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Multi-Area Automatic Generation Control Scheme including Renewable Energy Sources

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Abstract

In this paper, a multi-area Automatic Generation Control (AGC) scheme with Renewable Energy Sources (RES) suitable in a restructured interconnected power system has been proposed. Photo-voltaic and wind turbine generating system has been integrated with the grid. The developed scheme has been investigated for frequency control with and without RES units. A PID controller has been used to control the real power output of fossils fuel generators. The parameters of PID controller has been tuned according to Genetic Algorithm (GA) based performance indices. The functioning of proposed scheme has been tested on a 39-bus New England system and on a 75-bus Indian power system network. Frequency regulation market scenario has been considered in both the systems. The results of proposed AGC scheme with and without RES units have been compared.

Keywords: *renewable energy sources (RES), PV system, WTG system, flywheel energy storage system (FESS)*

1. Introduction

Around the world, governments have been paying more attention on policies that promoting the clean or Renewable Energy Sources (RES) to serve customer demand. Renewable energy currently provides more than 14% of the world's energy supply [1]. According to the some part of the world's weather conditions, it does not allow the construction of photovoltaic (PV) plant only and/or wind generator (WG) only stand-alone plants, despite the availability of these technologies for energy supply in off grid systems. Thus, the hybrid plants are guaranteed the continuity of the supply mixing the different renewable energy resources – like PV, WG, even micro-hydro – limiting the diesel generator set (DGS) use for back-up purpose only. In addiction a hydrogen fuel cell (FC) can be added to the designed hybrid plant in order to realize a system without DGS [2]. In connection to this, RES technology such as Photo-voltaic (PV) system and Wind Turbine Generator (WTG) are the two most attractive technologies.

The photovoltaic (PV) plants, on the cost point of view, have some disadvantages over other conventional energy resources. In the restructured power system scenario, without specific public incentives which calculate the social advantages offered by PV technology, the photovoltaic is not yet competitive with other resources. The price per watt for a PV module decreases in the recent years, specifically, the price/Watt peak in European countries has declined from €5.5 in 2001 to €2.1 in 2011 [3]. The thermal conventional technologies are actually more expensive in term of social costs, but customers no directly pay this social cost that is in charge on the society [4]. The influence of PV system on power system frequency control is discussed in [5].

Integrating WTG system with energy storage units in a multi-area Automatic Generation Control (AGC) scheme, the generated electric energy can be effectively controlled the frequency deviation and meet the demand of control area. The desired characteristic of WTG systems (wind farm) is to get the maximum output power for a certain wind speed. When the

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WTG systems connected to a grid, the wind farm will have no reserve to supply power under emergency i.e. when the grid frequency is low. In order to participate RES units particularly, WTG systems in frequency regulation, the wind farms should operate with reserves. When the system frequency is higher or lower than the nominal value, the pitch controller of wind farms helps to increase or decrease the captured wind power and this feature helps the wind farms to participate in power sharing [6].

The grid frequency can be controlled by controlling the real power output of the conventional generating plants. RES can be used for frequency regulation services. Advantage of using RES is that energy can be stored in energy storage system when it is in abundance and later on, it can used to bring the system frequency at nominal value. Nowadays, energy storage devices like Flywheel Energy Storage System (FESS) [6-8], battery storage energy storage (BESS) [9-10], advanced capacitor [11-12], superconducting magnetic energy storage (SMES) [9, 13] are used for frequency regulation application.

Dynamic properties of wind turbin have been discussed in [14]. The proposed dynamic model of wind turbin consideres rotational effects of blade in mathematical equation form and then sove it using finite element method. Due to the non-linear characterstic of fuel cell model, a large change in the output voltage of fuel cell take place, when load changes, therefore for the application of feul cell in distributed generation system, a constant output voltage of feul cell is required [15].

This paper presents a multi-area AGC scheme including RES systems suitable in competitive electricity market. The developed scheme analyzes the effect of RES systems on frequency regulation. In modeling the RES systems, direct conversion of the sunlight and wind speed into electricity has been utilized in case of PV systems as well as in case of WTG systems also. A FESS has also been integrated with PV and WTG systems. In this work it is assumed that the RES units are delivering its maximum real power output at a given time while proportional, integral and derivative (PID) controller has been used to change the real power output of conventional generators. Parameters of the PID controller are tuned using the Genetic Algorithm. Integral of the square of the area control error (ISACE) have been utilized as the fitness function for genetic algorithm.

The proposed AGC scheme has been tested on 39-New England system which is divided into two control area and on a 75-bus Indian power system divided into four control areas. A deregulated electricity market scenario has been assumed in both the systems. The PV generator is included in area-1 and WTG system in area-2 in case of 39-bus system and similarly, one PV system in included in area-2 and one WTG system in area-4, in case of 75-bus system. The Flywheel Energy Storage System (FESS) has been included in the respective areas of both the system, where PV generators and WTG systems are considered. The performance studies have been carried out by using the MATLAB SIMULINK for transactions within and across the control area boundaries.

2. System Modelling

During the past one and half decade, many electric utilities and power network companies, world-wide, have been forced to change their way of doing business, from vertically integrated monopoly to an open market environment. Electricity reforms are being brought to introduce commercial incentives in generation, transmission, distribution and retailing of electricity, with resultant efficiency gain, in many cases. The introduction of competition in electricity market may cause emergence of several new entities. Such as, Generating Companies (Gencos), Transmission Company (Transco), Distribution Companies (Discos), and an Independent System Operator (ISO): The system operator is an entity entrusted with the responsibility of ensuring the reliability and security of the power system. It is an independent entity and does not participate in the electricity trading. It usually does not own generating resources, except for some reserve capacity in certain cases. In order to maintain the system security and reliability, the SO procures various services, such as supply of emergency reserves or reactive power from the other entities in the system. These services are known as the ‘ancillary services’. One of such service is the frequency regulation.

Frequency Regulation Services: Frequency regulation is the minute-to-minute adaptation of the generator output to meet the imbalance between total supply and demand in the system.

In order to maintain the system security and reliability, the System Operator (SO) procures various services, such as supply of emergency reserves, frequency regulation and reactive power from the other entities in the system. These services are known as the ‘ancillary services’. One of such service is the frequency regulation. Frequency regulation helps to maintain interconnection frequency, minimize differences between actual and scheduled power flows between control areas, and match the generation to the load within the control area. In frequency regulation service many commercial transactions can take place such as Poolco, bilateral, and a combination of these two.

In Poolco based transaction [16], the Discos and Gencos of the same area participate in the frequency regulation through system operator. SO accepts bids (volume and price) from power producers (Gencos) who are willing to quickly (within about 10-15 minutes) increase or decrease their level of production. Consumers (Discos) also can submit bids to SO for increasing or decreasing their level of consumption. In each hour of operation, the SO activates the most favorable bid.

In bilateral transaction, Gencos and Discos negotiate bilateral contracts among each other and submit their contractual agreements to a SO. The players are responsible for having a communication path to exchange contract data as well as measurements to do load following in real-time. In such an arrangement, a Disco sends a pulse to Genco to follow the predicted load as long as it does not exceed the contracted value. The responsibility of the Disco is to monitor its load continuously and ensure the loads following requirements are met according to the contractual agreement. A detailed discussion on bilateral transactions is given in [17-18].

2.1. Calculation of Area Control Error (ACE)

In a practical multi area power system, a control area is interconnected to its neighboring areas with tie lines, all forming part of the overall power pool. If P_{ij} is the tie line real power flow from an area-i to another area- j and m is the total number of areas, the net tie line power flow from area-i will be:

$$P_{tie-i} = \sum_{\substack{j=1 \\ j \neq i}}^{m} P_{ij} \tag{1}$$

In a conventional AGC formulation, P_{ij} is generally maintained at a fixed value. , in a deregulated electricity market, a Disco may have contracts with the Gencos in the same area as well as with the Gencos in other areas, too. Hence, the scheduled tie-line power of any area may change as the demand of the Disco changes.

Thus, the net change in the scheduled steady-state power flow on the tie line from an area- i can be expressed as:

$$\Delta P_{tie-new} = \Delta P_{tie-i} + \sum_{\substack{j=1 \\ j \neq i}}^{m} D_{ij} + \sum_{\substack{j=1 \\ j \neq i}}^{m} D_{ji} \tag{2}$$

Where, ΔP_{tie-i} is the change in the scheduled tie-line power due to change in the demand, D_{ij} is the demand of Discos in area-j from Gencos in area-i , and D_{ji} is the demand of Discos in area- i from Gencos in area-j.

Generally, $\Delta P_{tie-i} = 0$ (Conventional AGC). During the transient period, at any given time, the tie-line power error is given as:

$$\Delta P_{tie-i-error} = \Delta P_{tie-i-actual} - \Delta P_{tie-i-new} \tag{3}$$

This error signal can be used to generate the Area Control Error (ACE) signal as:

$$ACE_i = B_i \Delta f_i + \Delta P_{tie-i-error} \tag{4}$$

Where, B_i is the frequency bias factor and Δf_i is the frequency deviation in area-i.

2.2. Modeling of PV Generator

In Photovoltaic technology, there is a direct conversion of sunlight into electricity through the use of photovoltaic array. The incoming solar radiation or sunlight is measured in units Watts/meter^2.

The assumptions made in the mathematical modeling of PV generators are: All the energy losses in a PV generator, including connection losses, wiring losses and other losses are assumed to be zero. Second, is the PV generator has a maximum power point tracker i.e. $\eta = 1$, where, η is the conversion efficiency of PV generator.

The output power of the PV system can be expressed as follows [19]:

$$E_{PVG} = \eta_{PVG} \times S \times \Phi \times (1 - 0.005(T_a + 25)) \quad (5)$$

Where, Φ is the solar irradiation (W/m^2), S is the surface area of the PV modules in m^2, T_a is the ambient temperature and η_{PVG} is the conversion efficiency of PV generator. From (5), it is clear that the output power of PV system mainly depends on ambient temperature (T_a), and solar radiation (Φ) because conversion efficiency of PV array η_{PVG} and S surface area of PV array are constant. In this work, it is assumed that E_{PVG} is linearly varied with Φ only.

The transfer function of PV is represented by a simple first order system and described in [19]:

$$G_{PV} = \frac{\Delta E_{PVG}}{\Delta \Phi} = \frac{1}{1 + sT_{PVG}} \quad (6)$$

Where, T_{PVG} is called time constant of PV system.

In Figure 1, converter is bidirectional i.e., it not only can supply ac power to the load, but also can charge the FESS by rectifying the surplus power when the total supply power exceeds the load power.

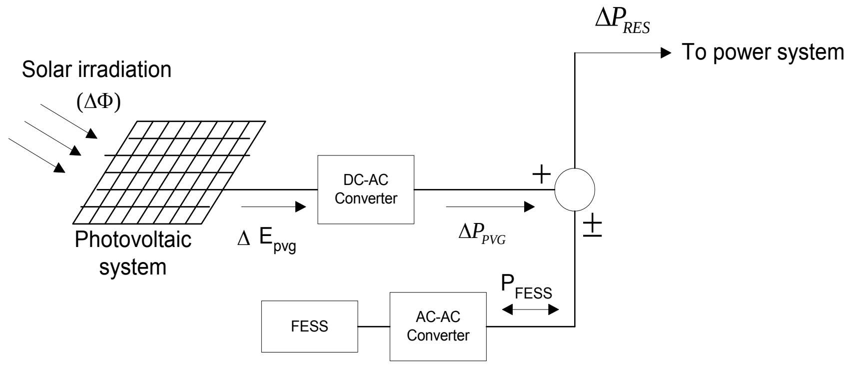

Figure 1. Grid-connected PV System

2.3. Modeling of Wind Turbine generator (WTG)

The generated power of the wind turbine generator depends on the wind speed V_W. The mechanical power output of the wind turbine is expressed as [20]:

$$P_W = \frac{1}{2} \rho A_r C_p V_w^3 \quad (7)$$

Where, ρ is the air density in kg/m^3, A_r is the swept area of blades in m^2, C_p is the power coefficient (dimensionless) which is a function of tip speed ratio (λ) and blade pitch angle (β) in degrees, V_W is the wind speed in m/sec.

The transfer function of WTGs is given by simple linear first order lag by neglecting all the non-linearity [19],

$$G_{WTG} = \frac{\Delta E_{WTG}}{\Delta P_W} = \frac{1}{1 + sT_{WTG}} \quad (8)$$

Where, T_{WTG} is called time constant of wind generator, and taken as 1.5 sec.

A wind farm is a group of wind turbines in the same location used for production of electric power. A large wind farm may consist of several hundred individual wind turbines, and cover an extended area of hundreds of square miles. Nowadays, onshore wind farms are capable of not only generating power but also providing ancillary services [22]. Onshore wind farms can actually be considered as WTGs as they can be operated as conventional generators [23].

In order to have improved frequency response the wind farm should operate with reserves. The most important feature of the wind farm to participate in power sharing when the system frequency deviates from the nominal value is that the pitch controllers of wind farm increases or decreases the captured wind power [24].

In case when the WTG systems are connected to grid, variable-speed wind turbine used, the rotational speed is decoupled from grid frequency by power converter. The inertia constant for wind power is time dependant. The typical inertia constant for the wind turbines is about 2-6 sec [25]. Depending on the type of generator units, typical inertia constants for the grid power generators are in the range of 2-9 sec [26]. A complete configuration of WTG system into AGC for area-i is shown in Figure 2.

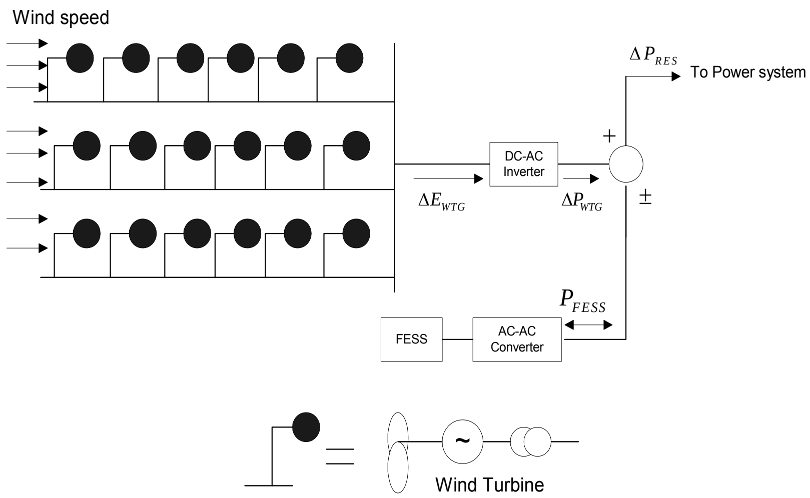

Figure 2. Configuration of WTG System in the Proposed AGC Scheme [5]

2.4. Modeling of Flywheel Energy Storage System (FESS)

Integrating an Energy Storage System (ESS) into the PV and WTG systems can suppress the fluctuations in solar radiations and wind velocity (speed). Flywheel Energy Storage System (FESS) stores energy in the form of the kinetic energy stored in the rotating flywheel and can be retrieved later as an electrical output. There are some advantages of FESS over Battery Energy Storage System (BESS), and they are higher power density, insensitivity to environmental conditions, no hazardous chemicals etc. The kinetic energy stored in the rotating flywheel is given by:

$$E = \frac{1}{2} J \omega^2 \tag{9}$$

Where, E is the Energy stored in the flywheel in N-m, J is the flywheel moment of inertia in N-m-sec^2, and ω is the rotational velocity in rad/sec.

A FESS integrates the function of a motor, flywheel rotor and generator into a single integrated system. The motor (while "charging" the flywheel), which uses electric current from the utility grid to provide energy to rotate the flywheel, spins constantly ω to maintain a ready source of kinetic energy (E). The generator (while "dis-charging" the flywheel) then converts the kinetic energy of the flywheel into electricity (ΔP_{FEES}).

In the present study, it is assumed that FESS has enough capacity to store surplus energy generated by the generating units. When the demand in control area increases, the FESS can release enough energy to the connected load within a very short time. Therefore, when PV system is included in the AGC block for area-i, then the net power generated in the system can be expressed as:

$$\Delta P_{RES} = \Delta P_{PVG} \pm \Delta P_{FEES} \tag{10}$$

Similarly, when WTG system is considered in the AGC block for area-i, then the net power generated in the system can be expressed as:

$$\Delta P_{RES} = \Delta P_{WTG} \pm \Delta P_{FEES} \tag{11}$$

The transfer function of the storage systems FESS can be taken as first order lag [19],

$$\frac{\Delta f}{\Delta P_{FEES}} = \frac{K_{FEES}}{1 + sT_{FEES}} \tag{12}$$

Where, K_{FEES} is the gain constant and T_{FEES} is the time constant.

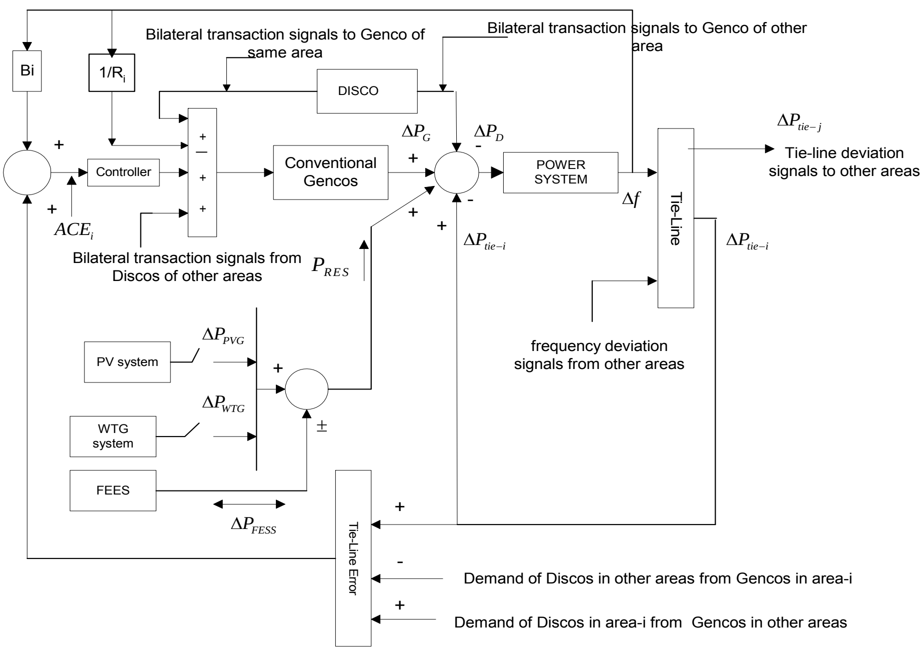

Figure 3. AGC Block diagram for area-i.

In the present study, Beacon's Smart Energy 25 flywheel has been considered to extract and/or deliver power that is sealed in a vacuum chamber and spins between 8,000 and 16,000 rpm. At 16,000 rpm the flywheel can store and deliver 25 kWh of extractable energy [27].

The overall block diagram of AGC scheme includes RES (PV system and WTG systems) for an i^{th} area of m-area power system is shown in Figure 3. The generation subsystems comprise conventional generators, WTGs and PV. The energy storage subsystem includes an FESS that is connected to the load side. Assume only the studied WTG; PV and FESS require suitable power converters for exchanging energy with the studied ac system. The FESS is assumed to have enough capacity to store surplus energy generated by the generating subsystems. When the power demand increases, the FESS can release enough energy to the connected load within a very short time.

The form of a PID controller can be expressed as the sum of three terms, proportional, integral, and derivative control. The transfer function of such a PID controller can be expressed as:

$$G_C(s) = K_p + \frac{K_i}{s} + K_d s \tag{13}$$

Where, $K_{p,} K_i, K_d$ are the proportional, integral and derivative gain constant of the controller. Optimal values of $K_{p,} K_i, K_d$ can be determined by many ways, one of them, is suggested by the Donde et al [15].

Initially, parameters ($K_{p,} K_i, K_d$) of PID controller area selected using Least Square Minimization method, which gives stable results. ACE is minimized using the GA optimization toolbox GAOT in MATLAB proposed by C. R. Houck [28] to obtain the optimal PID parameters. The fitness function taken in the present work is integral of the square of the Area Control Error (ISACE).

The problem to determine $K_{p,} K_i, K_d$ is formulated as follows: Minimize (Integral of square of the Area Control Error).

$$ISACE = \int \sum_{i=1}^{m} (ACE_i)^2 \tag{14}$$

Where, m is the number of area in the system.
Subjected to:

$$K_{p,i}^{\min} \le K_{p,i} \le K_{p,i}^{\max}$$
$$K_{i,i}^{\min} \le K_{i,i} \le K_{i,i}^{\max}$$
$$K_{d,i}^{\min} \le K_{d,i} \le K_{d,i}^{\max}$$

Where, $K_{p,i}, K_{i,i}, K_{d,i}$ are the proportional, integral and derivative gains of the PID controller of i^{th} area. $K_{p,i}^{\min}, K_{i,i}^{\min}, K_{d,i}^{\min}$ and $K_{p,i}^{\max}, K_{i,i}^{\max}, K_{d,i}^{\max}$ are the lower bounds and upper bounds of the PID controller.

3. Test System

The proposed AGC scheme for a multi-area power system, described in the previous section, has been tested on a 39-bus New England system [29] and on a 75-bus Indian system [30]. The 39-bus system has been divided into two control areas and the 75-bus system into four control areas. For 39-bus systems, three Discos and at least one Genco have been considered in each area. The number of Gencos and Discos in the 39-bus system and in the

75-bus system is given in Tables 1 and 2, respectively. A general purpose Governor- Turbine model has been used, which is taken from [31].

The commercial multimegawatt variable speed wind turbine of rating 1.5MW developed by General Electric (GE) has been considered in this study. A wind farm consists of WTG units of rating 1.5MW each has been considered in area-2 of 39-bus system and in area-4 of 75-bus system. In 39-bus system, one PV system of rating 2MW and 4MW of rating, one PV system has been considered in 75-bus system.

Table 1. Control Areas in 39-Bus Power System

Control Area	Area Rating(MW)	Market Participants
AREA-1	400	Genco 1,2,3,4,5, PV Genco-1, Discos 1,2,3
AREA-2	500	Genco 6,7,8,9,10, WTG-1,Discos 5,6,7

Table 2. Control Areas in 75-Bus Power System

Control Area	Area Rating(MW)	Market Participants
AREA-1	460	Genco 1,2,3
AREA-2	994	Genco 4,5,6,7,8, PV GENCO-2
AREA-3	400	Genco 9,10,
AREA-4	4470	Genco 11,12,13,14,15, WTG-2

The typical profile of solar radiation and wind speed, for both the systems, was taken from the National Renewable Energy Laboratory website [32], recorded of May, 2010, as shown in Figure 4(a) & 5(a) Power output as given in Equation (4) has been find out using the PV system and WTG system model given in section (2.2). The real power output of PV and WTG system is taken in per unit depending upon the area rating. The typical real power output of PV and WTG system in p.u. is shown in Figure 4(b) & 5(b).

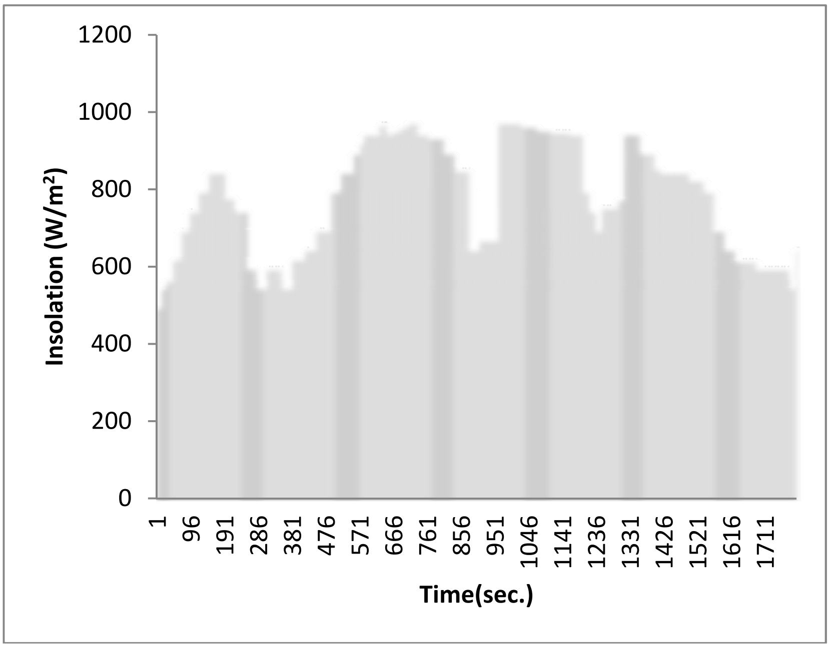

Figure 4(a). Real Irradiance Data used for the Proposed AGC Model

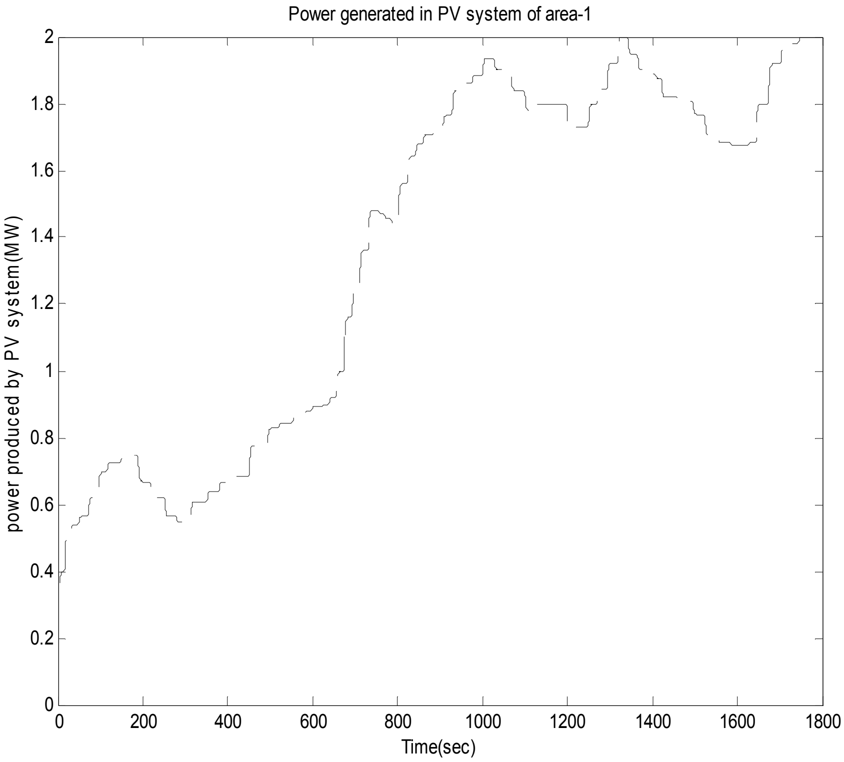

Figure 4(b). Power Output of PV System of area-1 of 39-bus System for 30 min

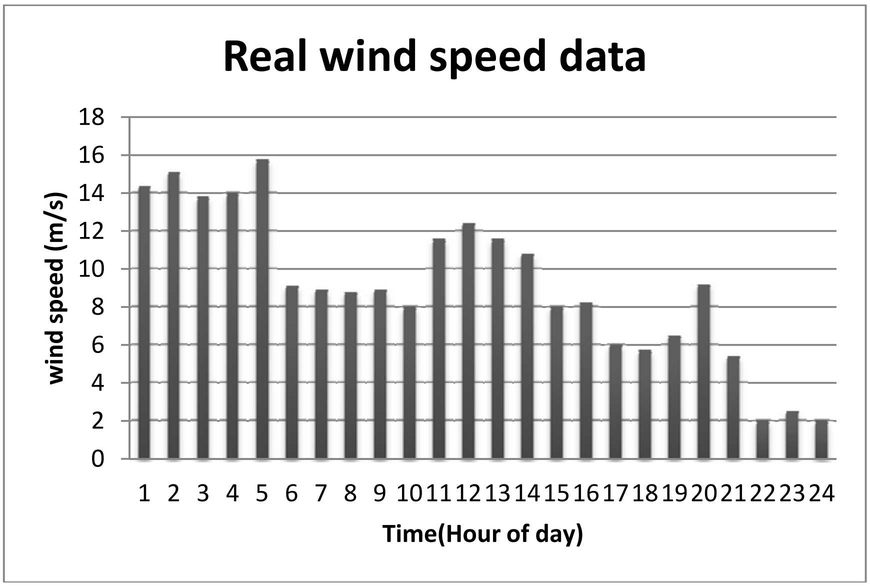

Figure 5(a). Real Wind Speed Data used for the Proposed AGC Scheme

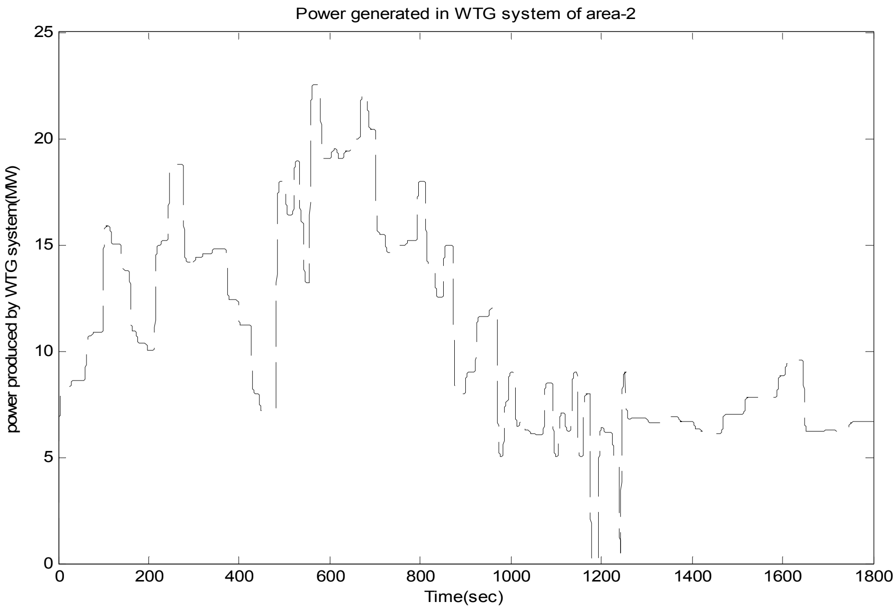

Figure 5(b). Power Generated by WTG System of area-2 of 39-bus System for 30 min

4. Simulation Results

To analyze the effect of RES units on frequency regulation, simulation studies have been carried out on the proposed AGC model for two cases. For first case, AGC model has been considered without RES units and for second case with RES units. It is assumed that RES units included in the network will supply the maximum output available at that particular time. Data sources for solar radiations and wind speed has been taken from National Renewable Energy Laboratory website [33]. If the solar radiations for 30 minute are of the form as shown in Figure 4(a), then real power output of PV system in MW for area-1 of 39-bus system will be of the form as shown in Figure 4(b). Similarly, if wind speeds for 30 min are of the form as shown in Figure 5(a), then real power output of WTG systems in MW for area-2 of 39-bus system will be of the form as shown in Figure 5(b).

In this work it is assumed that the RES units are owned by the system operator. PV and WTG systems give its full output whenever it is required, while the conventional generators change their power as per their participation factors (pfs). The pf for each generator is determined by utilizing their bids submitted to system operator [16]. The results for different systems are described below:

4.1. 39-Buse System

To simulate the 39-bus system, it is assumed that the generators and the loads are participating in the frequency regulation market. The Gencos and Discos bids for area-1 and area-2 were assumed as given in Table 3 and 4.

Table 3. Gencos and Discos Bids in Area-1 of 39-Bus System

Gencos/Discos	Price(Rs./KWh)	Capacity(MW)
Genco1	4.9	20.0
Genco2	5.1	15.0
Genco3	6.1	15.0
Genco4	5.4	25.0
Genco5	5.2	10.0
Disco1	5.2	4.0
Disco2	5.7	4.0
Disco3	6.1	4.0

Table 4. Gencos and Discos Bids in Area-2 of 39-Bus System

Gencos/Discos	Price(Rs./KWh)	Capacity(MW)
Genco6	4.9	20.0
Genco7	5.1	10.0
Genco8	6.1	15.0
Genco9	5.4	25.0
Genco10	6.5	10.0
Disco4	5.2	5.0
Disco5	5.7	5.0
Disco6	5.6	5.0

The bilateral contract considered in the system assumes that the 10% of area-1 load demand changes to be provided by Genco-2 itself and 20% by Genco-6 of area-2. Second transaction is between area-1 and area-2, 20% of area-2 provided by Genco-3 of area-1.

Assume a change in total load demand of area-1 by 80 MW (0.2 p.u.) and of area-2 by 50 MW (0.1 p.u) at time t=0. To meet this change in the load demand in area-1 without RES units, Genco-2 of area-1 supply 8 MW of power and Genco-6 of area-2 supply 16 MW of power, through bilateral transaction.

To implement the Poolco transaction, SO settles the Gencos' and Discos' bids, on the principle of the cheapest bid first. SO of area-1 sends the signal to Genco-1, Genco-2 Genco-5, to supply 20MW, 15MW, 10MW, Disco-1 to curtail its load by 4MW and the remaining (7MW) increases output by Genco-4, respectively. Since, from the Table 3, capacity of Genco-4 is higher than other Gencos but in terms of price, it is costly therefore, the price quoted by Genco-4 will become the market clearing price, whatever be the prices of other Gencos.

Whereas, in case of RES units in area-1, the load demand of area is meet out by the PV systems, WTG systems and conventional generators. As the power output of PV generator and WTG system is continuously changing as shown in Figure 4(b) and in Figure 5(b). Therefore, the output of conventional Gencos will also reduce.

The results of frequency deviations in area-1 with PV system are shown in Figure 6(a). The change in the power output of Gencos 1, 2, 4, 5 is shown in Figure 6(b) and the change in demand of Disco-1, participated in the market is shown in Figure 6(c).

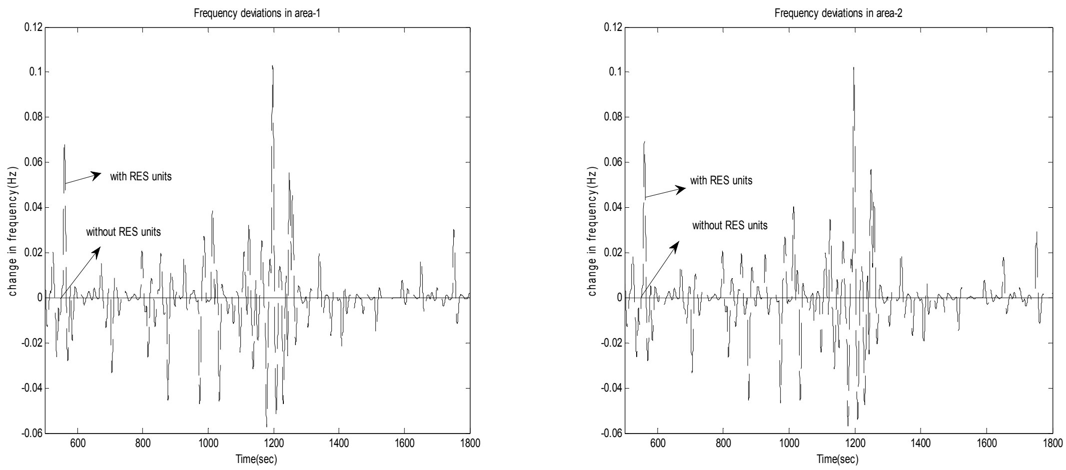

Figure 6(a). Frequency Deviations in area-1 and area-2 for 30 min

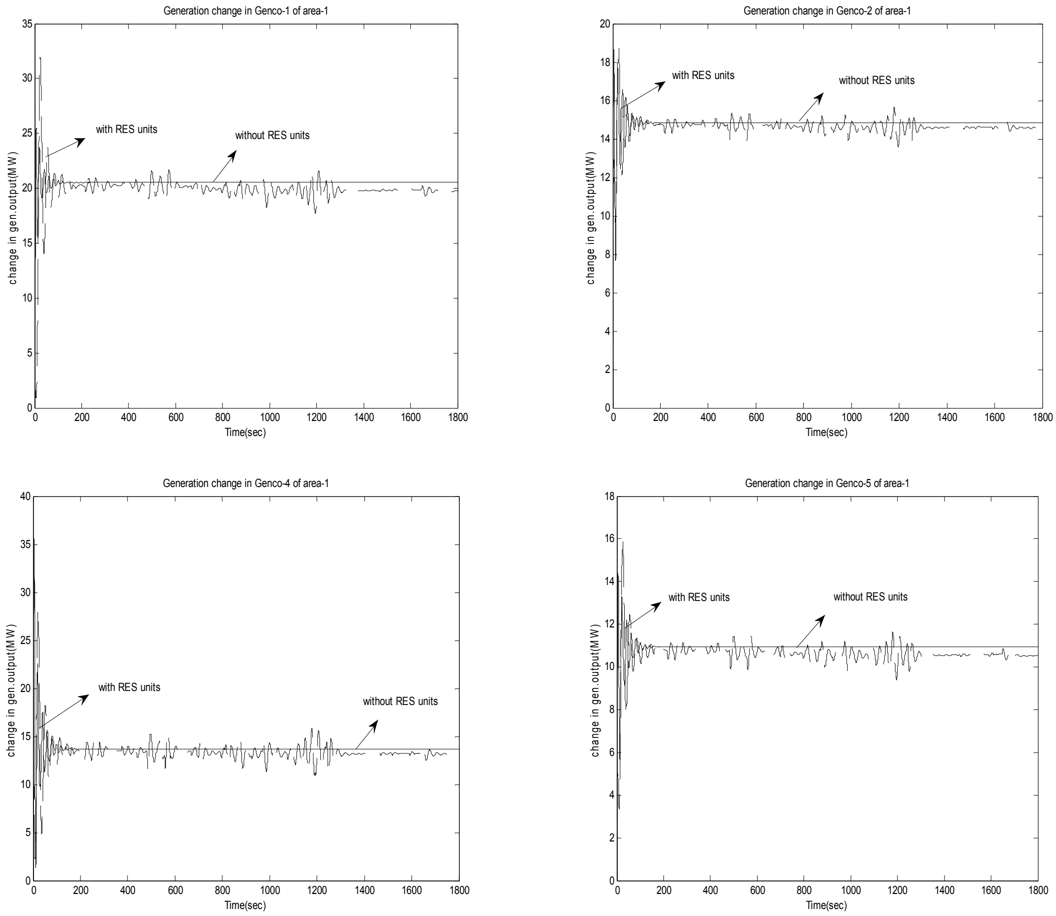

Figure 6(b). Generation Change in Genco-1, 2, 4 and Genco-5 of area-1 for 30 min

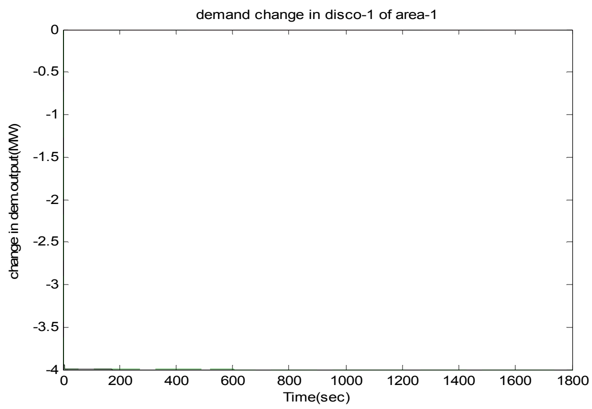

Figure 6(c). Demand Change in Disco-1 of area-1 for 30 min

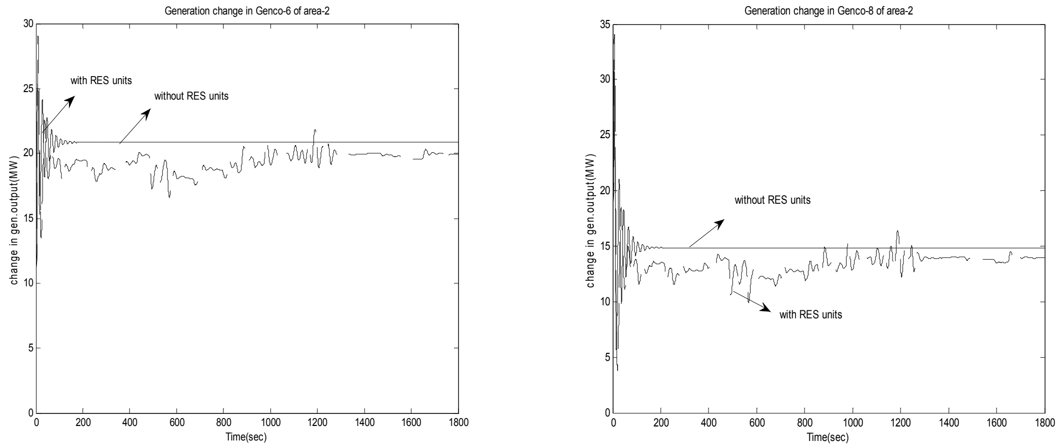

Figure 6(d). Generation Change in Genco-6 and Genco-8 of area-2 for 30 min

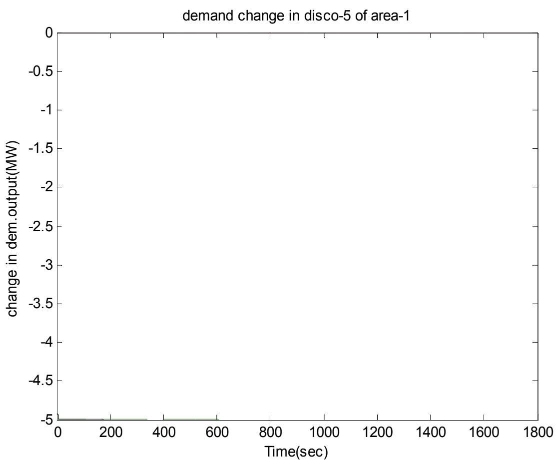

Figure 6(e). Demand Change in Disco-5 of area-1 for 30 min

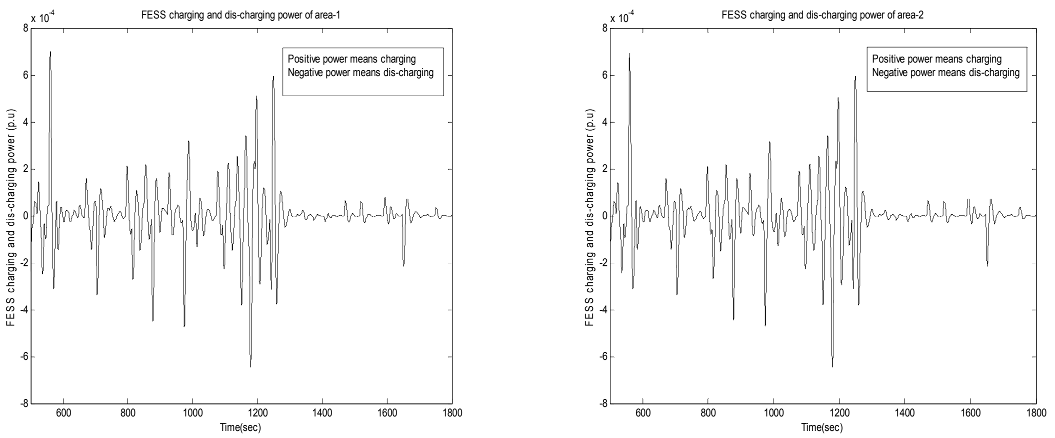

Figure 6(f). Charging and Discharging Powers of the FESS in area-1 and area-2 of 39-bus System for 30 min

The average change in the power output of PV system and other Gencos for area-1 is given in Table 5. The result shows that there are fluctuations in frequency output when PV systems are included. The fluctuations are due to the dynamic behavior of the PV system considered.

Table 5. Average Change in the Power Output of PV System and other Gencos in area-1

No. of Gencos/Disco	Output power in p.u.	Gencos output power in MW
Genco-1	0.0496	19.84
Genco-2	0.0365	14.6
Genco-4	0.033	9.62
Genco-5	0.023	9.5
PV Genco-1	0.00342	1.37
Disco-1	0.0099 (load Curtailment)	4 (load curtailment)

Table 6. Average Change in the Power Output of WTG System and other Gencos in area-2

No. of Gencos/Disco	Output power in p.u.	Gencos output power in MW
Genco-6	0.04818	19.28
Genco-7	0.03627	14.5
Genco-8	0.0241	9.62
WTG-1	0.004	1.6
Disco-5	0.125 (load Curtailment)	5 (load curtailment)

Similarly, to meet the change in the load demand in area-2 without RES units, Genco-3 of area-1 supply 10 MW of power through bilateral transaction.
To implement the Poolco transaction, SO of area-2 sends the signal to Genco-6 and Genco-8 to supply 20MW and 15MW of power, respectively. Since, the bid submitted by Disco-4 is 5.2 Rs/kwh. It is assumed that SO in favour of supplying power through WTG system in order to increase more and more participation of green energy technology.

With the inclusion of RES units in case of area-2, the results of frequency deviations in area-2 with WTG system are shown in Figure 7(a). The change in the power output of Gencos 6, 8 is shown in Figure 7(d) and the change in demand of Disco-5, participated in the market is shown in Figure 7(e). The average change in the power output of WTG system and other Gencos for area-2 is given in Table 6.

It is clear from the results that as RES units are included into the system; the real power output of the conventional Gencos reduces. Therefore, inclusion of RES units regulates the frequency deviations as well as increases the social benefits by reducing the fossil fuel power output. Figure 6(f) shows the charging and discharging powers of the FESS. Here, positive power means charging and negative power means discharging.

4.2. 75-Buses System

To simulate the 75-bus system, it is assumed that only the generators are participating in the market and Discos are not participated in the frequency regulation.

To simulate the results, the change in the load demand of area-2 and area-4 were assumed to be 0.0503 p.u. (50 MW) and 0.0223 p.u. (100 MW), respectively. Gencos bids of area-2 and area-4 were assumed as given in Tables 7 and 8, respectively.

Table 7. Gencos Bids in area-2 of 75-bus System

Gencos	Price(Rs./KWh)	Capacity(MW)
Genco-4	4.8	15.0
Genco-5	5.0	10.0
Genco-6	5.3	20.0
Genco-7	5.1	10.0
Genco-8	5.2	10.0

Table 8. Gencos Bids in area-4 of 75-bus System

Gencos	Price(Rs./KWh)	Capacity(MW)
Genco-12	5.1	10.0
Genco-13	4.5	30.0
Genco-14	5.0	20.0
Genco-15	5.3	10.0
Genco-16	4.7	30.0

Different bilateral contracts between area-2 and area-4 have been considered. The first contract assumes that 20% of Disco-5 (area-2) load demand change will be provided by Genco-13 of the area-4. The second contract is considers that Genco-5 of area-2 will provide 10% of load demand change of area-4.

In area-2, without RES units, Genco-13 of area-4 supplies 10 MW of power through bilateral transaction. To implement the Poolco transaction, SO issues the signal to Genco-4, 6 and 8 to supply 20MW, 15MW and 5MW of power, respectively.

The average change in the power output of PV and other Gencos that are participated in area-2 are given in Table 9.

The results of frequency deviations for area-2 and area-4 with and without RES units system for 30 min are shown in Figure 7(a).

When PV system is included in area-2 for frequency regulation, the area-2 Gencos change their power output as shown in Figure 7(b). The power output of MW PV generators for 30 min in area-2 is shown in Figure 7(c).

Figure 7(d) shows the charging and discharging powers of the FESS in area-2. Similarly, the power balance in area-4 can be achieved as follows:

To meet the load demand of 100 MW in area-4, Genco-12 and Genco-15 increase its output by 10MW, each, Genco-13 and Genco-16 by 30MW each and Genco-14 by 20MW, respectively. The average change in the power output of WTG and other Gencos that are participated in area-4 are given in Table 10.

Table 9. Average Change in the Power Output of PV and other Gencos in area-2

No. of Gencos	Output power in p.u.	Gencos output power in MW
Genco-1	0.04818	19.28
Genco-2	0.03627	14.5
Genco-4	0.0241	9.62
PV Genco-2	0.004	1.6

Table 10. Average Change in the Power Output of PV and other Gencos in area-4

No. of Gencos	Output power in p.u.	Gencos output power in MW
Genco-12	0.00217	9.7
Genco-13	0.00645	28.83
Genco-14	0.00432	19.31
Genco-15	0.00217	9.7
Genco-16	0.00645	28.83
WTG-2	0.000744	3.31

The response of the Gencos 11, 12 and 15 in area-4 participating in the market, with and without PV system, shown in Figure 8(a). The power output of 4MW PV generators for 30 min in area-4 is shown in Figure 8(b). The charging and discharging powers of the FESS in area-4 is shown in Figure 8(c).

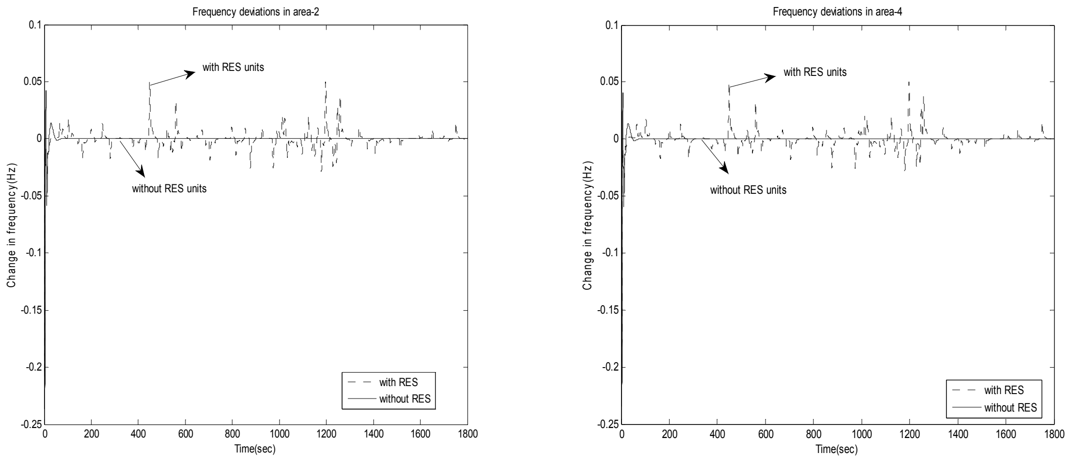

Figure 7(a). Frequency Deviations in area-2 and area-4 for 30 min

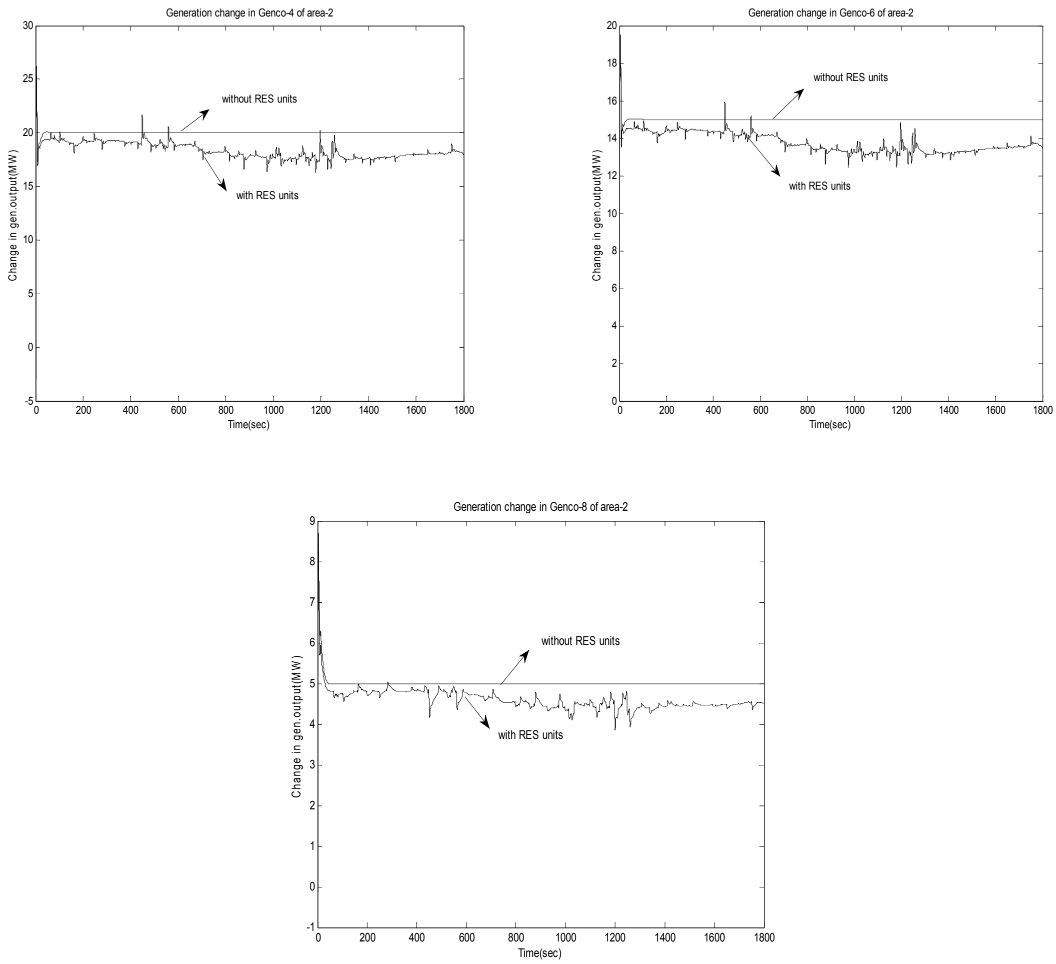

Figure 7(b). Generation change in Genco-4, 6 and Genco-8 of area-2 for 30 min

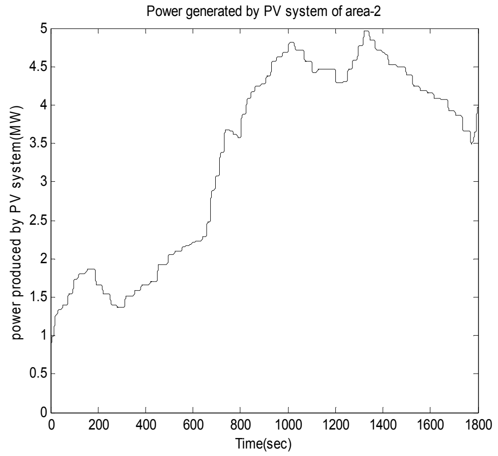

Figure 7(c). Power Output of PV System of area-2 in 75-bus System

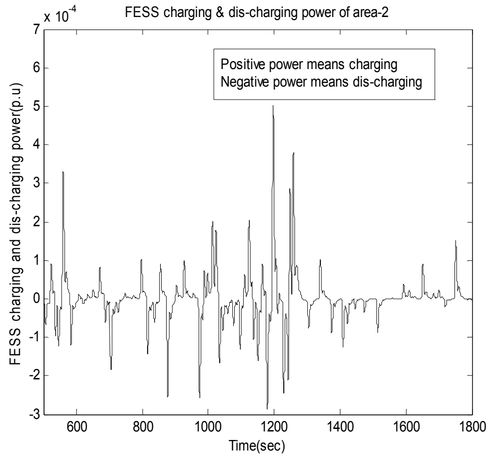

Figure 7(d). Charging and Discharging Powers of the FESS in area-2 for 30 min

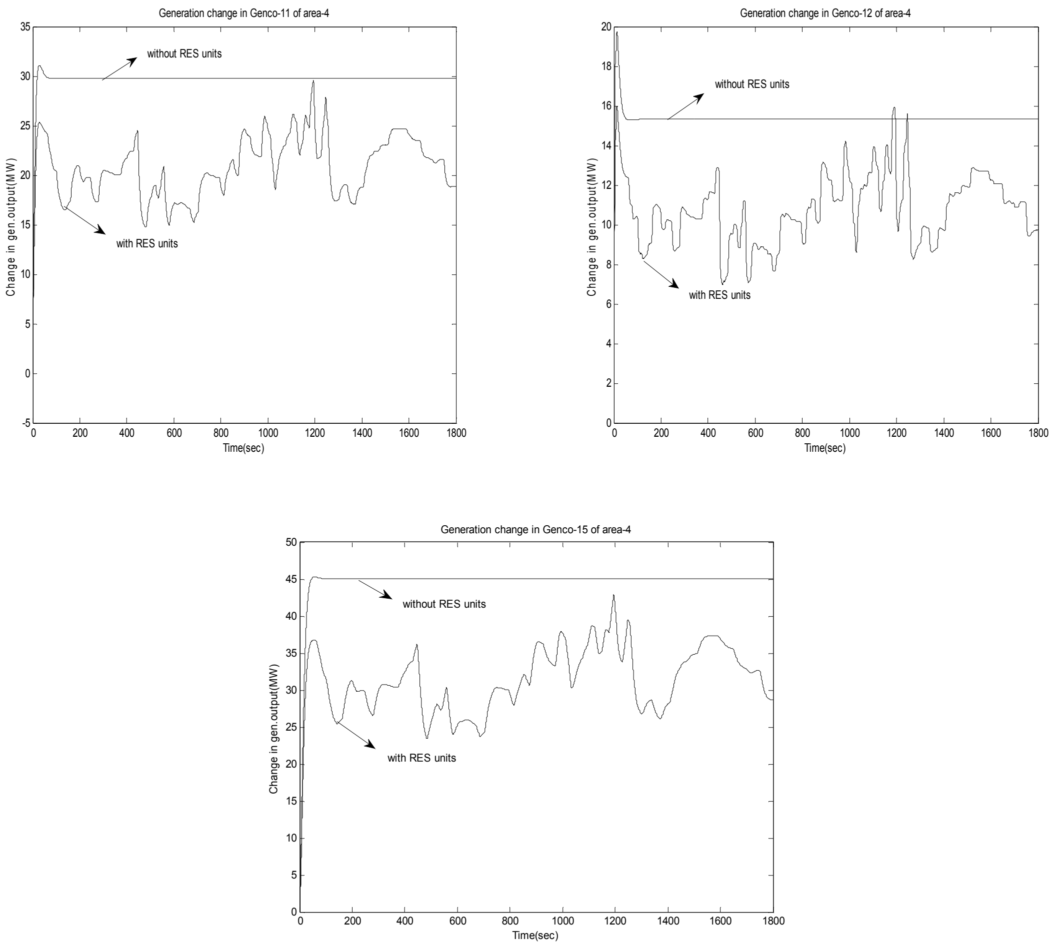

Figure 8(a). Generation Changes in Genco-11, 12 and Genco-15 of area-2 for 30 min

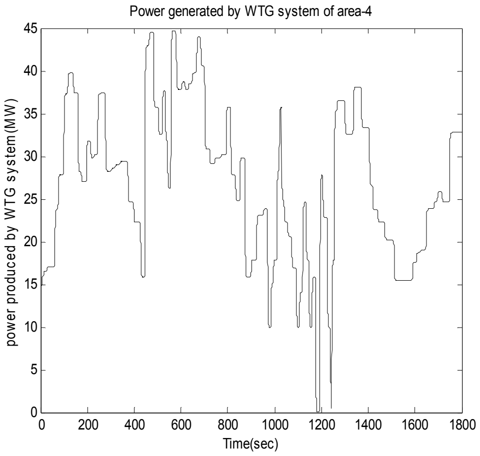

Figure 8(b). WTG Power Generated in area-4 of 75-bus System for 30 min

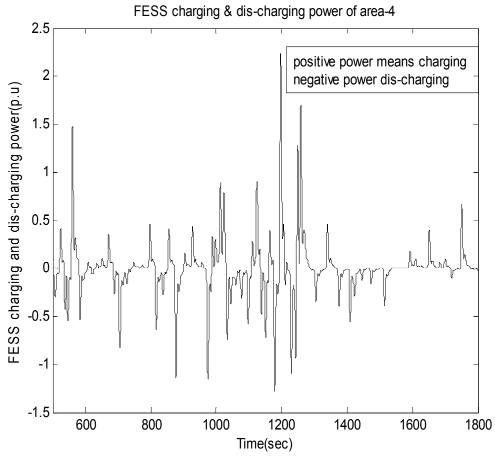

Figure 8(c). Charging and Discharging Powers of the FESS in area-4 for 30 min

5. Conclusion

In this paper, a multi-area AGC scheme with RES units and FESS has been proposed. In the proposed scheme, effect of RES units particularly, PV systems and WTG systems, for frequency regulation has been analyzed. It is observed from the results that inclusion of RES units for frequency regulation creates very small (order of 10^{-2}) fluctuating in the system due to the dynamic behavior of the RES units. The proposed AGC scheme keeps the grid frequency close to the nominal value. GA has been used tune the parameters of PID controller used in the AGC scheme. It is observed from the results that participating Gencos change their real power output according to their participation factor. Although per unit cost of PV system is more, but the use of PV system for frequency regulation increases the social benefits by reducing the fossils generator outputs. Adding of RES units (particularly, WTG systems) to the grid, an increase in the total system inertia. From the Simulation results it is observed that the larger inertia of the overall system, the system will have a poor damping and there is a reduction of the maximum deviations i.e. in the system frequency.

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