# Price Based Intelligent Automatic Generation and Control

Ph.D. Synopsis Submitted To Gujarat Technological University
For the Degree of

**Doctor of Philosophy**

In
Electrical Engineering

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**AUGUST - 2019**

# Abstract

In interconnected power system, the frequency deviates due to the mismatch between load demand and generation and as well due to the power feeding to the grid from the renewable energy sources that are highly intermittent in nature. At generator side, primary and secondary loop of Automatic Generation Control (AGC) helps regulate deviations in the frequency in a slow manner due to governor action. Moreover, Availability Based Tariff Mechanism (ABT) have been implemented to regulate the grid frequency in which the Unscheduled Interchange (UI) price is also closely linked with secondary frequency control. Even smart controllers with different techniques for AGC operation are proposed to regulate frequency on the generator side using different practices by the industries as well as by researchers, satisfactory results have not been achieved. Moreover, due to new polices of the government, such as price based AGC that considers generation marginal cost and UI price as well as introduction of Electrical Vehicles (EVs) that can also perform as a nonlinear load during their charging time is also proposed to regulate frequency. Here, due to slow response of generators against sudden load variation, uncontracted load, governor dead band, generation rate constraint and fluctuating power of grid connected due to renewable energy sources the actual system characteristics becomes non linear. Also, due to the frequent operation of the generator with these non linearites there is unnecessary fuel consumption, increased wear and tear on generators and increase in UI prices of ABT. It also causes tripping of the generators sometimes.

In the present work, for improving existing AGC mechanism, general framework for deriving the state space model of two area restructured power system having 2 numbers of Generating Companies (GENCOs) with thermal-thermal non reheat unit in each area and 2 numbers of Distribution Companies (DISCOs) with renewable energy sources has been considered. The model for UI price of ABT mechanism (CERC, 2016) has been used to analyze AGC performance based on real-time price linked to frequency. Marginal cost of generator and UI price are considered for the price based operation of the AGC. The fleet of Electrical Vehicles (EVs) operated by bidirectional charger followed by battery charging/discharging characteristics are also considered. The suggested diversified transmission link through which Load Frequency Control (LFC) is simulated, improves the Area Control Error (ACE) due to EVs.

AGC operation for two area restructured power system incorporated with renewable energy source have been simulated in MATLAB / Simulink environment with and without EVs.

The proposed concept has been shown to cope better than the existing AGC mechanism. By comparing the results the effectiveness of the proposed control scheme for the reduction in the deviations of frequency, generator power and UI price has been shown.

## 1. Brief description on the state of the art of the research

Worldwide electric power utilities had adopted the deregulated market scenario and the restructuring process is undergoing [29]. Generation companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs) and independent system operators (ISOs) are the individual entities in restructured power system. In the current state DISCOs having an authorization to have a contract with GENCOs in same area which is known as "Poolco Based Transaction" and also with any other control areas which is known as "Bilateral Transaction" under the supervision of ISO. For the reliability of power supply many ancillary services like reactive power compensation, voltage control, loss minimization, load following, scheduling, dispatch and energy balancing have been provided by system operators. In such a situation either ISO or Transmission System Operator (TSO) has been entrusted with the deal of procurement of these services. It has been observed that Automatic generation control (AGC), also known as "load frequency control (LFC)" is widely accepted for ancillary service in practice [39], [3], [4].The various issue like Load frequency control (LFC) in power system operation after deregulation has been discussed [26].

Operation of Price based AGC in a new restructured power system has been encouraged as future business environment for electric utility [17] and the case study with different load following contracts has been represented in [6]. Price based AGC outline is reported in [17, 23] by modifying the conventional AGC to simulate Bilateral and Poolco based transactions in the new market environment. In competitive electricity market a Price based frequency regulation is efficiently used by investigators [41]. Under the ABT mechanism the objective of the controllers running for the generation control is to nullify the deviations in supply frequency and also to reschedule the generators for the economical operation. So the UI price and the marginal cost can be included in to the system running under conventional AGC mechanism to satisfy the objective. In this direction Tyagi and Srivastava [37] have developed a mathematical frame work. In which the frequency is converted in the UI price signal in the secondary loop, called 'ABT control loop'. This UI price is compared with marginal cost of the generator to generate an error signal called ‘generation control error (GCE)’. This GEC helps to nullify the frequency deviations followed to the reference power setting by the generation control. But due to the UI price and marginal cost mismatch problem in running the model. Modified GEC scheme have been proposed [5] to over the above problem with the GCE generation based on comparisons made between the UI price signal, the marginal cost and the reference UI price and tested the model with CERC 2009 regulations UI prices. The GCE is the difference between UI price and marginal cost, sometimes the difference between UI price and reference UI price and sometimes even zero. If the frequency deviates from the rated value by considering the fixed value of the UI prices with system marginal cost near to or greater than the reference UI price. So, it can be concluded that the control scheme is highly sensitive for the variable values of the UI price and marginal cost. ABT based load frequency control loop for an interconnected power system presented in [13]. Also, for the multi area power system the price based frequency control is applied in [11], but it fails to bring the normal state of the frequency. It is concluded that by maintaining the balance between the supply and the load the deviations in the supply can be nullified at loading condition. Big penalties to be paid by GENCO for an inactive participation to control frequency against load variation. During the day for each 15 min duration an average frequency is monitored and the UI charges will be calculated against frequency value. To minimize UI charges GENCO set the generation. By following these issued an attempt has been made to develop a new control scheme to reduce the UI prices and generation fuel cost to normalize the frequency against deviations.

However, it is difficult for the synchronous generator to track the load deviation completely as electricity nature has restriction on the instantaneous process between generation and consumption due to slow dynamic response [13]. Also, because of frequent power changes with the integration of renewable energy sources it has been difficult to regulate frequency due to insufficient regulation reserve capacity and rapid power imbalance [27-28],30]. Thermal and hydro units itself can be used to regulated frequency. Due to limited regulation capacity, slow response according to the power demand changes and frequent operation of generator reduces life of generator-turbine unit and efficiency [45]. Finally increases generation cost, labour cost and maintenance cost due to wear and tear of generators [7]. Under these circumstances a usual frequency control by governor may no longer be capable to pay off for rapid load changes due to its slow response, which fallout into either voltage or frequency deviation or even tripping of generator.

Based on recent literature so far, AGC has been reformulated in restructured environment by implementing various methods like Particle Swarm Optimization (PSO) [25], Bacterial Foraging Optimization Algorithm (BFOA) [14], artificial intelligence methods like genetic algorithm [25], neural network [1], fuzzy logic [16], distribution energy storage technologies like Battery Energy Storage System [32], Flywheel [44], Super capacitor [19], LFC with SMES [31], battery swapping station [6] and many more. Among this variety of feasible solutions, Battery Energy Storage System (BESS) is extensive choice and recent technological aspect [8] now a day due to quick and fast action for lessening overshoots of frequency deviations in restructuring of power system [12]. Electrical vehicles are large distributed battery energy storage and will use broadly in upcoming transportation system [34] and has potential to provide the distributed spinning reserve to the power system [48]. Customer side Electrical vehicles (EV) will use widely due to limited life of petroleum products, less battery charging cost and for reduction in greenhouse gasses [2]. In [40],[36] potential to overcome load frequency control problem with electric vehicle, An EV swapping station [24] and energy storage system (BESS) with appropriate results [8] has been discussed. In present smart grid power system renewable power is intermittent and there is a need of controllable energy storage. Battery of EV can be used combine as a buffer and energy storage against the energy generated by renewable plants [45]. Vehicle to Grid (V2G) and Grid to Vehicle (G2V) schedule can be managed by vehicle users [42] followed by battery state of charge (SOC) condition to suppress frequency fluctuation in two area interconnected power system [20]. To enhance both performance and robustness for an operation of V2G and G2V mode a bidirectional controller with scheduled charging is required . For bidirectional operation to track the load changes constantly bidirectional charge controller are usually used in practice.

In the present work the strategy for EV bidirectional operation of charger for load frequency control by participating in AGC operation has been proposed and results with and without an EV integration to load frequency control have been simulated.

## 2. Definition of the Problem

The primary and secondary control loops of AGC help regulate grid frequency that would otherwise vary due to load deviation or changes in power generation from renewable energy sources. Simultaneously, in India, frequency linked UI price that is a part of ABT mechanism, also play a similar role for regulating the grid frequency. But, the actual generator system characteristics remains non linear due to the factors such as sudden load variation, governor dead band, generation rate constraint and fluctuating power of grid connected renewable energy sources. Governor under the control of AGC and UI price may be incapable of controlling sudden load changes and would also result in the fuel consumption and sometimes fall out either in frequency deviation or tripping of generators. In this environment, AGC operation for governor is difficult to track the exact value of power deviation due to its slow dynamic response and as a result frequency overshoots and settling time increases.

Hence, the problem can be defined as,

**"To design and develop additional control loop in AGC to reduce frequency overshoot and settling time".**

## 3. Objectives and Scope of the Work

Frequency deviations caused by the uncertain load variation and changes in power pumped by renewable energy sources into the grid need to be investigated. For this to come up with the solutions for the various issues such as minimization of settling time, peak overshoots in frequency deviation and UI price will be the main focus of my research. To control the deviations in frequency, generator power and tie line power we plan to devise new control mechanism.

**To achieve these objectives, the scope of work includes:**

1. To develop a mathematical model of two area restructured power system with thermal-thermal non reheat unit that can identify the deviations in frequency and power. Also, to simulate the same in MATLAB/Simulink environment.
2. Using the model developed, to observe deviations in frequency and power during AGC operation under Poolco based and Bilateral contract conditions between generating companies (GENCOs) and distribution companies (DISCOs) .

**3.** To devise a new control strategy for bidirectional charging / discharging of EVs that can help aggregated EVs to participate in minimizing the deviation in frequency and power.

**4.** To analyze the results of the new control mechanism for verification of its effectiveness in the AGC operation.

## 4. Original contribution by the thesis

The main contribution by the thesis is as follows,

1. Developed a mathematical model of two area restructured power system by considering thermal-thermal (non-reheat) and grid connected wind turbine unit. It is simulated under the different contracts between generating companies and distribution companies, such as POOLCO based contract and Bilateral contract. The effect of 10 % load variation has also been studied.
2. Developed frequency to UI price block which will convert the frequency deviation into price. From the UI price calculated and from marginal cost of generation, generation control error (GCE) is calculated. Based on GCE, price based automatic generation control (AGC) is performed.
3. Developed a mathematical model of grid connected Electrical Vehicles (EVs) with bidirectional charger. The bidirectional charger is applied to reduce the deviations in frequency, amount of generator power and UI price. Moreover, the concept of Load Frequency Control (LFC) signal is proposed to disperse all EVs by diversified transmission link through aggregators followed by Area Requirement (AR).
4. The proposed method of aggregated EVs to regulate frequency and power deviation is tested under Poolco based contract and Bilateral contract for peak hours and off peak hours. This work has shown that using this technique frequency and power deviations are minimized.

## 5. Methodology of Research, Results / Comparisons

### 5.1 System Configuration

The smart grid of isolated two area restructured power system with thermal – thermal non reheat unit [29] incorporated with wind energy system and proposed fleet of EVs is presented in Figure 1. Area 1 consists with of GENCO1 (Thermal Unit) and GENCO2 (Thermal unit) with

DISCO1 and DISOC2. Similarly, Area 2 consists of GENCO3 (Thermal Unit) and GENCO4 (Thermal Unit) with DISCO3 and DISCO4. The mathematical model of thermal-thermal non reheat unit is presented in Figure 2 and thermal-hydro unit is presented in Figure 3. For the visualization of the issues during AGC operation, local load and wind power blocks are represented. To normalize the load frequency, a fleet of aggregated EV batteries are considered and connected locally in both areas. Figure 4 represents the functional block diagram of wind turbine with pitch control [29] which consists of a power measurement transducer, a manual power set point control, a proportional plus integral feedback function, and a hydraulic actuator which varies the pitch of the blades. Any mismatch between supply and load results in frequency deviations, which generates area control error (ACE) and it is sent to the controller to establish the frequency control. 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 be controlled and finally electrical power will be controlled through generator.

### 5.1.2 Mathematical modeling of two area restructured power system

The mathematical models of thermal-thermal non reheat unit [39], EV modeling [48] and wind turbine modeling [21] are used for the simulation 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 is used in this work. For wind turbine the blade pitch control mechanism transfer function is considered presented in 150 KW MOD-OA horizontal axis machines installed on Block and Rhode Island, USA [31],[10]. The dynamics of the wind power generating unit is described by a first order system.

To represent the contract among the GENCOs and DISCOs a DISCO participation matrix (DPM) matrix is presented in Eq. 1. Matrix shows the total load power contracted by DISCOs with respective GENCOs; hence is the name “DISCO Participation Matrix” [39].

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

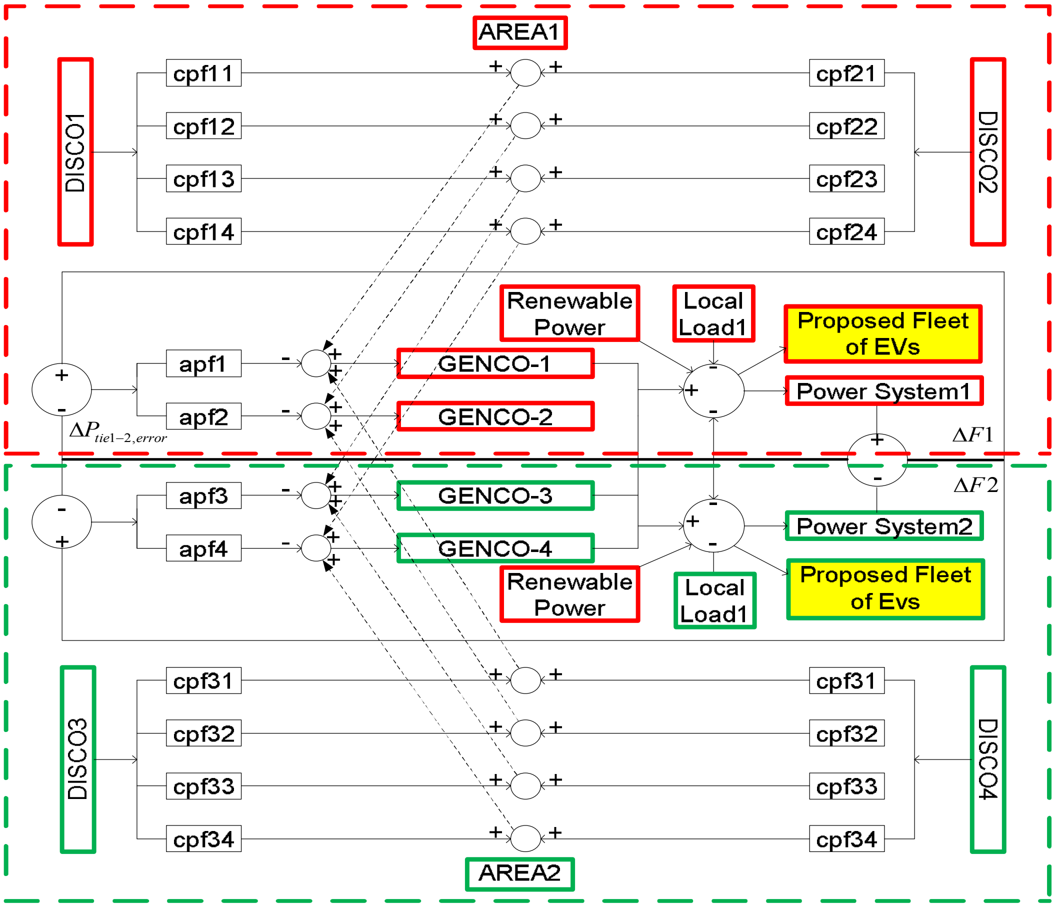


Fig. 1 Block Diagram of Two Area Restructured Power System

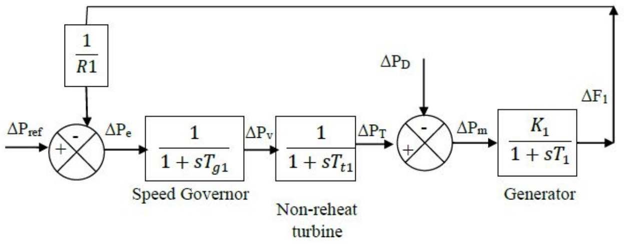


Fig. 2 Thermal Non Reheat Unit ( Ref. IEEE Committee Report (1973))

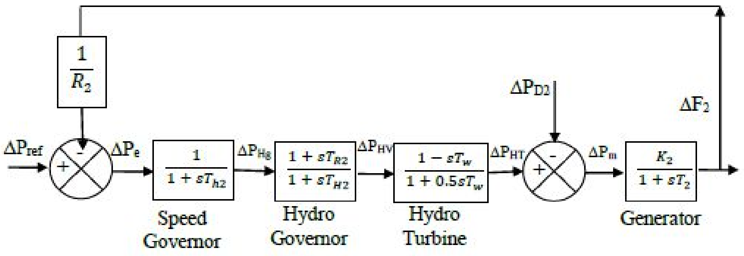


Fig. 3 Hydro Unit (Ref. Kundur (1994))

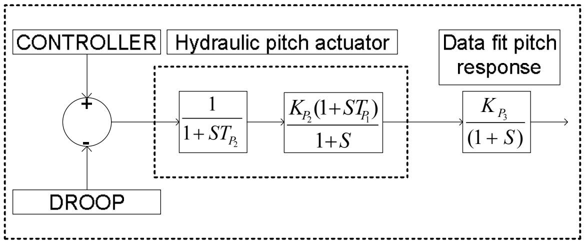


**Fig. 4 Functional Block diagram of wind turbine with pitch control**

where, $\sum_i cpf_{ij} = 1$ ,"cpf" refers to "Contract Participation Factor", which transmit information to respective GENCO to follow the demanded load by the DISCO and "APF" refers to " Area Participation Factor represents the participation of respective area generator in AGC. Suppose, that DISCO3 demands 150 MW power, out of which 30 MW is demanded from DISCO1, 45 MW from DISCO2, 60 MW from DISCO3 (itself) and 15 MW from DISCO4. The following mathematical formulas has been used for the simulation of the two area restructured power system [46]. The contracted power supplied by i<sup>th</sup> GENCO is given as

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

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

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

Where, $\Delta P_{Lj}$ is the total demand of 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 actual and scheduled steady state power flow through the tie-line are given as,

$\Delta P_{tie1-2,scheduled}$ =(demand of DISCOs in area II from GENCIs in area1- demand of DISCOs in area Ii from GENCIs 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 used to generate the respective area control error (ACE) signals as in the traditional scenario [3], [41].

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

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

Where, $P_{r1}$ and $P_{r2}$ are the rated capacities of area 1 and area 2.

The effects of actual loads on the system dynamics have been 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 the GENCOs according to ACE participation factors, i.e. $apf_1, apf_2, apf_3 \text{ and } apf_4$.As per the AGC integral control law shown in (10) the gain is optimized.

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

### 5.1.3 Price Based AGC Operation in Indian electricity market

The Central Electricity Regulatory Commission (CERC) of India introduced ABT mechanism in July 2002 for pricing bulk power. It comprises of three components: (a) Capacity Charge (b) Energy Charge (c) Unscheduled Inter-change (UI) Charge. The third component is Unscheduled Interchange (UI) Charge linked to frequency. UI rates will be small when frequency is above 50 Hz (Indian frequency) and high when frequency below 50 Hz. ABT meters record deviations from the schedule in 15 minute time blocks. For price based operation, data of UI curve from CERC, 2016 are used (see Figure 5), where the set frequency ranges between 49.7 and 50.05 Hz. Charges for deviation for each 0.01 Hz step is equivalent to 35.60 paisa/kWh in the frequency range of 50.05-50.00 Hz, and 20.84 paisa/kWh in frequency range below 50 Hz to below 49.7 Hz.

In the block diagram, shown in Figure 6, Primary and Secondary/ABT frequency control loops are presented. In Primary frequency control loop under the free governor mode of operation generators respond to change in frequency. In secondary frequency control scheme of UI price signal is used. The price based AGC scheme presented in [5] and shown in Figure 6 where the changes in the frequency is represented by the signal $S_1$ which is added with the fundamental frequency. Then signal $S_2$ is frequency to UI price signal which is converted according to CERC (2016). Actual generation with the addition of scheduled generation and changes at the generator output is represented by signal $S_3$ and calculated marginal cost is presented by signal $S_4$. Generation Control Error (GCE) presented by signal $S_5$ is the difference of the marginal cost and UI price signals. Positive value GEC represents generators will be in profit by increasing generation level and negative value of GEC represents the generators will be in profit by decreasing generation level. The mathematical modeling of Price based AGC is represented as follows.

When step changes of the load MW occurs in the power system, the frequency deviates by $\Delta f$ Hz.

$S_1 = \Delta f + f_0$, Where, $f_0$ is the fundamental frequency in Hz.

Deviations in the frequency generates signal $S_1$ corresponding to UI price signal $S_2$, which can be calculated as per the UI rate with respect to the frequency regulation issued by respective year.

if $S_1$<=49.7 Hz ; $S_2$=8032 Rs/MWH
if $S_1$<=50 Hz ; $S_2$=1780+20856*(50- S1) Rs/MWH
if $S_1$<=50.05 Hz ; $S_2$=35600*(50.05- S1) Rs/MWH
else $S_2$=0 Rs/MWH.

Then obtained UI price signal S2 is compared with the incremental cost signal S4 of generator, which generates Generation Control Error (GEC) signal S5. An incremental cost signal S4 for each generator is given as follows.

$S_4 = 2 * c_i * S_3 + b_i$ Rs/MWh

Where, $S_3$ is the difference of schedule generation ($P_{g0}$) MW and changes in the generator power ($\Delta P_{gi}$) MW given by the following equation.

$S_3 = P_{g0} + \Delta P_{gi}$

Now, $S_2$ is compared with the following logic to generate the Generation Control Error (GEC) $S_5$ Rs/MWh.

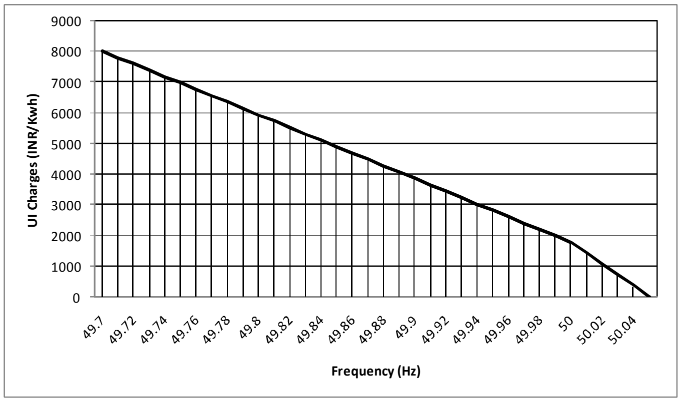


**Fig. 5 UI Curve (CERC, 2016)**

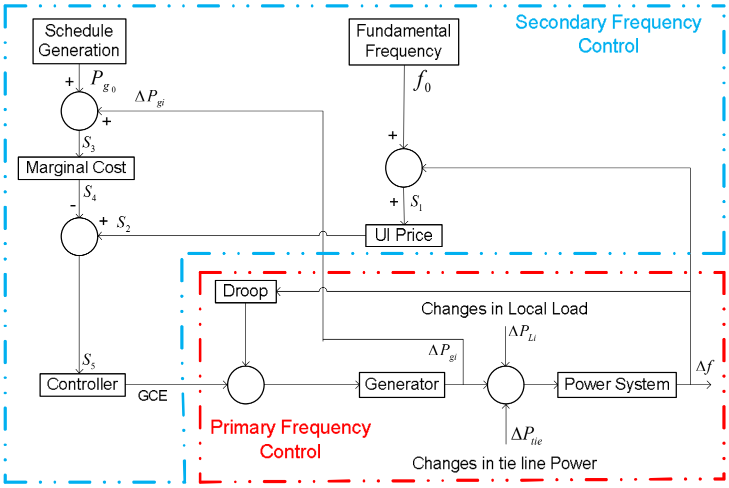
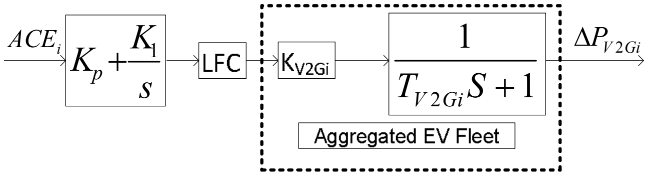


**Fig. 6 Block Diagram representation of ABT based AGC**

### 5.1.4 Electrical Vehicle and Control Scheme

By taking dynamic response in to consideration, the EVs are faster than the turbine and governor of thermal generator [34]. The frequency deviation due to supply and demand imbalance can be observed at from home outlet [15],[38],[22]. On the basis of LFC a EVs can control the charging power as shown in Figure 7, which handle the fluctuation caused by sudden load variation. The delay calculation function $T_{V2Gi}$ for the aggregated EV fleet is represented by the first order transfer function [39].

The power output of EV control methodology based on Area Control Error (ACE) and droop characteristics (MW/Hz) against frequency deviations of EVs, which is a change in power divided by a change in frequency as shown in Figure 8. Linear characteristics between 49.7 to 50.04 (CERC, 2016) Hz [23] is considered. ACE dispatched is in proportional to the magnitude of a gradient. Due to positive ACE, 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 it means increases in discharging power. PI gain controller is used for the bidirectional charge.



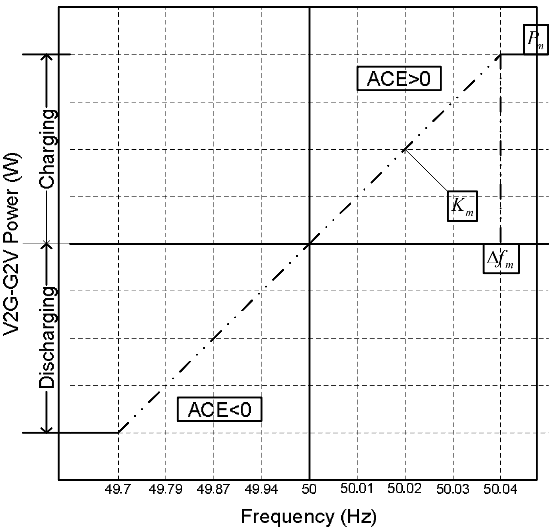


**Fig. 7 V2G Model**

**Fig. 8 V2G power Charging/Discharging control**

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

## V2G Power Control

Decentralized V2G control method [49] is used to maintain the power output ($P_{V2G}$) / ($P_{G2V}$) by the charging / discharging characteristics followed by figure 4 the battery can be controlled as

$$P_{V2G} = \begin{cases} K_{V2G}\Delta f & (\Delta f \geq 0) \\ Pm & \left(\left|K_{V2G}\Delta f\right| \geq P_m\right) \end{cases} \tag{11}$$

$$P_{G2V} = \begin{cases} K_{G2V}\Delta f & (\Delta f < 0)) \\ -Pm & \left(\left|K_{G2V}\Delta f\right| \leq -P_m\right) \end{cases} \tag{12}$$

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

$$K_{V2G} = K_m \left[ 1 - \left( \frac{SOC - SOC_{low(high)}}{SOC_{\max(\min)} - SOC_{low(high)}} \right)^n \right] \tag{13}$$

$$K_{G2V} = K_m \left[ 1 - \left( \frac{SOC - SOC_{high(low)}}{SOC_{\min(\max)} - SOC_{high(low)}} \right)^n \right] \tag{14}$$

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. It is necessary to develop a kind of algorithm in order to calculate the SOC limits because plug in time, V2G control and SOC level are changed.

### Battery SOC deviation control

The charging **(**$P_{V2G}$) and discharging ($P_{G2V}$) power can be controlled by tuning the gain $K_{V2G}$ and $K_{G2V}$ against frequency deviations by LFC based PI controller. PI controllers can track the changes occurring in the power system to get optimal performances. 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 are 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 [48] .

$$IAE\ of\ \Delta SOC_{Area1} = \int_0^\infty \left| \Delta SOC_{Area1} \right| dt \tag{15}$$

$$IAE\ of\ \Delta SOC_{Area2} = \int_0^\infty \left| \Delta SOC_{Area2} \right| dt \tag{16}$$

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. The value of IAE is subjected to,

$$K_{pi,\min} < K_{pi} < K_{pi,\max} \tag{17}$$

$$K_{Ii,\min} < K_{Ii} < K_{Ii,\max} \tag{18}$$

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.

### 5.2 Proposed Model to regulate grid frequency

Figure 9 represents the mathematical model of N-area interconnected power system. The following additions are made to the model: thermal plant with non reheat unit, wind turbine model and dynamic model for the discharging of EV battery. System operator from the control centre disperses the ACE signal to GENCOs and LFC signal to the aggregators through Area Participation Factor (APF). The LFC signal is dispersed from the aggregators to the EVs. The bidirectional charger allows the EVs to feed power into the grid.

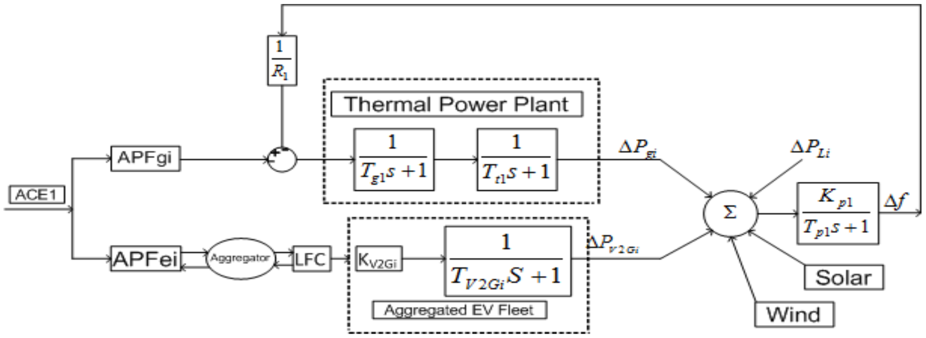


**Fig. 9 Proposed block diagram for the grid frequency regulation**

#### 5.2.1 Results

The results for the AGC operation under smart grid with the POOLCO based market, Bilateral market by considering 10% & 20% load variation with the consideration of ABT mechanism are presented. Results based on above consideration are presented in thesis.

#### Case I: Poolco Based Transaction (Load variation 300 MW)

In the case of Poolco based transaction, the load variation in area 1 only has been assumed. An ACE participation factors considered are, $apf_1=0.5$, $apf_2=1- apf_1$, $apf_3=0.5$, $apf_4=1-apf_3$ .The load demanded only by DISCO1 and DISCO2. DISCO3 and DISOC4 do not claim for power from any GENCOs and hence subsequent contract participation factors are zero. The

DPM value is given below. Table 1 represents the mathematical values of of GENCO power deviations which is represented in figure 10 to 13.

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

**Table 1: Calculate values for Case 1**

| Change in Generation | | | | | Tie Line |
|---|---|---|---|---|---|
| Unit | G-1 | G-2 | G-3 | G-4 | |
| MW | 150 | 150 | 0 | 0 | 0 |

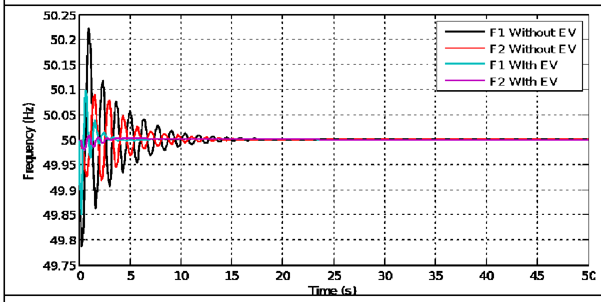
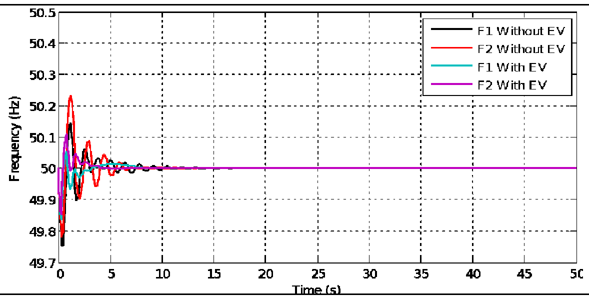
**Case II: Bilateral Transaction (Load Variation=300 MW & 200 MW)**

In this DISCOs contract with the GENCOs for power as per the DPM given. It has been assumed that each DISCO demands 10% load variation from GENCOs and each GENCO participates followed by an AGC as per apfs given are, $apf_1=0.75$, $apf_2=1- apf_1=0.25$, $apf_3=0.5$, $apf_4=0.5$ . Table 1 represents the mathematical values of of GENCO power deviations which is represented in figure 14 to 17.

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

**Table 2: Calculate values for Case 2**

| Change in Generation | | | | | Tie Line |
|---|---|---|---|---|---|
| Unit | G-1 | G-2 | G-3 | G-4 | |
| MW | 157.5 | 67.5 | 195 | 55 | -0.05 |

| **Case 1** | **Case2** |
|---|---|
|  |  |
| **Fig. 10 Frequency** | **Fig. 14 Frequency** |

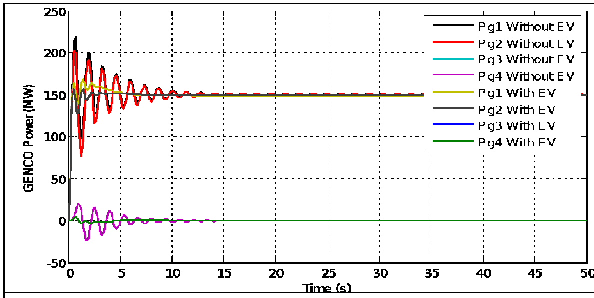


Fig. 11 GENCO Power

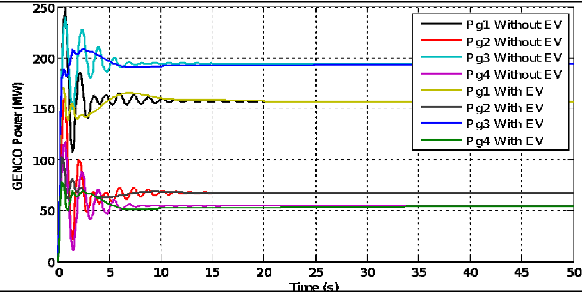


Fig. 15 GENCO Power

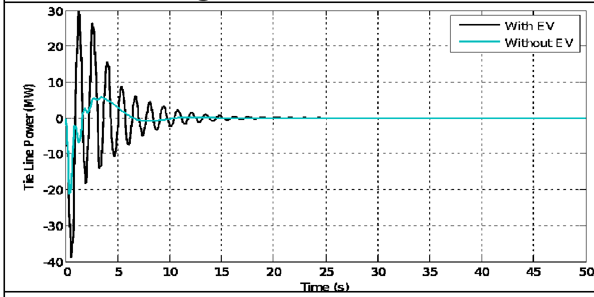


Fig. 12 Tie Line Power

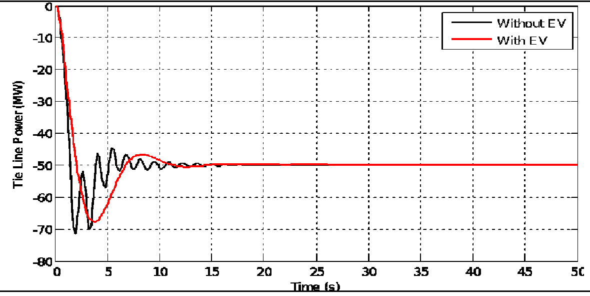


Fig. 16 Tie Line Power

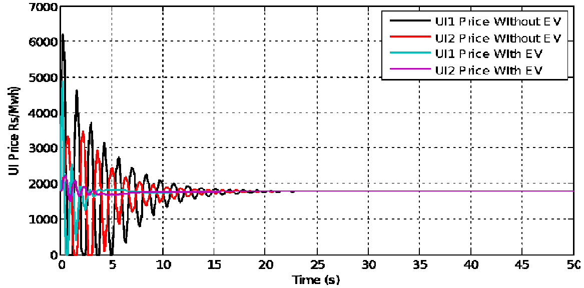


Fig. 13 UI Price

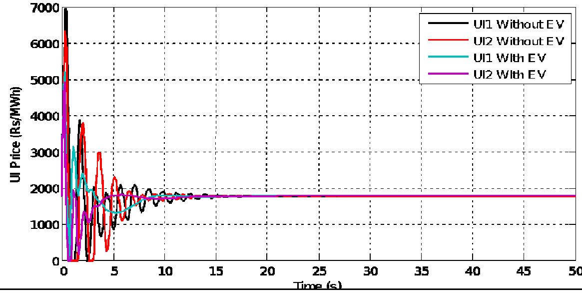


Fig. 17 UI Price

## 6. Achievements with respect to objectives

The research work has led to the development of new frequency regulation method by EVs for the generators running under ABT mechanism. Some case study results are discussed. The achievements from this work are summarized as below.

1. Due to slow dynamic response, the governor is incapable of regulating the frequency. Deviations in frequency and power due to load fluctuation and cyclic power variation of renewable source are analyzed from the results. A possible solution has been provided for a fleet of EV model. Fast dynamic response of battery operation switched by bidirectional charger help reduced deviations in frequency and power. The overshoots and settling time are lower in comparison to conventional AGC schemes. **[Publication 1]**
2. Extending the proposed concept to grid connected renewable energy sources, using EVs as storage and frequency regulator for cyclic fluctuation in the power, better performance has been achieved compared to conventional AGC system. **[Publication 1 & 2]**

3. The reduction in deviation of UI price has also been achieved using fleet of EVs along with a reduction in frequency and power deviation has been obtained during peak hours and off peak hours.**[Publication 3]**
4. The research work has shown that the impact of increased deviation in the frequency by wind power generation gets minimized with the help of dynamic storage. **[Publication 4]**

## 7. Conclusion:

Based on the research work carried out it has been observed that, sudden load variation and cyclic fluctuation in renewable power creates power imbalances between demand and supply. This results in frequency deviation at the output of the generator. Proposed research work has provided unique solution that has minimized the deviation in the frequency by load variation and renewable power generation. The dynamic storage (EV) mechanism suggested in this research has given better solution for stabilization of frequency fluctuation in restructured power system with the help of bidirectional charging controller. In our analysis of the effect of fleet of EVs, POOLCO based contract and bilateral contract has been considered during peak hours and off peak hours.

In case of POOLCO based market the frequency reduces from 48.76Hz (Without EV) to 49.84 Hz (With EV) while the frequency deviation settling time reduces from 25 s to 17s. Similarly, for Bilateral market the frequency reduces from 49.73 (Without EV) Hz to 49.83 Hz (With EV) while the frequency deviation settling time reduces from 17s to 10s. Lastly, for Bilateral market with contract violation frequency overshoots and settling time reduces from 49.57 Hz (Without EV) to 4955 Hz (With EV) and 14s to 8s.

Thus it has been found that the technique developed here gives better minimization in frequency and power deviation as well as deviation of UI price.

## 8. Copies of papers published and a list of all publications arising from the thesis

### 8.1 Publications based on work done so far are as follows

1. Y R Prajapati and V N Kamat, “Secondary frequency regulation / Automatic Generation Control under Deregulated Power System along with renewable energy sources using Electric Vehicle/ Distributed Energy Storage Systems”, IEEE International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT),2016.
2. Y R Prajapati, V N Kamat and J J Patel “Impact of Grid Connected Solar Power on Load Frequency Control In Restructured Power System”, i-PACT IEEE intern. Conf.2017 at VIT, Vellore University, Tamilnadu ,2017.
3. Y R Prajapati, V N Kamat and J J Patel “Price Based Automatic Generation Control (AGC) in restructured power system by considering peak hours and off peak”, Wulfenia Journal, Klagenfurt, Austria, ISSN- 1561 882X, vol. 25, No.3, March ,2018.
4. Y R Prajapati, V N Kamat and J J Patel “Impact of grid connected wind power on frequency regulation in restructured power system”, International Conference APGRES-2019, Banswara, RTU, 2019, Available on ELSEVIER-SSRN.

### 8.2 Publication Under Review

I. Y R Prajapati, V N Kamat and J J Patel, “Automatic Generation control in a smart grid using Electrical Vehicles as a Battery Energy Storage System” Intr. Jrn. Of Power and Energy Systems, ACTA Press Journal 20.6.2019.

II. Y R Prajapati, V N Kamat and J J Patel, “Load frequency control under Restructured Power System Using Electrical Vehicle as Distributed Energy Source”, Journal of the IE (India) Series-B, 20.6.2019.

III. Y R Prajapati, V N Kamat and J J Patel, “Simulation of AGC in Restructure Power System under Availability Based (ABT) mechanism by considering peak hours and off peak hours”, ECIT Transactions on Electrical Engineering, Electronics & Communication, 20.6.2019.

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