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FREQUENCY RESPONSE CHARACTERISTICS OF AN INTERCONNECTED POWER SYSTEM - A CASE STUDY OF REGIONAL GRIDS IN INDIA

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Abstract control area's contribution to the frequency response comprises of two components, namely, load response and governor response of generators. Load response (rejection) is the reduction in the power consumption of motors in response to a decline in the frequency and occurs directly (or with a minimal time lag) as the frequency changes. Generator governor (primary) response occurs in the 3-10 second time frame. It is the natural frequency response of a control area, which provides the self-healing immediately after a loss of generation. The frequency response characteristic of any system varies depending upon various factors such as the time of day, season of the year and size of the interconnection. The paper studies the types of generation and the loads (agricultural, industrial, and domestic) in the country and discusses the 'frequency response characterstics' for the Regional Grids in India. Specific incidences of sudden loss of large generation and large loads are studied and the frequency response is calculated state-wise and for the entire region. Incidents of such loss of generation or loads in the Northern Region after synchronization with the Central Grid (Western, Eastern and North-Eastern Grids) have also been studied and presented.

Keywords Frequency response, primary response, stiffness constant, power number.

1. INTRODUCTION

Frequency response is defined as the automatic, sustained change in the power consumption by load or output of generators that occurs immediately after a change in the control area's load-generation balance and which is in a direction to oppose a change in the Interconnection's frequency. It is also known as the power number of the system, stiffness constant, system inertia and system resilience and is denoted by the constant 'k' in the Area Control Error (ACE) equation ($ACE = \Delta P + k\,\Delta f$). During a contingency, such as the tripping of a generator or a loss of load block, the frequency changes due to the mismatch in load and generation. The level to which the frequency drops depends on the starting point as well as the system inertia. It is the system inertia, which provides the initial ability of the power system to oppose change in the frequency. Physically, it may loosely be defined by the mass of all the synchronous rotating generators and the motors connected to the system. If the system inertia is high, then the frequency will fall slowly and vice versa, during any system contingency. System inertia is *not* frequency control per se, but it does influence the time taken for frequency to change after a loss of generation or load. Higher system inertia provides more time to the generator governors to respond to a change in frequency and hence is desirable. The various resources that contribute to the response of a control area are shown in the resources pyramid (Fig. 1). It is the natural frequency response of a control area, which provides the self-healing immediately after occurrence of a contingency. The control area's contribution to the frequency response thus comprises of two components namely load response and governor response of generators.

Primary response is the generator governor response, which occurs in the 3-10 second time frame. The changes in the generator output (MW) are in response to the change in frequency and are independent of any commands. Primary response is responsible for the initial arrest of frequency variations, but does not restore the frequency or the tie-line flows to schedules. Under frequency and df/dt relay operation occurs in the millisecond time frame, even before the primary response comes into the play. Secondary response is slower and is activated by the control commands such as those issued by the AGC systems and tie line flow control systems. Tertiary response comprises all subsequent actions taken such as bringing in non-spinning reserves, manual load shedding, etc.

Load response (rejection) is the reduction in the power consumption of motors in response to a decline in the frequency and occurs directly (or with a minimal time lag) as the frequency changes.

Frequency response is actually a negative value i.e., the generator output should increase as frequency drops. The frequency response assumes greater significance in times of system restoration after a disturbance, islanding or black out since frequency control during restoration is extremely important.

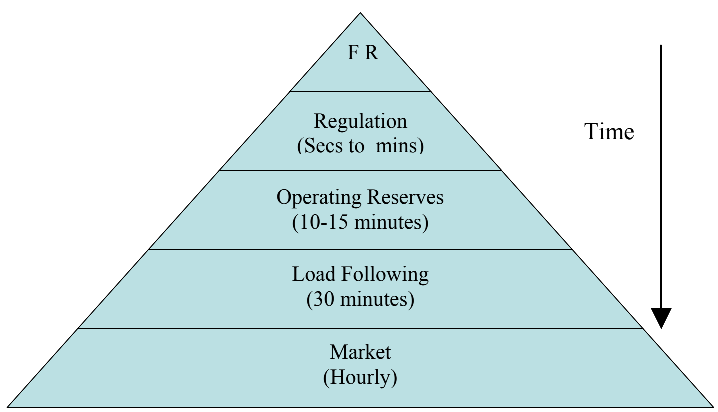

Fig. 1

FR: Frequency Response

2. THE INDIAN SCENARIO

India is divided into five regional grids namely the Northern, Southern, Eastern, Western and the Northeastern grids with a total All-India installed capacity of 127,673 MW. The fuel based breakup of the generation for the entire country is Hydro – 26.32%, Thermal – 65.78% (Coal – 54.20 %, Gas – 10.64%, Diesel – 0.94%), Nuclear – 3.05% and Renewable – 4.85% (as on 30-Nov-2006). Because of the uneven distribution of the fuel resources, the coal based thermal generation is mainly located in the Eastern part with Hydro generation concentrated in the North and the Northeast and some reservoir based hydro in the South. The load centers are mainly located in the North, West and South parts of the country with low load areas in the East and Northeast part. The North, West, East and the Northeast grids are operating synchronously and all the four regions are interconnected with AC as well as HVDC links. The Southern Region is connected to the East and West by HVDC links. Each regional grid is further divided into state grids, which form the respective control areas. Within a region, the various control areas are interconnected by AC links and it is these individual control areas and the regional boundaries that have been considered for calculating the frequency response.

From the frequency response perspective, the types of loads and their geographical distribution are important. Broadly speaking the loads can be classified as Industrial, Agricultural, Domestic and Commercial. At the end of 2004-2005 (Fig. 2), the industrial load constitutes about 44.5% of the total connected load, agriculture 19.8% and domestic and commercial together about 28.4%. The country's load has evolved over a period of time and as can be clearly seen from Fig. 2, there is a decline in the industrial load and a steady growth in the agriculture, domestic and commercial loads. Industrial loads comprise the high inertia heavy rotating loads which provide a good frequency response whereas; domestic and commercial loads use more efficient electronic load control devices, which, in general, reduce the frequency response.

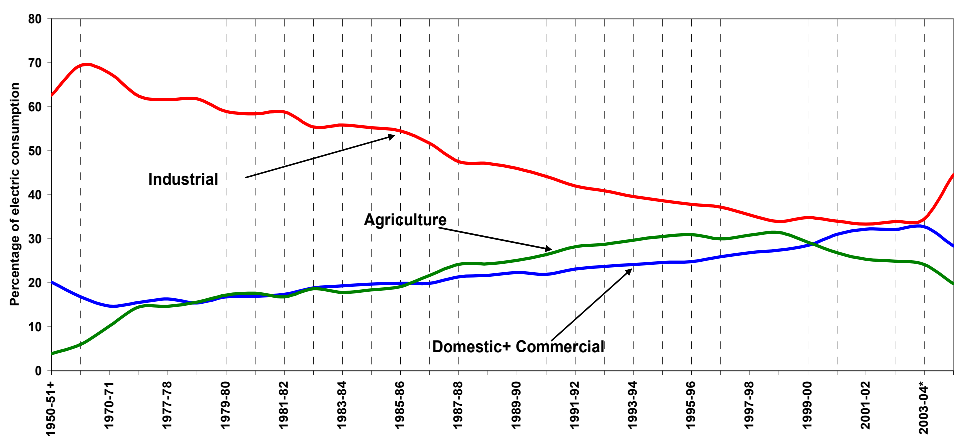

Fig. 2

3. CALCULATION OF FREQUENCY RESPONSE

3.1 Theoretical Background

The inertia constant 'H' for rotating machines is denoted by[14],

$H = (J\ \omega_{0m}^2)/2VA_{base}$

where, J = combined inertia of the generator and turbine

ω_{0m} = rated angular velocity in mechanical radians per second

The reduction in load following a decline in frequency is characterized by the load reduction factor "d", which is defined as the percentage change in load for a percentage reduction in frequency[1,6]. The general rule of the thumb is that a 1% change in frequency causes a 2% change in the load.

The simplest way to calculate the frequency response of a control area is to use the "1% of load" approach. However, this does not give very good results. A statistically rigorous approach is required to give better results.

3.2 NERC Methodology

The method used to calculate the frequency response in the Indian context has been adopted from the methodology suggested by the North American Electric Reliability Council (NERC)[6].

Each control area has been considered to have its own internal generation and interconnections with the neighboring control areas. Any contingency, which occurs (a loss of generator or a load block), will manifest itself as a change in frequency and a change in the control area's tie-line exchanges with its neighbors. The frequency response of the control area is calculated using the following.

Actual net interchange immediately before the disturbance = P_A

Actual net interchange immediately after the disturbance = P_B

Change in net interchange = $P_B - P_A$

Load (+) or generator (-) loss causing the disturbance = P_L

Control area response (Δp) = $(P_B - P_A) - P_L$

Change in frequency (Δf) = $f_B - f_A$

Frequency response characteristic = $\Delta p / \Delta f$

The data for the above calculations is taken from the real time telemetered data recorded by the SCADA systems installed at the Regional Load Dispatch Centers. Statistically speaking, about 30 observations are required to give a large enough sample to have confidence in the results. Both average and the median can be used to arrive at the frequency response, though the median is a better measure of the central tendency while analyzing a highly variable population like the frequency response events. The total frequency response of a region is the sum of all the control areas within the region.

4. CASE STUDY – FREQUENCY RESPONSNE CHARACTERSTICS OF INDIAN GRIDS

System contingencies such as tripping of a large generating unit, tripping of HVDC back-to-back stations (or inter-regional HVDC links) and loss of a large block of load (tripping of ICTs) have been recorded and analyzed to arrive at the frequency response characterstics of the concerned region. Such incidents have been recorded both for Northern Regional Grid and the Southern Regional Grid over a period of time (December 2004 to September 2006 for Northern Region and March 2003 to May 2004 for Southern Region).

4.1 Northern Grid

The Northern Region comprises the states of Punjab, Haryana, Rajasthan, Delhi, Uttar Pradesh, Uttaranchal, UT Chandigarh, Himachal Pradesh and Jammu & Kashmir. Each state forms a control area. The load profile in the Northern Region is Industrial – 36.28%, Domestic – 26.70%, Commercial – 8.71%, Agriculture - 19.50% and others (including traction) – 8.81%. Contingencies resulting in a loss of generation varying from 500 MW to nearly 3300 MW and loss of load blocks from 400 MW to 600 MW have been recorded, data captured and analyzed to arrive at the frequency response characterstics of each control area and the region as a whole (Fig. 3).

Twenty-seven events have been captured (two not considered for analysis) and it is found that the frequency response characteristic of the Northern Region varies between 312 MW/Hz to 1075 MW/Hz. The average response is 678 MW/Hz and the median is 688 MW/Hz.

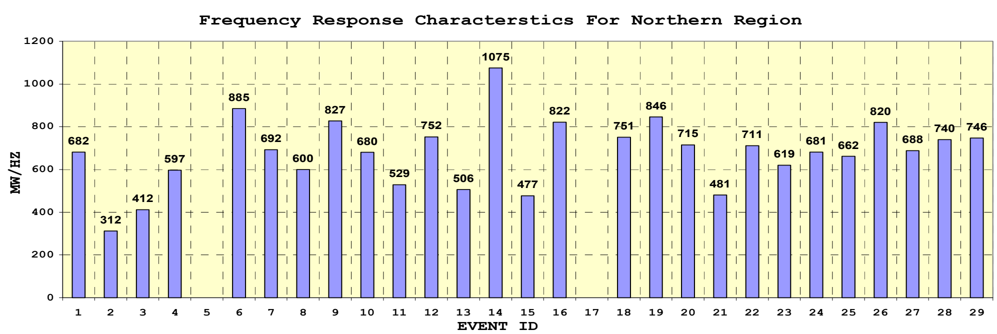

Fig. 3

A state like Delhi has a typically urban load, which is predominantly domestic and commercial (Domestic – 49.04%, Commercial – 27.88%, Industrial – 15.17%, Agriculture – 0.56% and others including traction – 7.35%). The frequency response characteristic for Delhi is found to vary from 16 MW/Hz to 328 MW/Hz. The average response is 96 MW/Hz and the median 82 MW/Hz (Table 1).

For a state like Punjab, which has predominantly industrial and agricultural load (Domestic – 21.86%, Commercial – 5.58%, Industrial – 40.39%, Agriculture – 27.92% and others including traction – 4.24%). The average frequency response is 100 MW/Hz and the median is 87 MW/Hz.

4.2 Southern Grid

The Southern Regional Grid comprises of the states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry and South Goa. The load profile in the Southern Region is Industrial – 38.17%, Domestic – 22.17%, Commercial – 6.97%, Agriculture - 26.13% and others (including traction) – 6.56%. Similar events of loss of generation & loads have been recorded and analyzed for each control area in the Southern Region and for the region as a whole. The frequency response for the Southern Region (Table 2) has been found to vary from 575 MW/Hz to 1515 MW/Hz with an average response of 1020 MW/Hz and a median of 1042 MW/Hz (Fig. 4).

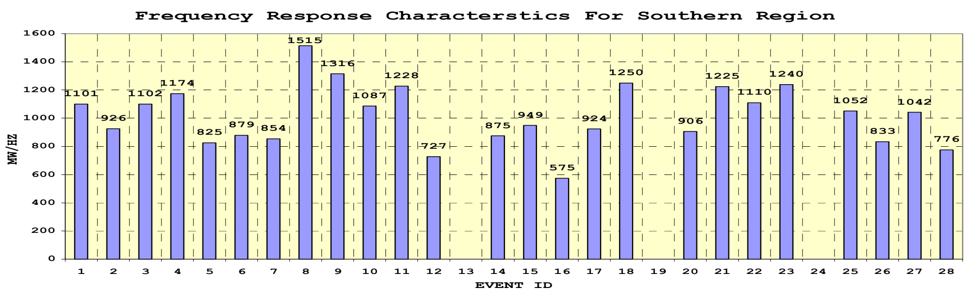

Fig. 4

Table 1 Frequency response characteristics for northern region

Event ID	Date	Time	Occurrence	Frequency Response Characterstics (MW/Hz)										
				Loss	Punjab	Haryana	Rajas than	Delhi	UP	Uttar anchal	HP	JK	Chandi garh	Northern Region
1	16-12-04	23:27	Ropar #3,4,5	600	62	64	161	111	216	10	13	19	7	682
2	17-12-04	8:10	Tanda #1,2,4	282	113	46	61	36	-12	8	10	-13	6	312
3	27-12-04	13:35	Dadri(T) ICT #1,2	-400	12	215	15	19	323	46	15	23	4	412
4	02-01-05	22:27	Panipat #2,4,5,6	635	-23	3	174	35	184	29	6	16	10	597
5	03-01-05	18:25	Panipat #4,6,7	Not Considered										
6	20-01-05	9:52	Dadri(T) ICT #1,2	795	87	56	136	69	41	0	3	0	0	885
7	05-02-05	23:33	Suratgarh Stn	1038	71	67	455	26	25	-8	10	16	0	692
8	24-02-05	20:01	Suratgarh Stn	800	48	43	70	16	307	-2	-4	0	1	600
9	21-03-05	16:03	Singrauli #7	488	40	75	145	156	236	15	20	34	0	827
10	14-04-05	11:36	Suratgarh, Kota Stn	2110	65	49	205	75	239	1	14	4	0	680
11	21-04-05	20:40	Anpara Stn	567	97	73	79	129	285	12	10	6	1	529
12	13-05-05	17:24	Singrauli #7	471	46	4	65	117	172	3	2	2	0	752
13	17-05-05	12:53	NJPC, Baspa, Suratgarh Stns	3276	87	114	212	194	388	1	171	55	0	506
14	17-06-05	22:36	Anpara #2,5 Obra #10 to 13	1188	86	48	205	137	404	0	-46	103	1	1075
15	30-06-05	12:06	HVDC Pusauli B/B	500	178	87	148	114	275	5	13	110	0	477
16	06-07-05	1:23	Dadri Stn	1100	101	-87	43	55	249	20	11	37	2	822
17	25-08-05		Anpara	Not Considered										
18	09-09-05	9:40	Ropar Stn	950	198	104	53	53	124	0	2	1	0	751
19	11-09-05	12:48	Dadri Th Stn	730	162	111	78	52	117	1	0	0	1	846
20	14-09-05	6:02	Singrauli #6	500	64	61	132	89	298	11	12	18	1	715
21	06-10-05	14:39	Singrauli #7	500	100	77	150	30	189	0	9	15	0	481
22	14-10-05	12:29	Rihand #3	500	146	72	144	100	143	1	7	15	0	711
23	16-11-05	11:51	HVDC Pusauli B/B	500	54	109	105	20	122	3	8	11	0	619
24	03-01-06	2:22	Ropar Stn	600	62	99	238	89	221	27	8	17	1	681
25	19-01-06	5:04	Suratgarh Stn	1150	106	177	144	115	174	22	3	0	3	662
26	27-02-06	2:55	Rihand Stn	935	77	51	216	11	261	0	-4	-24	0	820
27	21-04-06	9:53	Anpara #5	480	63	260	38	127	367	71	63	163	0	688
28	23-05-06	13:49	Singrauli Stn	969	74	25	95	71	191	9	14	10	3	740
29	16-08-06	11:59	Ropar Stn	1240	128	166	290	-8	165	-15	23	-3	6	746
Median					**77**	**72**	**144**	**71**	**216**	**3**	**10**	**15**	**1**	**688**
Average					**85**	**80**	**143**	**76**	**211**	**10**	**15**	**24**	**2**	**678**

Table 2 Frequency response characteristics for southern region

EVENT NO	DATE	TIME	OCCURRENCE	LOSS	Frequency Response Characteristic MW/HZ					
					ANDHRA PRADESH	KARNATAKA	KERALA	TAMILNADU	PONDY	SOUTHERN REGION
1	04-03-03	13:54	VTS 2,3,6 TRIP	630	292	416	114	260	6	1101
2	06-03-03	18:40	SIMH U2 TRIP	500	319	169	228	257	9	926
3	16-03-03	13:34	KOLAR TRIP	672	187	300	133	484	8	1102
4	28-03-03	16:31	KOLAR TRIP	775	314	286	109	320	0	1174
5	12-04-03	15:38	KOLAR TRIP	850	236	157	119	309	1	825
6	20-04-03	16:38	KOLAR TRIP	620	218	161	127	342	3	879
7	21-04-03	9:35	KOLAR TRIP	555	222	212	129	245	3	854
8	03-05-03	17:08	SIMH UNIT TRIP	500	455	579	158	306	12	1515
9	05-05-03	14:43	SIMH UNIT TRIP	500	345	450	205	295	11	1316
10	06-05-03	9:36	SIMH UNIT TRIP	500	222	426	91	298	7	1087
11	10-05-03	3:42	SIMH UNIT TRIP	1000	300	628	200	211	0	1228
12	18-05-03	22:45	KTPS UNITS TRIP	550	235	255	149	190	5	727
13	19-05-03	12:00	VTPS6 UNITS+SIMH1 UNIT + GAS UNITS	1100	NOT CONSIDERED					
14	20-06-03	1:50	KOLAR TRIP	490	179	270	152	370	0	875
15	28-06-03	12:49	KOLAR TRIP	750	200	278	57	437	1	949
16	29-06-03	13:00	KOLAR TRIP	630	203	93	120	195	0	575
17	01-08-03	12:27	KOLAR TRIP	427	314	180	143	307	6	924
18	05-09-03	11:35	RTPS UNITS TRIPPED	1000	383	658	58	202	8	1250
19	29-09-03	14:20	KOLAR TRIP	750	NOT CONSIDERED					
20	08-10-03	13:10	KOLAR TRIP	1060	220	280	111	294	2	906
21	17-11-03	22:46	SIMH UNIT TRIP	1000	167	245	171	187	0	1225
22	21-12-03	14:10	MTPS UNIT TRIP	855	209	488	75	323	0	1110
23	15-01-04	4:33	TTPS UNIT TRIP	682	380	318	53	480	0	1240
24	04-02-04	15:51	KOLAR TRIP	1428	NOT CONSIDERED					
25	05-03-04	14:45	KOLAR TRIP	1188	335	380	172	176	6	1052
26	13-05-04	4:21	VTPS TRIP	1000	192	266	47	278	9	833
27	15-05-04	17:30	KTPS UNITS TRIP	750	385	301	75	132	3	1042
28	21-05-04	13:30	SIMH+GAZK TRIP	776	322	166	79	167	0	776
Average					**273**	**318**	**123**	**283**	**4**	**1020**
Median					**236**	**280**	**120**	**294**	**3**	**1042**

4.3 Combined Northern Grid and Central Grid

On 26th August 2006, the Northern Grid was synchronized with the Central Grid (Western, Eastern and North Eastern Grids). Post synchronization, three events occurred which have been captured to calculate the frequency response characterstics of the combined grid. The frequency response has been found to vary from 1550 MW/Hz to 1664 MW/Hz with an average of 1611 MW/Hz and a median value of 1620 MW/Hz. The number of events captured so far is not adequate to give a figure with higher confidence level and more events need to be captured. Theoretical simulation studies carried out prior to the synchronization of the two large grids (North and Central) suggest that the frequency response of the combined system should be of the order of 1800 MW/Hz.

5. DISCUSSION

From the results obtained, it is evident that the frequency response characteristic of a control area is a highly variable parameter and it is difficult to accurately quantify the system's natural response. The factors affecting the FRC are the system size, frequency at the start of the incident, generator loading, losses, distance of generators from the point of loss, load composition, number of generators in service at the time of the incident, type of generation, governor action, time of day, season and interconnections with the neighbors. For instance in summers, systems tend to have a larger proportion of motor load. An area serving heavy industrial load or agricultural pumping load would have a better frequency response than an area serving predominantly domestic and commercial load. There is an increasing trend in the all silicon load (electronic devices) component not only in the domestic and commercial segments but also in the industry. These electronic loads do not provide the desired frequency response. The industry also uses variable speed drives/solid state drives, which do not provide the traditional response to frequency variations.

During periods of high loads, the frequency response is available mainly from the load since the generating units are operating near their full capacities. During light load periods, units are operating at less than their full capacities and governor response is available. No spinning reserves are available in the Indian system.

The type of generation too has an important role to play in the frequency response. Combined Cycle Gas based generation exhibits a positive frequency response, which means that the generation actually reduces with a decline in the frequency. This is because of the slow down of the auxiliaries. In India, the nuclear generation is totally inflexible as governors are blocked for various reasons. Most of the governors on the hydro and thermal generating units are blocked or have a delay configured thereby inhibiting the response. In the prevailing shortage scenario in the country, the generating units are almost always operated near the full capacity and even if governors are free, these units are not capable of picking up further generation. Moreover, no attempt is made to utilize the short-term overload capability of the machines. In the past, free governor mode of operation was used as suggested by JG Siroux[1]. The report also suggested maintenance of reserves equal to the single largest generating unit in each region. However, because of a huge demand – supply gap, these could not be maintained.

5.1 Under-Frequency and df/dt Relays

Under frequency relays (UFR) and df/dt relays are installed in all the regions to arrest a fast fall in frequency and below a per-designated level (e.g., 48.80 Hz in Northern Region). The UFRs and df/dt relays act in the millisecond timeframe and are the first to provide relief by way of load shedding. A unique use of the under frequency relays has been made by the state of Tamil Nadu at Aliyar HPS where the machines are running in the synchronous condenser mode and generation is picked up by the units using a signal from the UFR.

5.2 Limiting Factors

The factors affecting the accuracy of the calculation of the FRC are:

(a) A large number of events must be captured and subjected to statistical treatment before a reasonably accurate figure can be obtained. This is also necessary to rule out the impact of high variability of the load.

(b) Small excursions, which are significantly smaller than the maximum governor deadband, should not be included.

(c) Both load and generation are continuously changing naturally.

(d) Identification of the exact point of disturbance and interpretation of the time window to be measured. "Immediately before" and "immediately after" are subject to interpretation.

(e) Limitation of the sampling rate of the data recorded by the SCADA system (normally 10 second samples are available in the SCADA). At times, there is also a loss in part of the telemetered data due to various reasons and this causes inaccuracies.

5.3 Interdependencies of P, Q, V & f

In the study undertaken, it is assumed that active power-frequency (P-f) and reactive power-voltage (Q-V) dependencies are decoupled. With the reduction in frequency the active power drawn by the motor load reduces. However, as the motor load is primarily inductive, the reactive power drawn increases (negative correlation). This leads to a reduction in the voltage, which in turn further decreases the active power[5]. Thus, in addition to the P-f and Q-V relation, the P-V and Q-f relations cannot be ignored. This becomes all the more important in systems where frequency and voltage vary widely. The Transmission Planning Criterion of CEA adopts the following load model[7]:

$$P = P_0\,(f/f_0) \qquad \ldots(1)$$

$$Q = Q_0\,(V/V_0)^2 \qquad \ldots(2)$$

This model considers the reactive demand of load to be frequency independent. For composite load model as per the IEEE Committee Report [17], the following must be considered:

$$P\,(v,f) = (a_1 v^{n1} f^{m1} + a_2 v^{n2} f^{m2} + a_3 v^{n3} f^{m3}) P_0 \qquad \ldots(3)$$

$$Q\,(v,f) = (a_4 v^{n4} f^{m4} + a_5 v^{n5} f^{m5} + a_6 v^{n6} f^{m6}) Q_0 \qquad \ldots(4)$$

The coefficients a_1 to a_6 are normally associated with load categories such as general residential load, industrial load and agricultural load. However, the coefficients are fractions with sum to unity i.e.,

$$a_1 + a_2 + a_3 = 1.0 \qquad \ldots(5)$$

$a_4 + a_5 + a_6 = 1.0$ …(6)

In the Northern Region, studies carried out revealed that there is a change of 2% in the voltage with a change of 1% in the frequency.

5.4 Introduction of Competition in the Electricity Sector in India

Power utilities are being unbundled to bring in competition in India. Availability based tariff and open access in transmission at the inter-state level have been implemented successfully. Market mechanisms are being developed further and establishment of a Power Exchange is envisaged in the year 2007. The balancing market is provided by the UI mechanism. Implementation of intra-state ABT is being taken up. These factors are responsible for an ever-increasing pressure to bring about economy and efficiency. Market mechanisms have stressed the existing transmission systems more than ever before. All these have a direct bearing on the security of the grids and good frequency response of the system is necessary.

6. TRENDS WORLDWIDE

Extensive work has been done by the NERC in the USA on the frequency response. Frequency response is one of the important services that the utilities have to provide. NERC has also proposed a Frequency Response Standard. It is mandatory to calculate and report the frequency response characterstics for each control area using the methodology provided by NERC.

Calculations of the frequency response characterstics by the Eastern Interconnection and the Western Interconnection in the USA show that there is a declining trend in the frequency response obtained. The period considered is ten years (1993 to 2003) for the Eastern Interconnection and five years (1998 to 2002 both inclusive) for the Western Interconnection[4]. Theoretically speaking, there should be an increase in the frequency response since load levels are increasing and new generation is added. Evidence, however, suggests otherwise. Many reasons are contributing to this decline in the frequency response in the United States:

(a) Steam turbine generators operating on “sliding pressure” or “boiler follower” control and/or with “valves wide open operation”.

(b) Blocked governors on nuclear units.

(c) Less heavy manufacturing in the North America.

(d) Variable speed drives that do not provide the traditional load rejection.

(e) Increasing percentage of combined cycle gas based generation, which actually gives a positive frequency response. This phenomenon reportedly contributed to a blackout in Malaysia in 1996.

(f) Deregulation and market pressures have resulted in a reduction in the reserves maintained by the utilities. There is an increase in the number of reserve sharing groups as compared to the past when utilities maintained full reserves for their individual largest contingency.

(g) New generator designs having less inertia i.e., less mass per MW of output.

NERC suggests that though some decline in the frequency response is not a problem for large interconnections, it is difficult to arrive at the cut off point below which it could become a serious issue. Primary frequency response becomes a major consideration in islanding/disturbance situations. Initiating black start in an area with poor frequency control is not desirable.

There is also an ongoing debate as to whether frequency response capability should be a mandatory requirement of all generators or it could be a commercial product (ancillary service). As a matter of fact, in the prevailing deregulated environment with ever-increasing pressures for economy and efficiency, it is a costly proposition to maintain a part of generation as idle capacity just to provide support during contingent situations. Some suggest that all generators should have operating governors, respond to frequency deviations equitably and this should be a mandatory requirement for connection to the grid. Others argue that the market can better determine the best use of resources.

7. CONCLUSION

There is an increase in the sizes of the generating units, the present maximum size is 500 MW and very soon there would be units of 1000 MW size. The tripping of a single generating unit of such a large size would create a far more severe contingency and tripping of the entire station is another credible contingency. There is also an increasing trend in the share of combined cycle gas and nuclear-based generation. Load profiles are changing and there is a reduction in the percentage of the load providing the self-healing in case of contingencies. Power systems will be faced with increasingly silicon-intensive loads. As a result, the mechanical inertia of the system will be less than with today's motor-intensive loads. Because such inertia helps the system "ride through" momentary disruptions, the coming of predominantly silicon-based loads could contribute to dynamic instability[15]. In these circumstances, there is a need for having a good frequency response characteristic for each control area. Free governor mode of operation and provision of reserves by each utility is required. Though the Indian Electricity Grid Code (IEGC)[16] has mandated these, much needs to be done on the implementation front. Ancillary services are absent in the Indian Electricity Market and there is a need to develop these.

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