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Frequency Linked Price using Unscheduled Interchange (UI) Signals of Two Area Power System

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ABSTRACT:

Unscheduled Interchange (UI) price is one of the components of ABT, acts as a Secondary Control mechanism for regulating the grid frequency. This UI price signals fluctuate according to change in grid frequency which can be accessible by participants (generator or load) connected to the grid. This paper, discusses the UI linked frequency price of two area power system for Evolutionary Algorithms. CERC, 2013 UI rate curve has been used for this analysis.

KEYWORDS: Availability Based Tariff, Unscheduled Interchange, Deregulated Electricity Market, Generation Control Error, Incremental Marginal Cost, Shuffled Frog Leaping Algorithm.

I.INTRODUCTION

The successful operation of power system requires the balance between supply and demand on a minute to minute basis. In well developed countries the ancillary service called Automatic generation control (AGC) which measures the deviation in frequency and tie-line power flow instantly due to change in scheduled interchange. Automatic Generation Control is one of the most important ancillary services in deregulated market. This task also becomes more challenging in present deregulated electricity market**.** Primary control (FGMO) is necessary to maintain frequency within the desirable limits. As the interconnections grow larger in size and the interchanges between areas also increases, so the primary control by governors has to be supplemented by secondary control (AGC) [2]. Both Primary and secondary controls are necessary to keep frequency and schedules within acceptable ranges for reliability. Even a large deviation can be brought in to zero within few minutes using AGC in United States. But in India Automatic Generation Control is incompatible because of generation shortage.

The power generation capacity of India has steadily increased over past few years, but demand growth has gone far ahead of supply growth. This tends to an energy shortage .In year 2003 the electricity has gone through a major transformation from vertical integrated utility (VIU) to open market system which encourage the trading activities and competition in the Indian electricity sector. Before 2002, grid operators in India faced a major problem in the form of grid indiscipline, because of random fluctuation in grid frequency 48 Hz to 52 Hz on daily basis resulting in frequent blackouts.

The UI mechanism was introduced in 2002 before the market in electricity was developed. The objective of the regulations was to maintain grid discipline as envisaged under the Grid Code through the commercial mechanism of Unscheduled Interchange Charges by controlling the users of the grid in scheduling, dispatch and drawl of electricity [10].

The term Availability Based Tariff stands for a rotational tariff structure for power supply from generating stations on a contracted basis. The special features of this tariff are to handle the peculiar problem of grid operation in India, which is the frequency, linked pricing of UI.

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2. ABT –UI MECHANISM

The ABT introduced a three part tariff structure by unbundling the fixed and variable energy charges. The first component is a fixed one and it is purely depends on the availability of generating stations. This is called as “Capacity Charge”. The second part of this ABT is the variable component which is based on the fuel consumption given by the schedule of the day and is known as “Energy charge”. In addition to these two charges, a third charge contemplated in the ABT scheme is for the unscheduled interchange of power (UI charges). The UI charges are payable depending upon what is deviated from the schedule and also subject to the grid conditions at that point of time [10].

This ABT element was introduced to bring the effective discipline in power system. Under this scheme UI charges will be payable, if i)a generator generates more than the schedule, thereby increasing the frequency; ii) a generator generates less than the schedule, thereby decreasing the frequency; iii) a beneficiary overdraws power, thereby decreasing the frequency; iv) a beneficiary under draws power, thereby increasing the frequency [10].

It is clear that the UI charges are a commercial mechanism to maintain grid discipline. The UI charges penalize whosoever caused grid indiscipline, whether generator or distributor, is subject to payment of UI charges that who are not following the schedule. UI rate is high during low frequency which discourages the over drawl of power to the beneficiaries and UI charge is low, if the above statement is Vice versa. As long as the actual generation or withdrawal is strict to the given schedule, the third component of ABT is zero [2]. If the frequency is above 50 Hz (nominal frequency of Indian System), UI rate will be less and if it is below 50 Hz, it will be more, which discourages beneficiary the over drawl of power.

3. PRICE BASED AUTOMATIC GENERATION CONTROL (PBAGC)

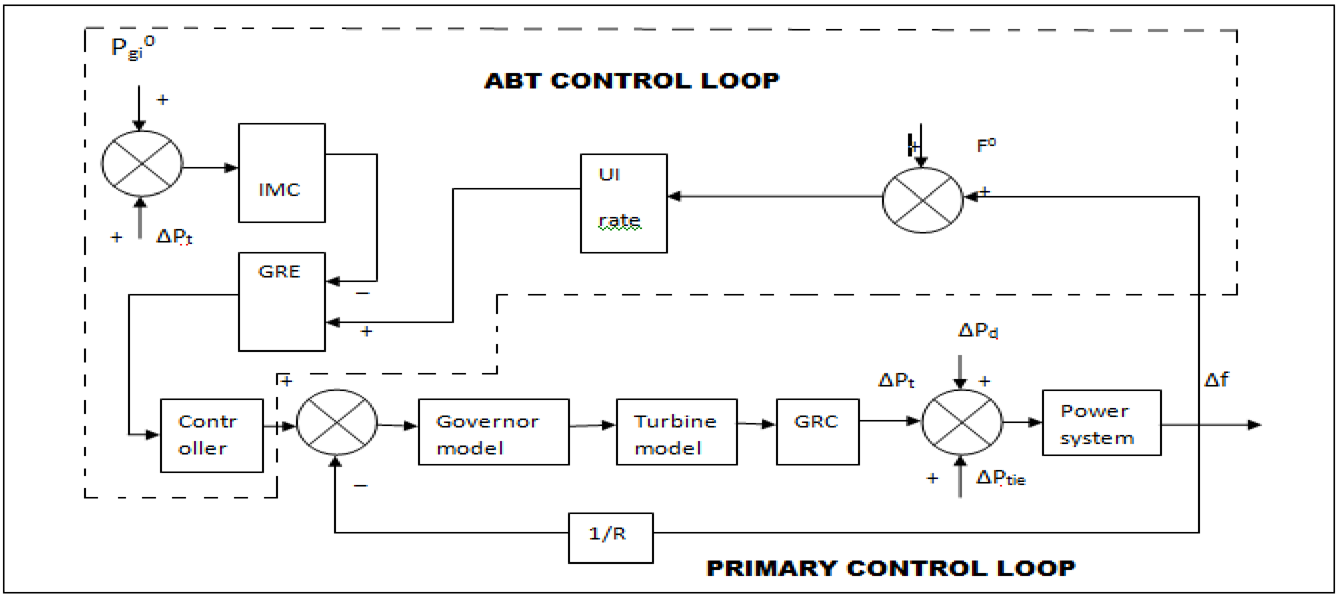

Fig 1: FGMO and ABT Based Frequency Control Loop

It explains the PBAGC ensuring that the generation units respond to the UI price signal automatically. Fig 1. Shows both primary and ABT based secondary control mechanism. The primary control remains same that of the conventional method but the automatic secondary control uses UI price signals. Primary control responds to a change in frequency instantly by Free Governor Mode of Operation (FGMO), and the secondary control loop operates automatically following the UI price signals which is available in real time. In case there is a need of more generation that cannot be supplied through primary control. This can be satisfied by ABT based secondary control mechanism.

Fig 2. shows the ABT Based Frequency Control Loop. Each generator monitors UI price ρ, its marginal cost ɤ and compares, and then the error signal (ρ- ɤ) is generated. This error signal is fed in to an Integral controller which brings the frequency to its nominal value.

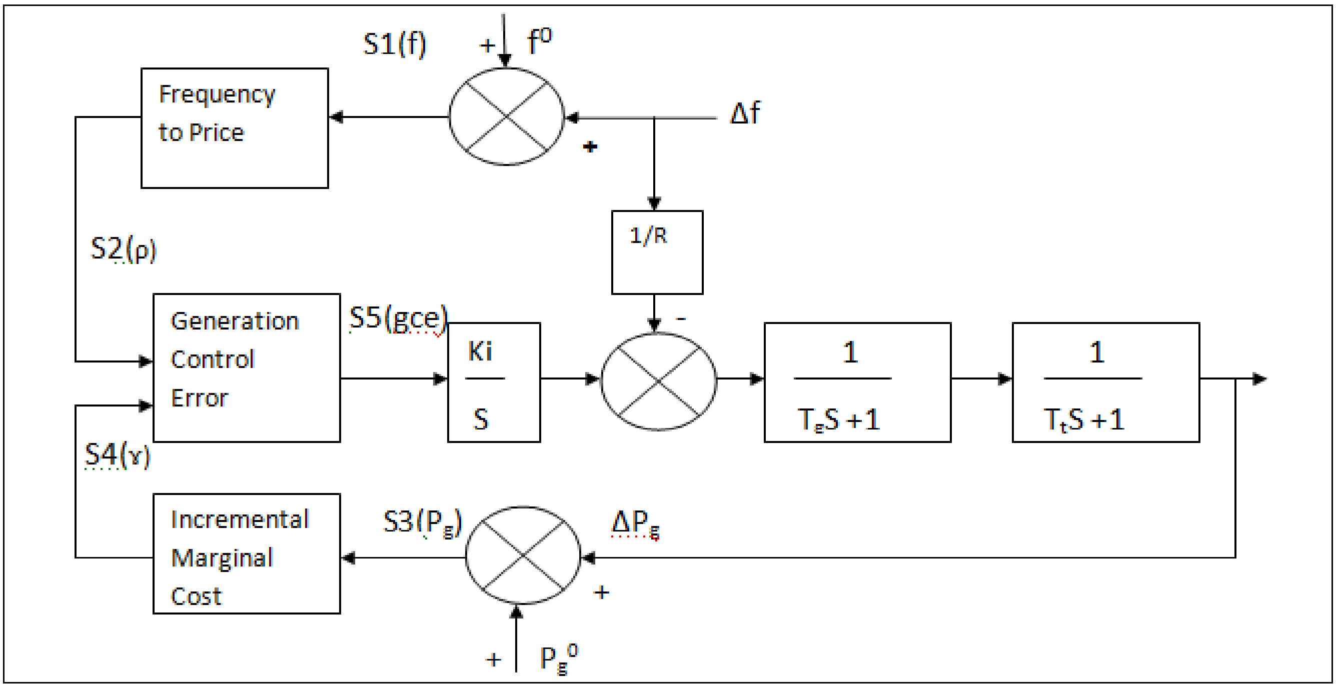

Fig 2: ABT Based Frequency Control Loop

4. SYSTEM MODELING

I. FREQUENCY-UI PRICE BLOCK

UI curve was introduced in the year 2000. It has been ordered by Central Electricity Regulatory Commission (CERC), so as to meet the states objectives of ABT mechanism. Initially, the frequency range in UI price was set in between 49.0 Hz to 50.5 Hz (CERC, 2000) and the maximum price limit was 4800 INR/MWh at 49.0 Hz and the minimum price was zero INR/kWh at 50.5 Hz [2]. In CERC2009, the frequency range was set between 49.2 Hz to 50.3 Hz and the price limit was zero to 7350 INR/MWh.

We have used the UI rate curve 2013, for frequency to UI price conversion as shown in Figure.3,. The actual frequency is the sum of the frequency deviation and the nominal frequency and it is given in equation (1) as follows,

Frequency signal S1 (f) = $\Delta f + f^0$ Hz.

Where, Δf is the change in frequency and f^0 is the nominal frequency 50 Hz.

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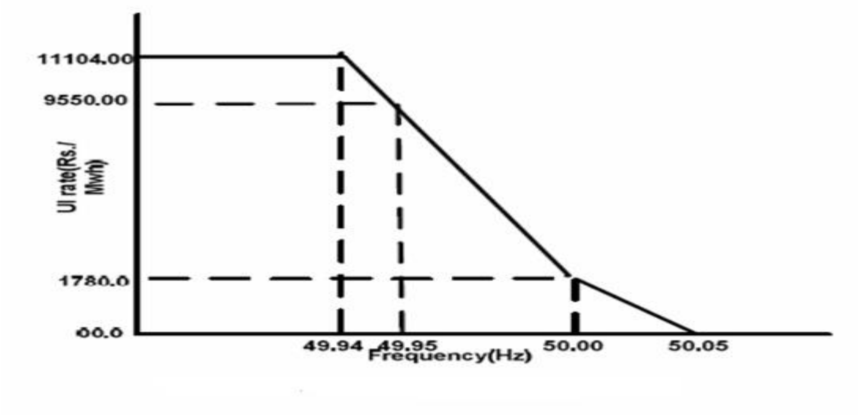

Fig 3: UI rate CERC, 2013

```
 if u>50.05
y=0;
elseif u<=50.05
y=35600*(50.05-u);
elseif u>50
y=35600*(50.05-u);
elseif u<=50
y=1780+155400*(50-u);
elseif u>49.95
y=1780+155400*(50-u);
elseif u<=49.95
y=9550+155400*(49.95-u);
elseif u>49.94
y=9550+155400*(49.95-u);
else u<=49.94
y=11104;
end
```

Fig 4: UI rate (CERC, 2013) block

II. INCREMENTAL MARGINAL COST

In general marginal cost of generation, γ is related to the turbine generator power output [2]. For each generator, Overall cost of the generation is given by the quadratic equation (2),

$$C_i\,(P_{gi}) = a_i + b_i\,P_{gi} + c_i\,P_{gi}^2 \text{ INR/h} \quad (2)$$

Then, the incremental marginal cost of generator is given by equation (3),

$$\gamma_i = \frac{dci}{dPgi}\,(P_{gi}) = 2\,c_i\,P_{gi} + b_i \text{ INR/MWh} \quad (3)$$

Incremental cost signal S4 (γ) is given by the following equation (4)

$$S4\,(\gamma) = 2 * c * S3 + b \text{ INR/MWh} \quad (4)$$

Where c and b are the incremental cost coefficient of the system. S3 (P_g) is given by the equation (5),

$$S3\,(P_g) = P_g^0 + \Delta P_g \text{ MW} \quad (5)$$

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Where, ΔP_g is change in turbine generator output and P_g^0 is an initial scheduled power of generation and P^0 is the UI rate corresponding to nominal frequency $f^0 = 50$ Hz. $P^0 = 1650$ INR/MWh shown in Figure.3. Further s2 (ρ) and S4 (ɤ) signal is compared as per the flowchart Fig 5 .and generate the error called GCE.

III. GENERATION CONTROL ERROR (GCE)

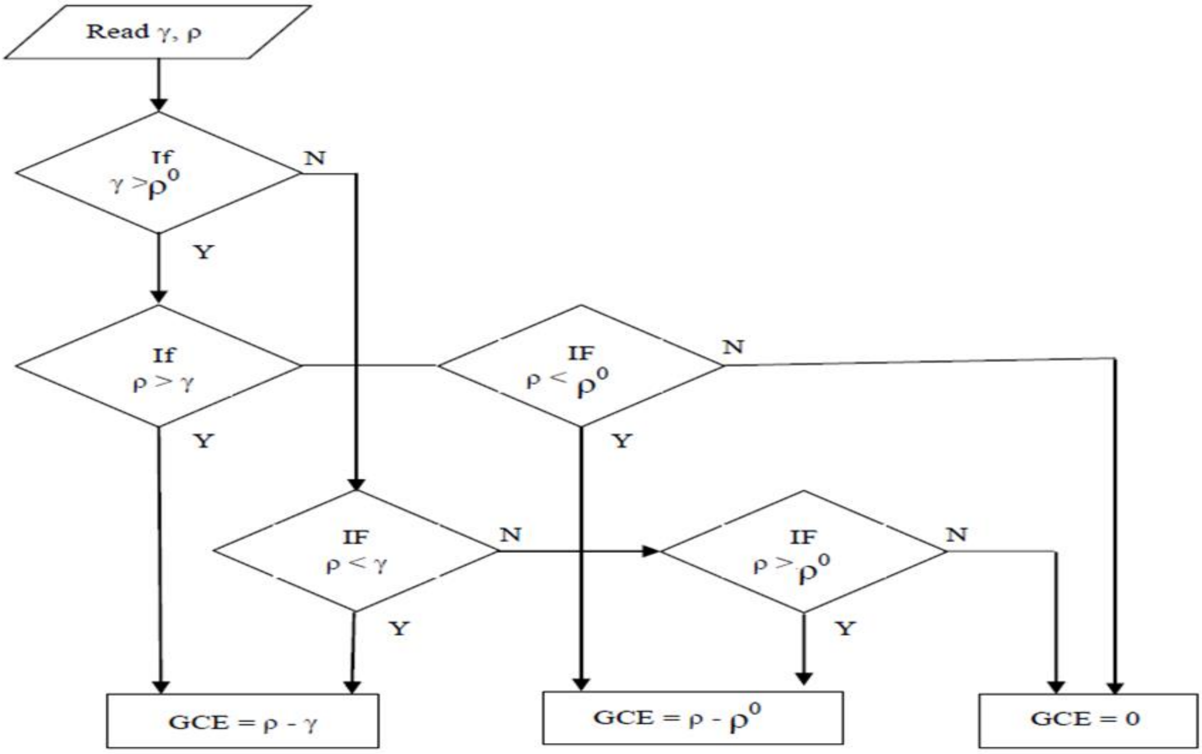

Fig 5: Flowchart for Calculating GCE

5 SHUFFLED FROG LEAPING ALGORITHM

A memetic algorithm known as Shuffled Frog Leaping Algorithm is used in this paper. A memetic algorithm (MA) is a population-based approach for a heuristic search in optimization problems. Meme (pronounced 'meem') is a contagious information pattern that replicates by parasitically infecting human and/or animal minds and altering their behavior, which causes them to propagate the pattern. The actual content(s) of a meme, called memotype(s), are analogous to the chromosome(s) of a gene. An idea or information pattern is not a meme until it causes someone to replicate it or to repeat it to someone else Memes will be positively selected mainly for increased communicability among the hosts (described as frogs in the SFLA). Genes will be selected mainly for sexual reproducibility. Memetic and genetic evolution are subjected to the same basic principles, i.e. possible solutions are created, selected according to some measure of fitness, combined with other solutions and possibly mutated. Memetic evolution, however, is a much more flexible mechanism. Genes can only be transmitted from parents or parent in the case of asexual reproduction to offspring. Memes can, in principle, be transmitted between any two individuals. Since genes are transmitted between generations, higher organisms may take several years to propagate. Memes can be transmitted in the space of minutes. Gene replication is restricted by the rather small number of offspring from a single parent, whereas the number of individuals that can take over a meme from a single individual is almost unlimited. It is much easier for memes to undergo variation since the information in the nervous system is more plastic than that in deoxyribonucleic acid and since individuals can come into contact with many different sources of novel memes. Therefore, meme spreading is much faster than gene spreading. The other difference between

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'memes' and 'genes' is that memes are processed and possibly improved by the person that holds them – something that cannot happen to genes. The flowchart for the SFL algorithm is given in Fig 6.

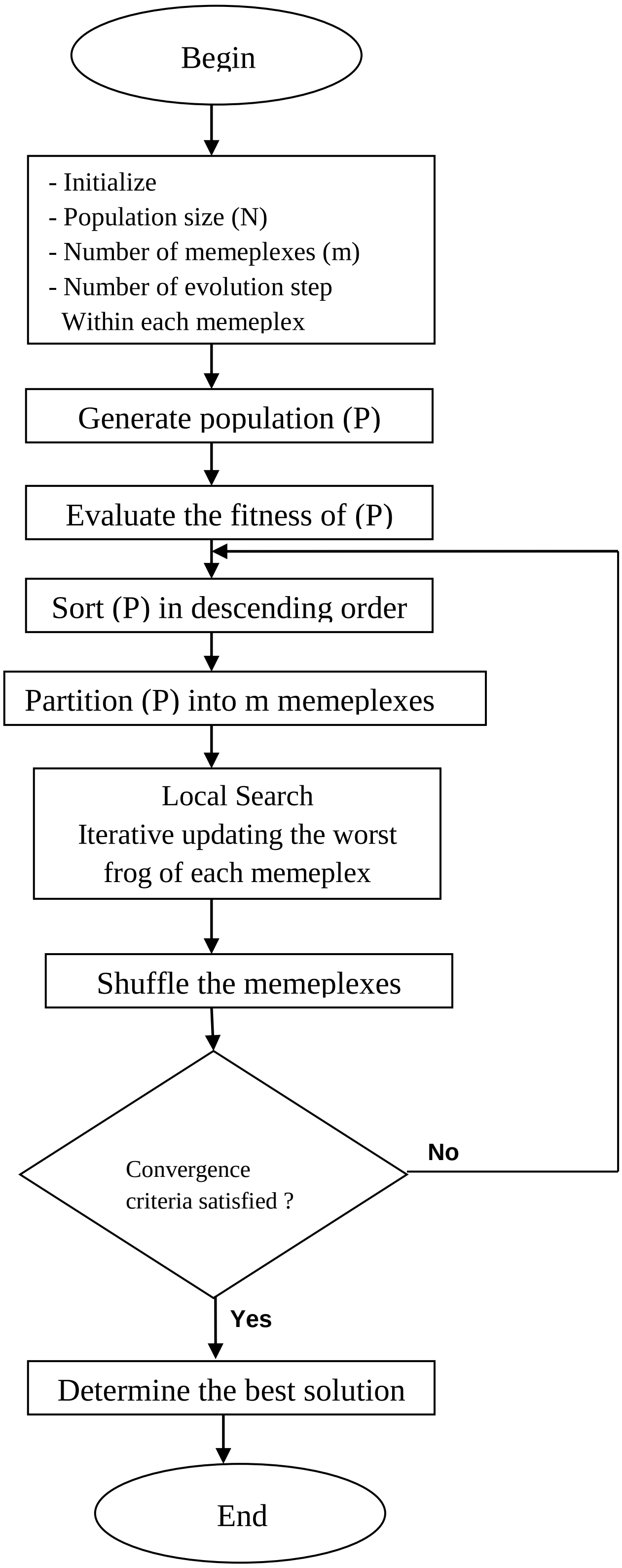

Fig 6: Flowchart of SFLA

6. SIMULATION DIAGRAM

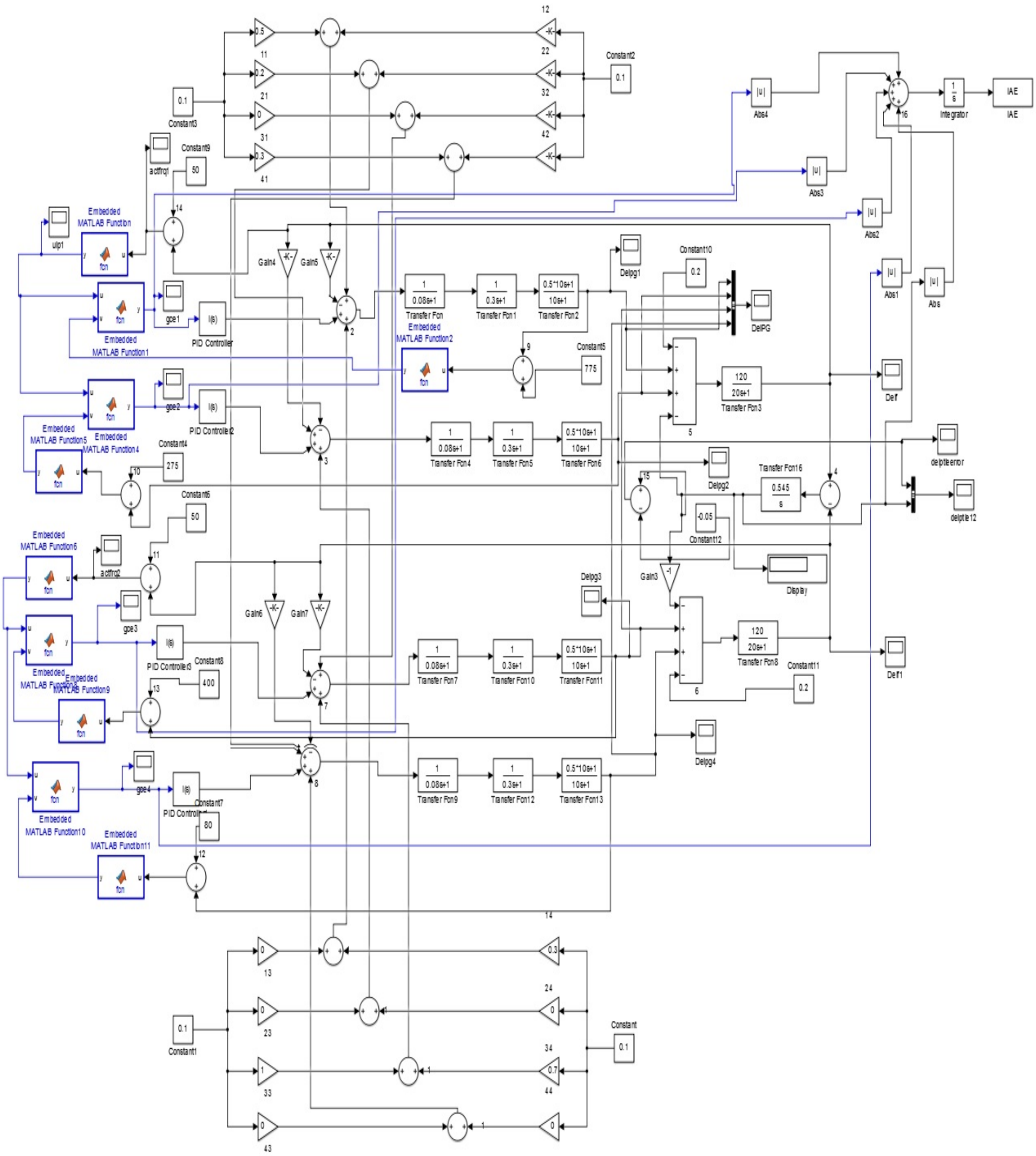

Fig 7: PBAGC model for Two Area four Generator System using MATLAB/SIMULINK

The test system is a single area system having a capacity of 2000 MW supplied by three generating stations which follows the schedule as per merit order. The system data and Generator data are given in Table 1 and Table 2 respectively.

Table 1: System Data

Input Data	Ratings/Values
Base power Area rated power Pr1=Pr2	2000 MW 2000 MW
Area inertia constant	5 seconds
Area damping co-efficient : D1=D2	$8.33*10^{-3}$pu MW/Hz
Droop of each generator:R1=R2=R3=R4	2.4 Hz/pu MW
Governor time constant of each generator: Tg1=Tg2=Tg3=Tg4	0.08 seconds
Non reheat time constant of each turbine: Tt1=Tt2=Tt3=Tt4	0.3
Reheat unit of each turbine time constant : Tr1=Tr2=Tr3=Tr4	10
Reheat fraction unit of each turbine time constant : Kr1=Kr2=Kr3=Kr4	0.5
P_{tiemax}	200 MW
Synchronizing co-efficient 2II*T12	0.545 pu MW/Hz

Table 2: Generator Data

Parameters		Generators		
	G1	G2	G3	G4
Capacity(MW)	1000	1000	1000	1000
b_i (Rs./MWh)	1600	2000	2400	3600
c_i (Rs./MWh^2)	0.4	0.4	2	2.5

Disco Participation Matrix

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

Table 3: Generation Schedule (in MW)

System Marginal Cost (Rs./MWh)	Generator 1(MW)	Generator2(MW)	Generator3(MW)	Generator4(MW)
1850	775	275	400	80

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6. SIMULATION RESULT

Case-1: The marginal cost of the system is higher than the nominal UI rate of year 2014; Fig 8 and 9 shows, the frequency deviation in area 1&2. Fig 10 shows, the response of load change in four generators and Fig 11 shows the tie-line actual and error power deviation. Fig 12,13,14 and 15 shows, response of change in GCE of all four generators.

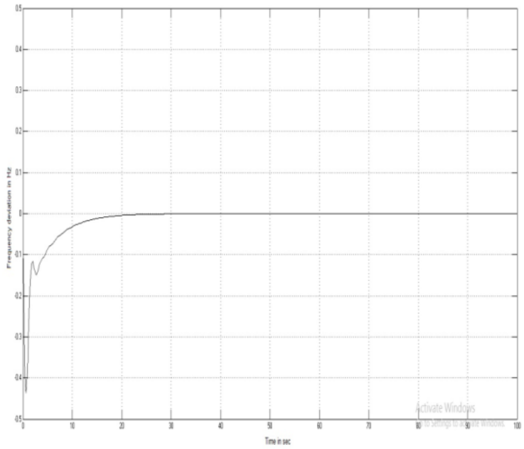

Fig 8: Area1 Frequency deviation vs. Time

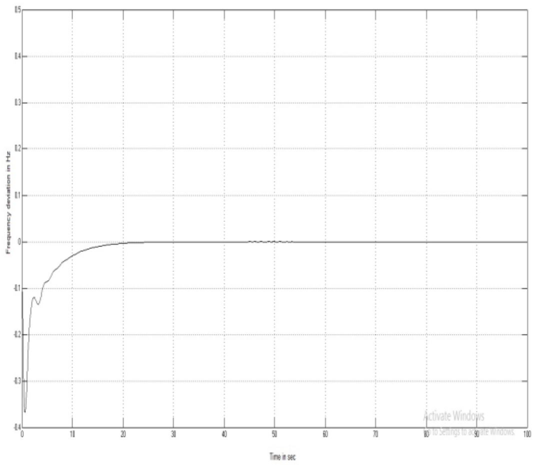

Fig 9: Area2 Frequency deviation vs. Time.

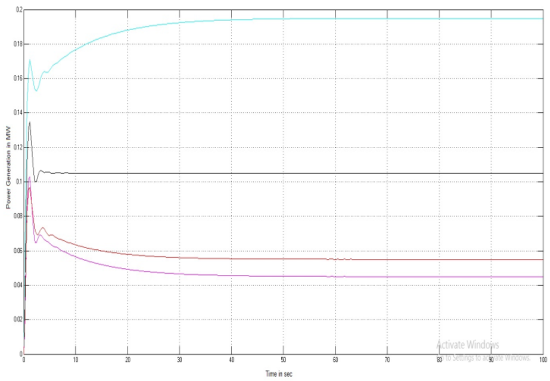

Fig 10: Generated power vs Time

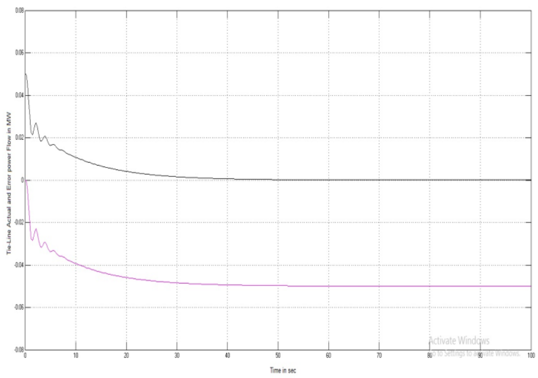

Fig 11: Tie-Line Power flow vs Time

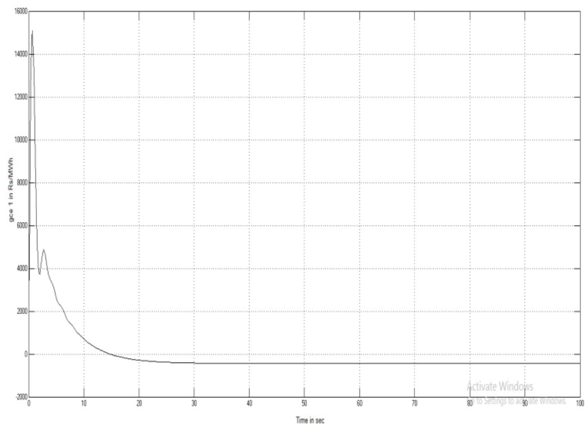

Fig 12: Gce 1 vs Time

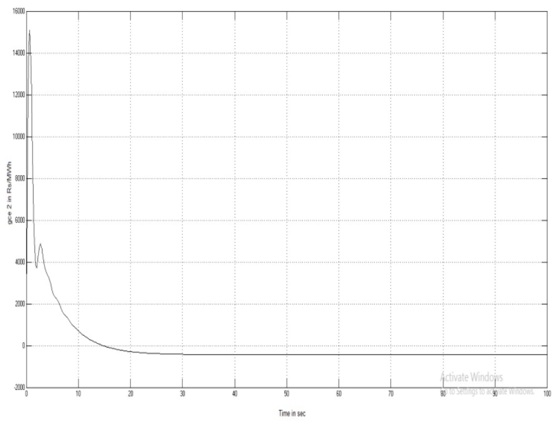

Fig 13: Gce 2 vs. Time

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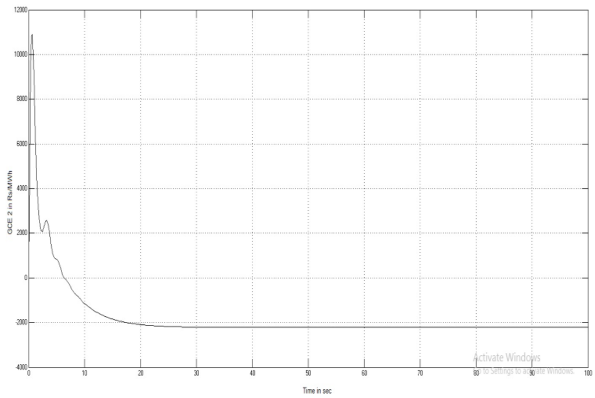

Fig 14: Gce 3 vs Time

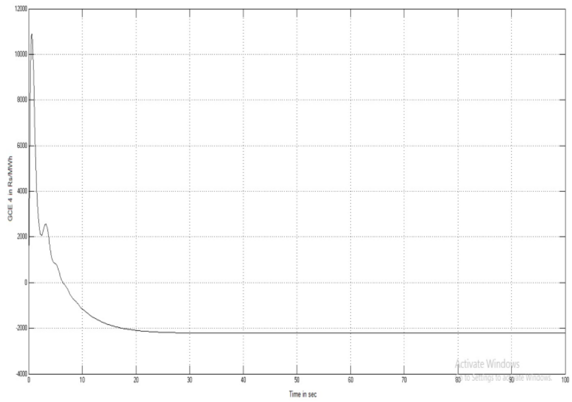

Fig 15: Gce 4 vs. Time

Calculation for generation in MW

Moreover, as given by Eq. (24), in the steady state, the Gencos must generate

$$\Delta P_{G1} = 0.5(0.1) + 0.25(0.1) + 0(0.1) + 0.3(0.1)$$

$$= 0.105 \text{ pu MW} = 210 \text{ MW}$$

Similarly,

$$\Delta P_{G2} = 0.045 \text{ pu MW} = 90 \text{ MW}$$

$$\Delta P_{G3} = 0.195 \text{ pu MW} = 390 \text{ MW}$$

$$\Delta P_{G4} = 0.055 \text{ pu MW} = 110 \text{ MW}$$

7. CONCLUSION

This paper discusses Frequency linked price using unscheduled interchange price signal of two area power system. The effect of UI signals has been studied through different case of system marginal cost. The SFL algorithm is implemented to tune the gains of the Integral controllers in both areas. This helps in saving of unnecessary exchange of UI.

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