Generation Scheduling under ABT using Forecasted Frequency by Artificial Neural Network and Statistical Tool

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***Abstract*—The Generation Scheduling (GS) is a day ahead activity of distributing load amongst state owned and central sector generators in India. Under Availability Based Tariff (ABT), the cost of central sector power depends upon system frequency. It is necessary to modify the conventional scheduling algorithm to incorporate central sector contribution as a separate generator with frequency dependant cost function.**

Thus, it is necessary to estimate frequency of next day as accurately as possible and use it in the modified algorithm to harness maximum benefits of ABT.

In this paper two methods of estimating frequency of the next day are compared, one is statistical method and the other is use of Artificial Neural Network (ANN). The results show that ANN can estimate frequency more accurately than statistical method.

The modified scheduling algorithm is then used to demonstrate the use of anticipated frequency and its contribution in achieving more realistic schedule to derive maximum benefits of ABT.

I. Introduction

THE conventional Generation Scheduling (GS) is a day ahead activity in an utility which gives guide-line around which actual real time generation and dispatch are clustered. The conventional generation scheduling aims at minimizing the cost of generation subject to load–generation balance, generator limits, transmission line loading, contingencies, security constraints and stability considerations. Most of the utilities have central sector generation in addition to their own generation in India. The central sector power is charged as per ABT.

The ABT is a tariff for bulk power transfer between state beneficiary and central sector generating stations in India. The tariff has three components viz Fixed Charge, Energy Charge and Unscheduled Interchange (UI) charge. The last component, UI charge is frequency dependant [1]-[2]. Any deviation from schedule is to be paid through frequency dependant UI rate. Hence frequency plays important role in dispatch decisions.

The conventional GS algorithm is modified to include anticipated frequency as one of the parameters along with anticipated load and generation. The modified scheduling algorithm incorporates frequency dependant availability based tariff. It is therefore necessary to predict frequency at any time of the day and make it available to scheduler to decide cost of central sector generator.

The efforts are made to estimate hourly frequency using statistical tool and ANN. The feasibility of using statistical method for frequency estimation is reported in [5]. While procedure of designing an ANN for load prediction is reported in [8]. In the present work the design of ANN for frequency prediction is reported and its accuracy is compared with statistical method. The comparative study shows the superiority of ANN over statistical method for frequency estimation.

The benefits of predicting frequency and modifying cost of central sector generation in generation scheduling are justified by applying it to the test system.

II. Generation Scheduling undr Availability Based Tariff

To make a day ahead schedule of generation more appropriate, it is necessary to incorporate frequency as additional input along with anticipated load in optimal generation scheduling, since cost of central sector power depends upon frequency in ABT.

The conventional algorithm of generation scheduling is thus modified to incorporate frequency dependant part of tariff ie UI rate and UI charge [3],[4].

The central sector share in generation scheduling is accounted by considering power available from grid as an additional generator with incremental cost of generation as UI Rate [3]. The cost function of grid generator is modified accordingly. Thus, under ABT, the GS is a problem of minimization of total cost of power to be generated by internal generators and to be purchased from grid.

The cost function to be minimized is ,

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$$C_t = C_{gr}\left(P_{gr}\right) + \sum_{i=1}^{n} C_i\left(P_{gi}\right) \qquad (1)$$

Subject to constraints

$$\left(P_{gr} + \sum_{i=1}^{n} P_{gi}\right) - P_L - P_D = 0 \qquad (2)$$

$$P_{gi_{(\min)}} \le P_{gi} \le P_{gi_{(\max)}} \qquad (3)$$

$$P_{gr_{(\min)}} \le P_{gr} \le P_{gr_{(\max)}} \qquad (4)$$

Here

- C_i = Cost of active power generation in Rs per MW per Hr by i[th] generator
- C_{gr} = Cost of purchase of power in Rs per MW per Hr from grid generator
- P_{gi} = Power output of i[th] generator (MW)
- P_{gr} = Total power to be purchased from grid generator (MW)
- P_{ij} = Transmission line power flow (MW)
- P_L = Transmission loss (MW)
- P_D = Load demand (MW)
- $P_{gi(\min)}$ = Minimum generation limit of i[th] generator
- $P_{gi(\max)}$ = Maximum generation limit of i[th] generator
- $P_{gr(\min)}$ = Minimum limit on drawal of power from grid generator
- $P_{gr(\max)}$ = Maximum limit on drawal of power from grid generator

Total Power to be purchased from grid generator has two parts as

$$P_{gr} = SI + UI \qquad (5)$$

- Scheduled Interchange (SI): - This is scheduled power (MW).
- Unscheduled Interchange (UI): - This is the deviation from the scheduled power (MW).

Total cost of power purchased from grid, C_{gr} (P_{gr}) also has two parts-

- Cost of power corresponding to scheduled interchange C_{SI}
- Cost of power corresponding to unscheduled interchange C_{UI} = UICharge

$$C_{gr}\left(P_{gr}\right) = C_{SI} + C_{UI} \qquad (6)$$

where,

$$C_{UI} = UIcharge = UI \times UIrate \qquad (7)$$

As usual, the Lagrange Multiplier technique is used to solve the GS problem. This modified algorithm was validated for its applicability on 26 Bus Test System shown in Fig. 1 and reported in [3],[4]. The 26 bus system consists of 6 generators out of which, generator at bus 26 is considered as grid generator with remaining 5 generators at different buses as internal generators. The transmission line connecting grid generator to rest of the system is considered to have large capacity.

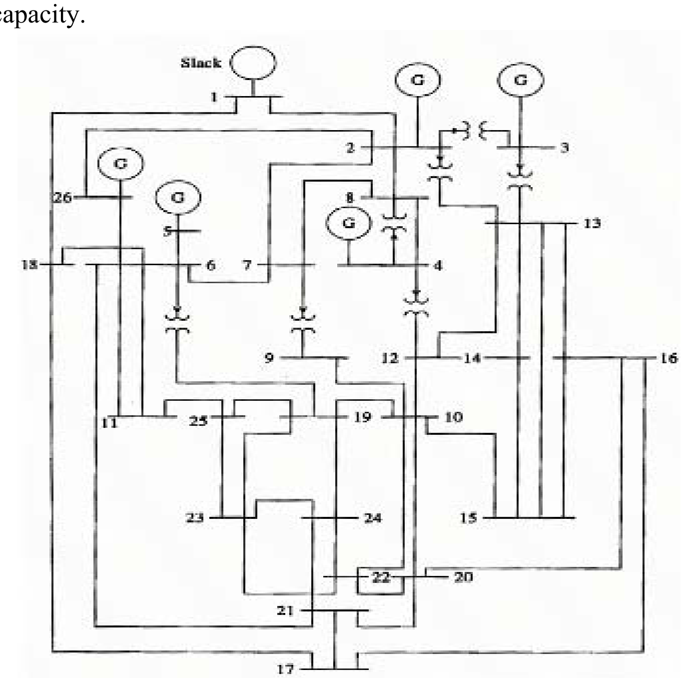

Fig. 1. 26 Bus System with 6 generators

The present UI rate depends on frequency as shown in Fig.2

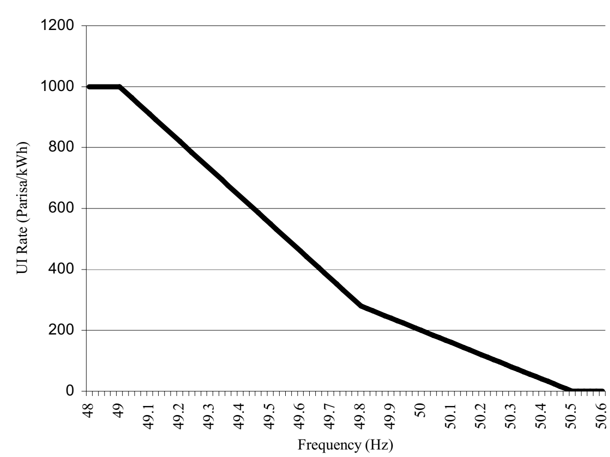

Fig. 2. UI rate and frequency under ABT

UI rate, UI, UI charge and hence cost of power purchased from central sector under ABT is frequency dependant. As such, UI rate cannot be incorporated in the optimization process unless frequency is predicted beforehand. Once frequency is predicted scheduling can be done using forecasted frequency, load and available generation.

III. Estimation of Frequency

Forecasting frequency is a complex task. Frequency variation is uncertain and random. System frequency depends on load generation balance. To model the dependency of frequency variation and factors affecting it is very difficult.

Underestimation of frequency at low frequency condition, results in the commitment of more units in view of maximizing own generation and under-drawing from central sector at higher cost. Conversely, over-estimation of the frequency at high frequency condition, may involve extra drawal of power from central sector generating plants and backing down the low cost own generators. Thus, accuracy in forecasting frequency has a significant impact on cost of generation.

Efforts are made to forecast frequency using Statistical method and Artificial Neural Network.

A. Estimation of frequency by Statistical Method

When the large historical or experimental data with random nature is available, statistics is useful in abstracting the information contained in the random variations [6]. The probability distribution of frequency is skewed. Weibull distribution is used to calculate the average frequency.

The hourly frequency data collected from State Load Dispatch Center (SLDC) Kalwa for the years 2003-2008 is used to analyze the variation of frequency. The feasibility of estimating frequency using probability theory and statistical tool is already reported in [5],[9].

The program is developed using MATLAB to estimate hourly frequency. 23 samples of frequency of that hour for the years 2003 to 2007 are used. The frequency values of the year 2008 are used for validation.

Fig. 3 shows the estimated mean value of frequency on Monday at given sample hours. Absolute Percentage Error (APE) is calculated to check the accuracy of statistical tool. Table I shows the comparison between actual frequency and estimated frequency at specific hours of 21st January 2008.

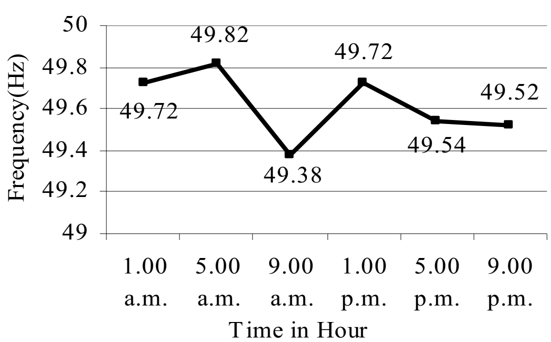

Fig. 3. Statistically estimated mean value of frequency at different hours

TABLE I
COMPARISON OF ESTIMATED FREQUENCY AND ACTUAL FREQUENCY

Hour	Mean value of frequency(Hz)	Actual frequency (Hz) on 21st Jan 2008	Absolute Percentage Error
1.00 a.m	49.72	49.8	0.160643
5.00 a.m	49.9	49.48	0.848828
9.00 a.m.	49.38	49.08	0.611247
1.00 p.m.	49.72	49.27	0.913335
5.00 p.m.	49.54	49.17	0.752491
9.00 p.m.	49.52	49.25	0.548223

It may be noted that estimated frequency by statistical method is within 1 % of actual frequency

B. Estimation of frequency by ANN

ANN offers significant benefits over traditional techniques such as reduced modeling efforts and reasonably good accuracy. ANN learns by experience the functional relationship between input-output through training. ANN has proved to be capable of finding internal nonlinear interdependencies within data. The simplicity of building ANNs and quick response for taking adequate decision justifies the use of ANN for frequency forecasting.

The feed-forward neural network along with error back propagation algorithm is trained by using historical data of frequency for last few years. The previous day 24 frequency values and previous week's, same day's 24 frequency values are considered as 'input' to neural network. 24 frequency values of the day form 'output' of neural network. The single hidden layer is used.

The development of ANN model for forecasting the hourly frequency of Mondays of January, along with the results are discussed in the next paragraphs.

1) Development of ANN for Hourly Frequency of Mondays of January:

The historical data of hourly variation of frequency of Mondays of January for last five years i.e. from 2004 to 2008 is used to form the train-set and test-set. Out of total 22 samples, 70 % samples are chosen randomly as train-set and remaining 30 % as test-set. The input and output neurons are 48 and 24 respectively. The architecture has one hidden layer. The network is trained with one neuron in hidden layer initially and hidden nodes are increased one by one to improve the networks learning ability and generalization capability. It is found that with 5 hidden neurons, the performance goal is met.

Once network is trained, the next step is to check the prediction accuracy of trained network by using the optimum set of weights obtained from trained network. APE is calculated at each hour to compare the accuracy of prediction capacity of trained neural network. Also Mean Absolute Percentage Error (MAPE) is calculated for each day.

The actual frequency of 21st January and 28th January 2008 is compared with frequency forecasted by ANN. Fig. 4 shows the actual frequency and frequency forecasted by ANN on 21st January 2008. The results are shown in Table II.

Fig. 5 and Table III show the comparison between actual frequency and forecasted frequency by ANN of 28th January 2008.

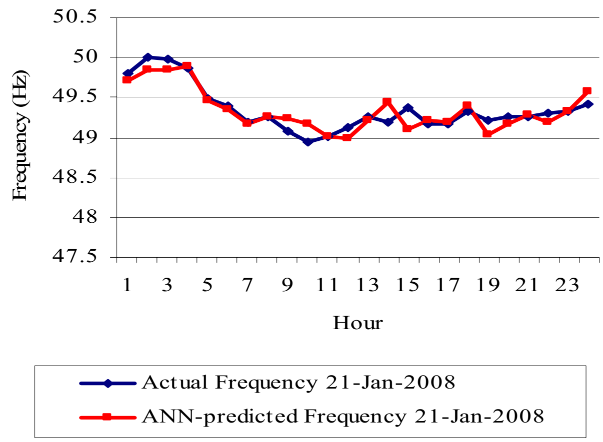

Fig. 4. Actual and ANN-predicted frequency on 21-January

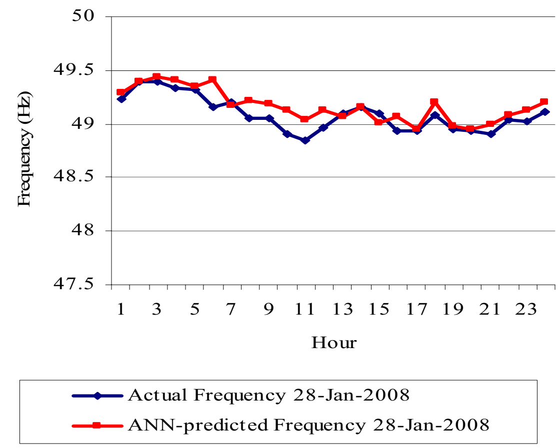

Fig. 5. Actual and ANN-predicted frequency on 28-Jan-2008

TABLE II
COMPARISON OF ACTUAL FREQUENCY AND FORECASTED FREQUENCY

Hour	Actual Frequency	ANN predicted Frequency	Absolute Percentage Error (APE)
	21-Jan-2008	21-Jan-2008	
Hr 1	49.8	49.72	0.160643
Hr 2	50	49.846	0.308
Hr 3	49.98	49.854	0.252101
Hr 4	49.87	49.887	0.034089
Hr 5	49.48	49.468	0.024252
Hr 6	49.4	49.357	0.087045
Hr 7	49.2	49.175	0.050813
Hr 8	49.25	49.262	0.024365
Hr 9	49.08	49.248	0.342298
Hr 10	48.95	49.176	0.461696
Hr 11	49.02	49.01	0.0204
Hr 12	49.13	48.992	0.280887
Hr 13	49.27	49.218	0.105541
Hr 14	49.2	49.438	0.48374
Hr 15	49.38	49.1	0.567031
Hr 16	49.18	49.21	0.061
Hr 17	49.17	49.187	0.034574
Hr 18	49.32	49.384	0.129765
Hr 19	49.22	49.032	0.381959
Hr 20	49.25	49.166	0.170558
Hr 21	49.25	49.284	0.069036
Hr 22	49.3	49.198	0.206897
Hr 23	49.32	49.316	0.00811
Hr 24	49.42	49.586	0.335896
		MAPE	**0.191696**
		Minimum APE	**0.00811**
		Maximum APE	**0.567031**
		Std-Deviation	**0.167891**

TABLE III
COMPARISON OF ACTUAL FREQUENCY AND FORECASTED FREQUENCY

Hour	Actual Frequency	ANN predicted Frequency	Absolute Percentage Error (APE)
	28-Jan-2008	28-Jan-2008	
Hr 1	49.23	49.287	0.115783
Hr 2	49.4	49.387	0.026316
Hr 3	49.39	49.442	0.105284
Hr 4	49.34	49.404	0.129712
Hr 5	49.32	49.351	0.062855
Hr 6	49.15	49.404	0.516785
Hr 7	49.2	49.177	0.046748
Hr 8	49.06	49.21	0.305748
Hr 9	49.06	49.191	0.26702
Hr 10	48.91	49.123	0.435494
Hr 11	48.84	49.035	0.399263
Hr 12	48.96	49.12	0.326797
Hr 13	49.1	49.061	0.07943
Hr 14	49.16	49.156	0.008137
Hr 15	49.1	49.006	0.191446
Hr 16	48.93	49.066	0.277948
Hr 17	48.94	48.947	0.014303
Hr 18	49.08	49.201	0.246536
Hr 19	48.95	48.982	0.065373
Hr 20	48.94	48.956	0.032693
Hr 21	48.91	48.993	0.169699
Hr 22	49.04	49.077	0.075449
Hr 23	49.03	49.127	0.197838
Hr 24	49.11	49.196	0.175117
		MAPE	**0.177991**
		Minimum APE	**0.008137**
		Maximum APE	**0.516785**
		Std-Deviation	**0.142406**

It is observed that minimum APE is 0.00811 % and 0.00814 % respectively for 21st Jan 2008 and 28th January 2008. Similarly maximum APE is 0.567 % and 0.517 % respectively for two samples.

The mean absolute percentage error of 21st January 2008 is 0.192 % and that of 28th January is 0.178 %.

The standard deviation of frequency for 21st January 2008 is 0.168 and that for 28th January 2008 is 0.142.

From results presented in this paper, it may be noted that the accuracy of ANN for prediction of frequency is very good.

C. Comparison of Two Approaches for Frequency Forecasting

Table IV and Fig. 6 show the frequency predicted by ANN model and statistically estimated frequency along with actual frequency on that day.

TABLE IV
ACTUAL FREQUENCY, FORECASTED FREQUENCY BY ANN AND STATISTICAL ANALYSIS

Hour	Actual frequency (Hz) 21st Jan 2008	Mean value of frequency(Hz) estimated by Statistical Tool 21-Jan 2008	Frequency predicted by ANN 21stJan 2008
1.00 a.m	49.8	49.72	49.72
5.00 a.m	49.48	49.9	49.468
9.00 a.m.	49.08	49.38	49.248
1.00 p.m.	49.27	49.72	49.218
5.00 p.m.	49.17	49.54	49.187
9.00 p.m.	49.25	49.52	49.284

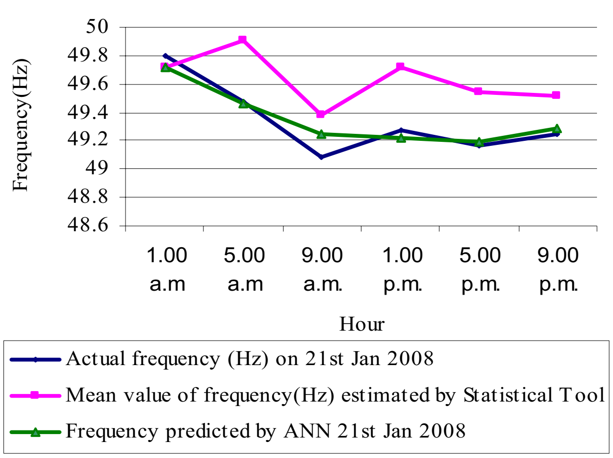

Fig. 6. Comparison of frequency predicted by ANN and Statistical tool on 21st Jan 2008

The ANN model predicts frequency with good accuracy than other approach of using statistical data and getting average frequency value. This justifies the applicability and superiority of ANN for predicting frequency.

IV. GENERATION SCHEDULING USING ESTIMATED FREQUENCY

The conventional GS approach is frequency independent. However under ABT, frequency dependant UI rate governs the cost of production. The generation cost of grid generator is calculated using forecasted frequency and program developed using modified GS algorithm. The comparison highlights the benefits of estimating hourly frequency, as system cost reduces considerably when compared with conventional approach. Table V gives the comparison of system operating cost at different hours obtained by conventional and modified approach when applied to 26 bus test system.

This justifies the use of prior knowledge of frequency in getting more appropriate schedule. The ANN-predicted frequency is more close to actual frequency than mean frequency value obtained from statistical method; hence use of ANN is preferable which gives maximum saving in system cost.

TABLE V
USE OF ESTIMATED FREQUENCY FOR PREPARING SCHEDULE

Hour	Load (MW)	Hourly System Cost (Rs/MW) by Conventional GS algorithm	Hourly System Cost (Rs/MW) by ABT based approach with statistically estimated frequency	Hourly System Cost (Rs/MW) by ABT based approach with ANN - predicted estimated frequency
1.00 a.m	1418	671240	612760	612760
5.00 a.m	1340	629840	620960	459360
9.00 a.m.	1626	785480	745960	731640
1.00 p.m.	1542	738680	704160	631720
5.00 p.m.	1500	715640	636760	564760
9.00 p.m.	1676	813920	799320	789040

It is hoped that the generation schedule so prepared will help the load dispatch operator in taking appropriate decision to earn the maximum benefits of ABT.

V. CONCLUSION

The optimum generation scheduling is normally a day ahead activity on the basis of anticipated load, generation, network condition and constraints. Under ABT scenario, new attribute is added to conventional GS problem that is frequency dependant part of tariff. This is applicable to deviation from the scheduled power, which makes the scheduling decisions frequency dependant.

Hence, frequency becomes an additional input to GS problem along with anticipated load and generation. The conventional generation scheduling algorithm is modified to incorporate the frequency dependant part of tariff.

The frequency is estimated using two approaches viz. ‘Use of probability theory and statistical analysis’ and ‘Use of Artificial Neural Network’. The accuracy of two approaches for frequency estimation is compared which confirms the superiority of ANN over other approach.

The use of prior estimated frequency while preparing schedule of generation results in saving in operating cost to earn maximum commercial benefits under ABT environment.

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VII. BIOGRAPHIES

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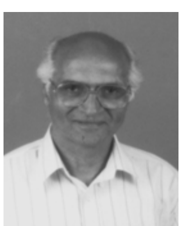

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