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Decline of Eastern Interconnection Frequency Response

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Abstract: System natural frequency response, or combined load and governing response, is defined and discussed. We analyzed 5 years of data and found that frequency response is declining, continuing a trend that has been reported previously.[1] The authors feel that this should be carefully considered, and make suggestions for improvements that should make it possible to keep better track of our declining frequency response.

Introduction

At the New York Power Pool, we have had digital disturbance recording equipment in service for over 10 years. By digital disturbance recording we mean equipment that makes a recording of 30 seconds or greater in length. To begin with, we were monitoring frequency alone, and were making records of 30-second duration for significant frequency disturbances. We have collected these recordings to use the data in computing the system natural frequency response and our own control area natural frequency response. We have more advanced recording equipment in place now,[2] but we have an important base of experience in these 30 second frequency recordings.

We have also recorded, over this period, the circumstances for each frequency disturbance. Most of these disturbances are drops in frequency resulting from the tripping of a generator, or loss of HVDC import, somewhere in the Eastern Interconnection. Disturbances due to load loss and other causes are much less frequent. Our trigger settings have generally been in the area of .025 Hz, and this results in an average of 12 recordings per month.

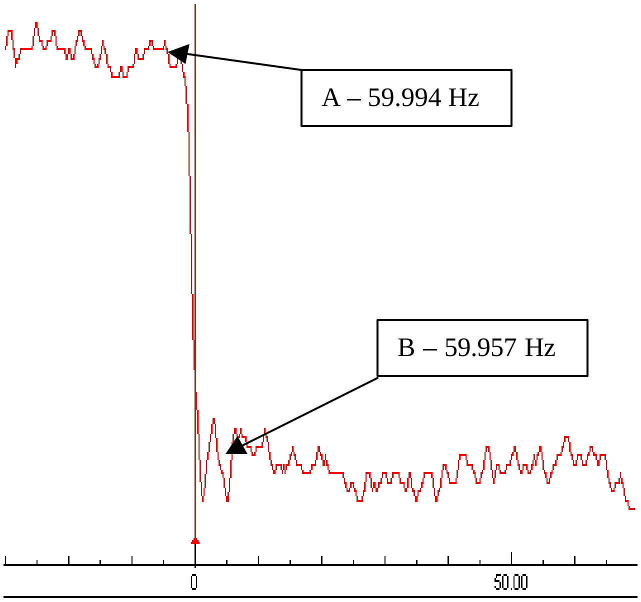
When we have been able to find out the exact circumstances, particularly the MW that was being generated by the machine that tripped, we have kept these circumstances in a database along with the frequency recordings.

Natural Frequency Response

This puts us in the position of being able to study the historical frequency response of the Eastern Interconnection. At this point in the development, we should point out that the observations we are describing were made in New York, but we are really observing the frequency response of the entire Eastern Interconnection. While our findings apply to the Eastern Interconnection only, the factors producing the trends we have identified may also be operating elsewhere. The Eastern is the largest interconnection in North America, and includes most of North America east of the Rocky Mountains.

By “frequency response” we mean the natural frequency response of the interconnection, also called the combined load and governing response. This is the response to a change in load or generation that takes place in the first few seconds after the change. This is well before each control area’s automatic generation control has time to begin to act.[3]

Example Incident



The frequency change for this example incident is the difference in the frequency before (NERC Point A) and the frequency after (NERC Point B).[4] Determining the pre-disturbance frequency is straightforward, but in determining the post-disturbance frequency, it is necessary to ignore or average out a transient response period. This particular incident shows a frequency change of .037 Hz. The example incident is the loss of the unit “Vogtle 2” on March 2, 1999. It was reported that the net generation at the time was 1200 MW. Since each minor tic mark represents 5 s, it can be seen that the transient following the loss of the unit has a period or roughly 4 s, therefore a frequency of ¼ Hz.

We have software that determines the frequency difference automatically, but this routine is not flexible enough to accommodate the all of the various transient conditions. We have returned to picking out the A and B points by hand.

Equilibrium Re-established

When a generator output is lost to the interconnection, the frequency immediately begins to fall. Two factors come into play. First, the remaining generator governors, to a varying extent, see the lower frequency and increase the amount of power generated. Second, some loads are naturally frequency dependent. Simple AC motors slow down and consume less power. For some types of loads this power reduction is much more than a direct proportion. A new equilibrium point is quickly reached, in a few seconds, and the frequency decline is arrested.

In the same way, when a block of load is suddenly lost, frequency immediately begins to rise, turbine governors act to decrease the generator output, frequency dependent loads begin to consume more power, and a new equilibrium is reached.

Beta

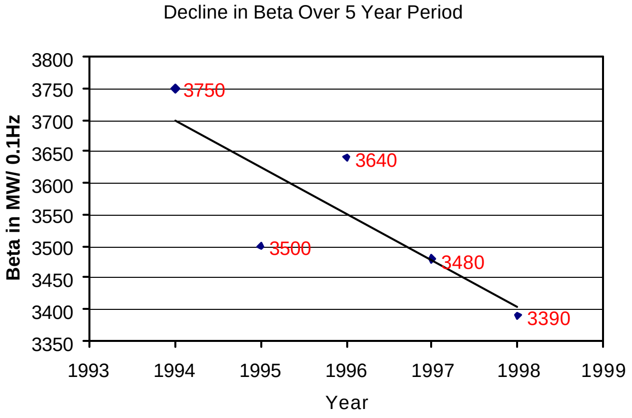
For the frequency response parameter we are using the Greek lower case letter β.[5] β expresses the number of MW change which produces a given frequency change. β can be expressed in MW per Hz, however, since this produces a very high number, and since the actual frequency changes experienced are much less than 1 Hz, β is sometimes expressed in MW per one-tenth Hz, MW per one-hundredth Hz, or MW per milliHertz. The most common unit in the literature is MW/0.1Hz so we have chosen to use that unit in this paper. In the example incident above, β would be 3240 MW/0.1Hz.

We are making the approximation, in this analysis, that this is a linear phenomena for generation changes that are small compared to the total capacity of the interconnection. β observed at any point in an interconnection should be the same. However the transient response observed immediately after the contingency will be different at different locations.

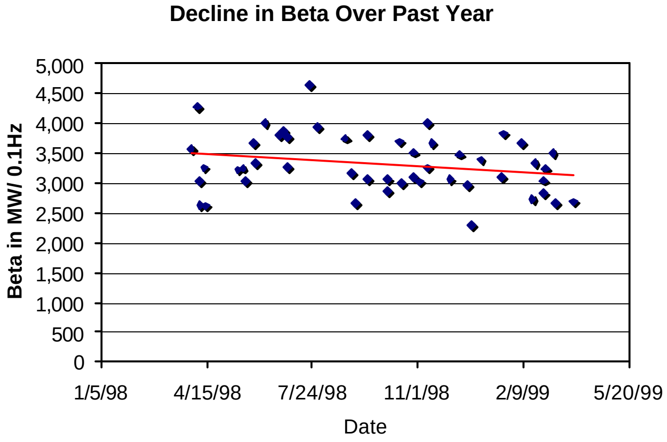
Decline in Natural Frequency Response

Analysis and graphical presentations of the data from the past 5 years shows an overall downward trend. That is, it is taking less MW loss each year to produce a given frequency drop. Although the downward trend is not dramatic, we believe there is cause for concern, especially since total connected capacity of the Eastern Interconnection has been going up. This would be expected to produce an increase in β. Also, as will be discussed, there are some errors attendant to this process, and these errors lead to overestimating β.

Our analysis shows β averaged over the calendar years 1994 through 1998, has showed a decline from 3750 MW/0.1Hz to 3390 MW/0.1Hz. On the plot of ß for the five year study period we have placed a trendline computed using a first order linear regression.



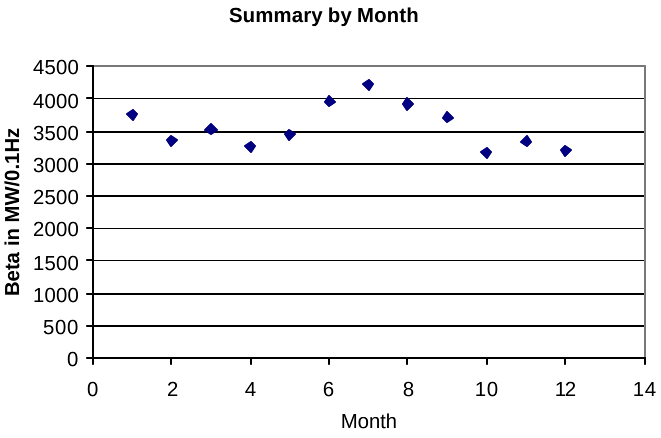
Actually the average ß for the year preceding the publication of this paper is 3320. We felt that each sample should be large include all 4 seasons and should be large enough to include all times of day. This decline in ß is a continuation of a previously reported trend.[1]



β computed for 49 incidents that have taken place over the one year period ending March 31, 1999 shows values declining slowly. Again we have placed a first order linear regression trendline on the plot.

Seasonal Variations

We noticed that ß is higher during peak months. This shows up well when we looked at the study period (1994 – 1998) one month at a time. The results are shown below.



Potential Errors

Computation of the frequency change is straightforward. It can be easily read from the plot, and should be the same anywhere in the interconnection. The number of MW lost is a potential problem, however.

There are several possibilities for error in the reporting of MW lost. The number we need for computing β is the net output, that is, the actual MW output immediately before the trip. Some entities may report instead the gross MW, that is with plant auxiliaries included. Some may report the unit capacity, or the reactor output in the case of a nuclear plant. It is interesting that all of these errors are in the direction of over-reporting the MW lost, leading to a β which is larger than the true value. We know of no reason that this source of error would have changed over the past years, however. If some work were done to make sure that the MW reported to be consistently the net MW output, there would be an average reduction in the reported MW lost. The present trend in declining β would be temporarily amplified. That is, β has most likely reached a lower value than we have calculated.

Missing Information

The information on what unit was lost is generally passed from control area to control area by telephone. Control areas usually know the circumstances when a unit trips in an adjacent area. This information is then passed on from one control area to another. Of those incidents that cause a frequency change of .025 Hz or more, we learn the MW lost for less than half of the incidents. The percentage varies widely from month to month, from 5% to over 50%. It seems that trips of a particular unit come in groups, possibly after a shutdown or rebuild. If a unit is having problems, and reports on that unit are reaching us, then the percentage for that month would be driven up.

Conclusions

So β is going down, but it has not descended to the point where it has become a problem. Textbook assumptions about frequency regulation and load damping lead to a β of 15,000 MW/0.1Hz or more.[6] We have shown at β was averaging around 3750 MW/0.1Hz at the beginning of the observation period and the average for the immediate past year at this writing is 3320 MW/0.1Hz. This continues a trend identified in a study funded by EPRI which covered the period 1970 to 1990.[1]

It is interesting that no one is really sure whether generator or load response is the dominant factor. Other work indicates both components are going down. It is very difficult to measure these effects during actual incidents due to the extremely small contributions from individual generators or load busses.

Analysis

Generator regulation is going down mainly because of the quest for efficiency. Steam plants are increasingly operated in sliding pressure mode, that is, in such a way that turbine governors are ineffective. Gas turbines are often operated in exhaust temperature control mode. Although all generating units of significant size have frequency governing in place, an increasingly number are being operated in such a way that they are not capable of picking up additional MW, thus their frequency governing is ineffective.

AC motor loads provide damping of frequency changes because motor speed is proportional to frequency, and power developed is at least proportional to speed and for some types of loads, proportional to the square or cube of speed. Because of the increase in use of solid-state drives, it is reasonable to believe that damping of frequency changes due to motors is decreasing.

Recommendations

Actually this natural frequency response is acceptable because the interconnection is so large. Loss of the largest single unit in the interconnection, in the 1300 MW class, produces a frequency decline of about .040 Hz, which is entirely manageable. Generation loss incidents that exceed this range have been extremely rare.

We believe that it is important to be aware that the combined governing and load frequency response is going down. Should there be islanding and the necessity for restoration, the early units started should be units with good ability to regulate. This should be considered when formulating restoration plans.

Because of this downward trend in β, we feel it is important to improve the reporting process and to begin to track frequency response more carefully and more formally. To better track this declining β we would recommend that a central point be established for reporting frequency changes of greater than .025 Hz, and the explanations for these changes. In the new environment, it will likely be necessary to have a system of incentives for accurate and prompt reporting.

Closing

We feel our industry should be tracking β for every frequency change over .025 Hz, and should be aware that β is decreasing and has reached 3320 MW/0.1 Hz. The authors would welcome comments and discussion by e-mail.

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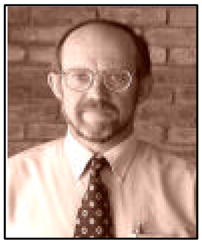
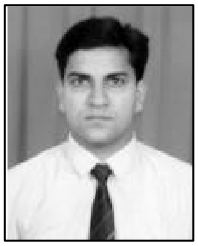
Biographies



Jim Ingleson



Makarand Nagle

Jim Ingleson began his electric power career with the municipal electric utility of the City of Jamestown, New York. He received his Bachelors and Masters degrees in Electric Power Engineering from RPI in 1970 and 1975**.** Starting in 1970 he worked for General Electric Company in various capacities, including construction and design of substations and generating plants, HVDC projects, and system protection engineering. Since 1979 he has been with the New York Power Pool near Schenectady, now serving as Senior Engineer in Operations Engineering. He is a registered professional engineer, an IEEE Senior Member, and an active member of the PES Power System Relaying Committee, where he currently chairs a working group which is surveying and reporting on relay testing practices.

Makarand Nagle is working in Entergy Services Inc. in their Transmission Operational Planning department at New Orleans. His main role in Entergy is to provide technical support to the transmission operation centers in the form of load flow analysis in support of outage scheduling, voltage stability, operating guidelines and local area security analysis. Makarand completed his Bachelors in Electrical Engineering from University of Bombay in 1993 and Masters in Electric Power Engineering from RPI in 1998. During a summer internship at New York Power Pool, he was involved in monitoring and analyzing frequency disturbances. Makarand worked in Chemtex Inc. as an Electrical Design Engineer for 3 years and as Project Engineer in Siemens Limited for 1.5 years before joining the Masters program at RPI.

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6. Richard P. Schulz, "Modeling of Governing Response in the Eastern Interconnection," Proceedings of the 1999 Winter Meeting of the IEEE Power Engineering Society, p. 561.

Appendix: Following are the events with known cause and known MW for a period of one year immediately preceding the publication of this paper. These are the 49 events shown in the second plot.

Date	Name	Time	MW	Hz Chg	Beta
3/31/98	396 Line	12:40	680	0.019	3,579
4/6/98	Phase 2 HVDC	20:47	600	0.014	4,286
4/8/98	Gavin 2	13:00	1270	0.042	3,024
4/9/98	Mountaineer 1	5:03	950	0.036	2,639
4/13/98	Phase 2 HVDC	16:24	1300	0.040	3,250
4/14/98	Gavin 1	6:06	1150	0.044	2,614
5/15/98	Phase 2 HVDC	21:41	1450	0.045	3,222
5/19/98	Sequoyah 1	10:43	1200	0.037	3,243
5/22/98	Gavin 1	9:54	1150	0.038	3,026
5/29/98	Oswego 6	13:21	770	0.021	3,667
5/31/98	Paradise 3	12:54	1000	0.030	3,333
6/9/98	Vogtle 2	9:01	1200	0.030	4,000
6/23/98	Hydro-Quebec	12:43	1100	0.029	3,793
6/27/98	Conemaugh 2	20:29	850	0.022	3,864
7/1/98	Perry 1	8:05	1018	0.027	3,770
7/1/98	Bruce 7	11:55	850	0.026	3,269
7/21/98	Mountaineer	14:54	1300	0.028	4,643
7/29/98	Canal 1	6:54	550	0.014	3,929
8/24/98	Vogtle 2	18:24	1200	0.032	3,750
8/30/98	Indian Pt 3	14:05	980	0.031	3,161
9/3/98	2 JEA Units	12:21	800	0.030	2,667
9/15/98	Millstone 3	17:35	1100	0.029	3,793
9/15/98	Canal 1	20:16	460	0.015	3,067
10/3/98	Susquehanna 1	14:24	1100	0.036	3,056
10/4/98	Marshall 4	17:21	660	0.023	2,870
10/15/98	Sequoyah 2	5:02	1180	0.032	3,688
10/17/98	Darlington 3	8:47	900	0.030	3,000
10/28/98	Darlington 1	0:03	950	0.027	3,519
10/28/98	Millstone 3	9:20	1148	0.037	3,103
11/3/98	Oconee 2	10:16	846	0.028	3,021
11/10/98	Amos 3	9:37	1300	0.040	3,250
11/11/98	Millstone 3	7:35	1160	0.029	4,000
11/15/98	Hope Creek	9:24	1100	0.030	3,667
12/2/98	Mystic 7	18:08	550	0.018	3,056
12/11/98	Millstone 3	8:41	1150	0.033	3,485
12/18/98	Mitchell 1	23:35	650	0.022	2,955
12/22/98	Seabrook	8:28	1100	0.048	2,292
12/31/98	Oconee 3	14:35	846	0.025	3,384
1/19/99	Rockport 2	12:47	1300	0.042	3,095
1/22/99	Rockport 2	20:03	1300	0.034	3,824
2/7/99	Canal 2	14:13	550	0.015	3,667
2/18/99	Bath Cty. Units	21:08	1200	0.044	2,727
2/20/99	Rockport 2	2:29	1300	0.039	3,333
2/28/99	Salem 1	1:39	700	0.023	3,043
2/28/99	Oconee 2	20:41	846	0.030	2,820
3/2/99	Vogtle 2	2:07	1200	0.037	3,243
3/9/99	Indian Pt 3	14:23	980	0.028	3,500
3/12/99	Harris 1	6:39	880	0.033	2,667
3/29/99	Brunswick 2	8:38	830	0.031	2,677