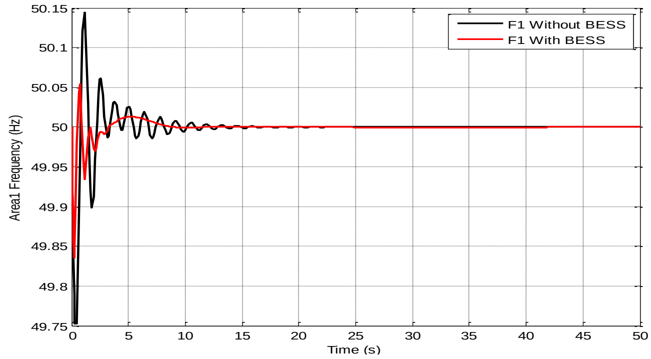

Fig. 6 Frequency deviations in Area1.

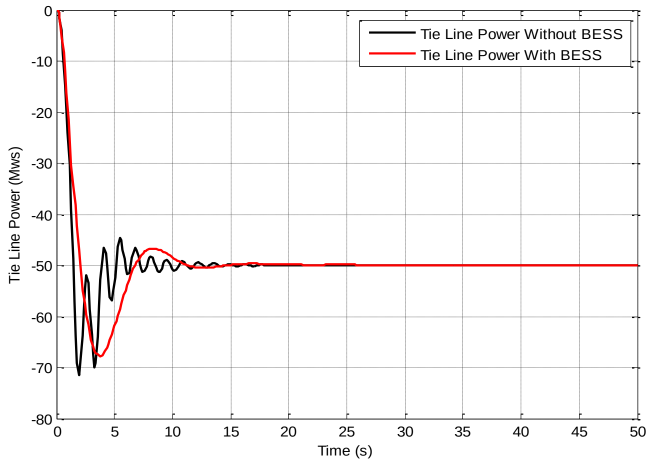

Fig. 7 Tie line power deviations

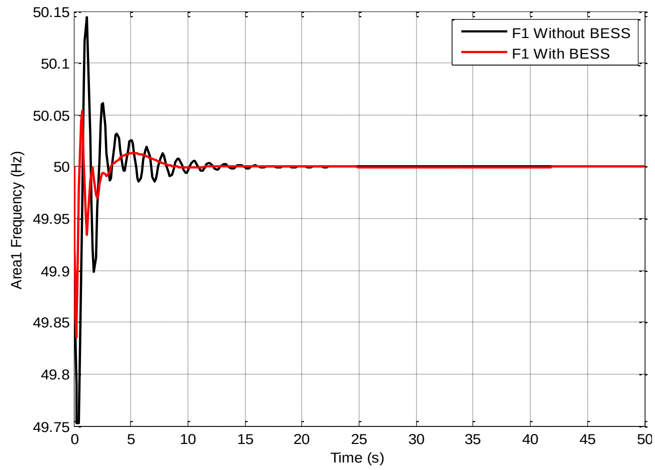

Fig. 8 Frequency deviations in Area1.

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