Frequency Triggers

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INTRODUCTION

Herein we discuss frequency-related trigger algorithms which are used to initiate disturbance recordings. Frequency-related triggers can also be used in other applications such as control room alarms or special protection schemes. The main types of frequency triggers which we will discuss are *absolute frequency*, *rate of change of frequency*, *oscillation of frequency* and *delta frequency*.

Definitions

Frequency – The number of alternations per second in the synchronous AC power system, in our case nominally 60 Hertz. Or in the case of frequency recorders, the number of data samples per second. The following are units of frequency and abbreviations of those units which are used in this paper:

Hertz	Hz.
milliHertz	mHz
MegaHertz	MHz

Trigger –A mathematical algorithm which has the capability of initiating a recording of data, sounding an alarm, or initiating some other logical function.

Assertion – When a trigger algorithm provides a logical output as described above, that is "assertion" of the trigger. It is common to say that a trigger occurred, but strictly speaking we should say that an assertion of the trigger has occurred.

Qualifications

We discuss our experience with several of these triggers, and ask that the reader keep in mind the following qualifications:

- Trigger algorithms of various manufacturers are discussed without prejudice. The different performance characteristics are useful in different situations. It is not our purpose to endorse or denigrate any of these various performance characteristics.

- The writers have experience with the products of many manufacturers but obviously not all. Those manufacturers' frequency triggers which we did not mention are no less worthy than those mentioned.

- The writers' direct experience is confined to the Eastern Interconnection (EI) of the United States and Canada. This is a very large and very stable interconnection. Readers who are interconnected elsewhere will need to take this into account.

- We are discussing specifically frequency; however, many of the concepts can be extended to other quantities such as voltage or power.

Main Categories of Frequency Triggers

Absolute Frequency

Triggering on absolute frequency is of use to call attention to frequency below a setting such as 59.940 Hz or above a setting such as 60.060 Hz, without regard to the type of excursion. We have enabled only a very few of such triggers. The recordings produced are not generally useful, because they most often show a slow movement toward the trigger level and a slow recovery. Still it can be useful to call attention to the time when a frequency limit was exceeded. Since frequency sometimes stays very high or very low for many minutes, we suggest that recordings not be extended when an absolute frequency trigger is maintained. Rather, a new recording can be initiated when the frequency is no longer outside the limit.

The frequency of the EI is occasionally scheduled off nominal, most often at 59.980 Hz for synchronous time correction. Essentially all such time corrections recently have been for positive time error (clocks ahead); however, the frequency has been scheduled at 60.020 Hz to correct for negative time error (clocks behind). Such time error corrections are maintained for a number of hours until the time error returns to within a specified limit. Time corrections obviously upset the balance of absolute frequency triggers; that is, the normal situation during a time correction would be that the low limit is much more likely to trigger, and the high limit is much less likely to trigger. This has the effect of making absolute frequency trigger less useful.

Rate of Change of Frequency

The general idea is that the time rate of change is computed at regular intervals and compared to a level setting. Trigger assertion occurs when the level setting is exceeded for a period of time. Generally the performance of rate of change of frequency triggers does not vary all that much; that is, they all seem to work pretty much alike. As a class, they are likely to detect several different kinds of events and are definitely sensitive to events which are close-by. Attempting to set them sensitively enough so that they will pick up a distant change in the load-generation balance will result in an unacceptably high number of triggers.

Oscillation of Frequency

We have implemented 3 installations of oscillation of frequency triggering, and the early results are interesting and will be summarized and reported in detail sometime in the future. The trigger algorithms and installations are covered in an earlier FDA work (Northeastern US Oscillation Detection and Recording Project, 2004 FDA Conference, April 26 – 27, 2004, Bertagnolli, Luo, Ingleson, Chow, Allcorn, Kuras, Mehta, Dickens, and Hackett), and as such will not be covered here.

Delta Frequency

This group of trigger algorithms works by computing two rolling averages, and comparing the difference between these averages to a level setting. The point is to detect whether a true change in the interconnection load-generation balance has occurred. With the proper algorithms and setting, it is possible to detect such a true change without regard to the distance of the event to the recorder. The usual result is that loss of generation above a given level can be detected anywhere in the EI. Loss-of-load incidents are sometimes detected as well, but are much less frequent.

We have had some problems with arriving at a good name for this class of trigger. Frequency Change Trigger has been used, but does not distinguish it from a Rate of Change Trigger. Step Frequency Trigger has been suggested, but seems to many to imply a step change in frequency, which has a definite mathematical meaning. We have also used Discrete Frequency Change. In this paper we are suggesting Delta Frequency Trigger because we believe this implies a non-continuous frequency, a frequency that makes a distinct and maintained change.

There were delta frequency triggers on DFRs within each of the two distinct power system islands which formed in New York State during the 2003 Eastern Interconnection power system disturbance. These recorders were set to make records 90 seconds in length, and it was our experience that the delta frequency triggers, generally set at a 19 mHz threshold, retriggered at least once within every 90 second record. The result was records that extended to the full duration of the islands, and in two cases there were records over 2 hours long! In this situation it was very helpful to have continuous records of this length, as they were a key part of the analysis. It would be well to keep this in mind, however, that if automatic extend on retrigger is enabled, the user should consider whether the recorder in use is capable of handling a very long record.

REAL FREQUENCY EVENTS

In this section we give a few examples of real frequency events as captured and recorded.

Figure 1
December 15, 2004
Belew's Creek 1135 Megawatt Unit Trip
38 mHz Drop

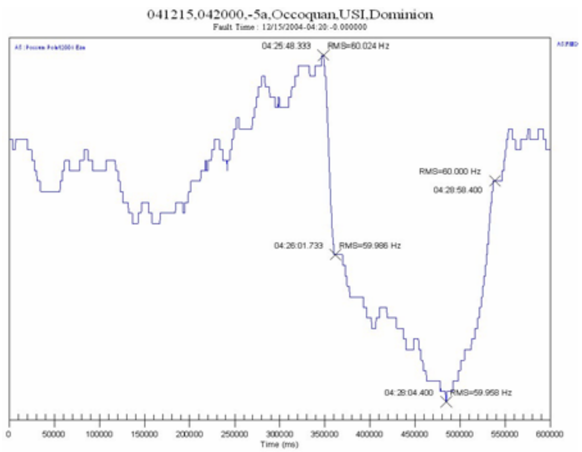


Figure 2
December 23, 2004
Very Large Frequency Drop
Three Distinct Stages
Frequency Dropped to 59.934 Hz
Cause Unknown at this Time

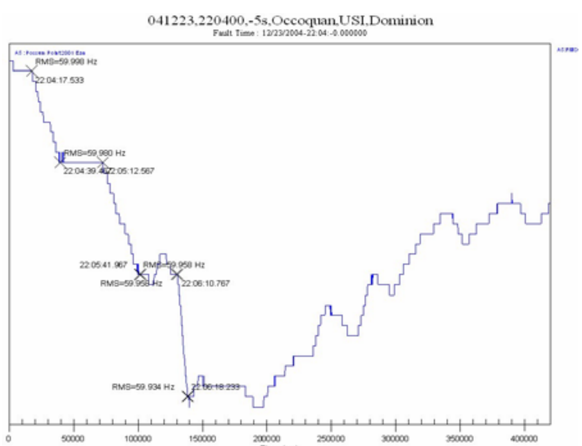


Figure 3
December 16, 2004
Pump Storage Units Coming Out of Pump Mode
28 mHz Rise

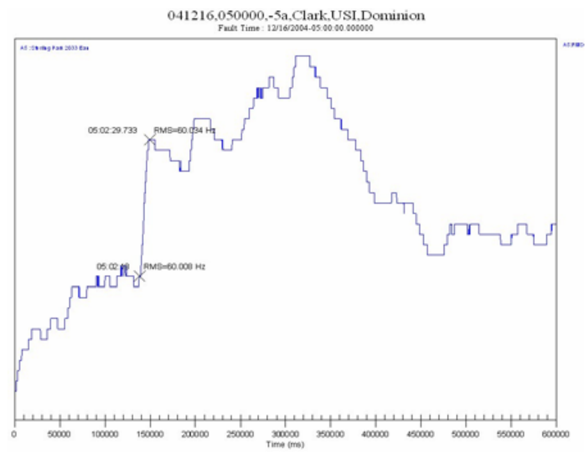
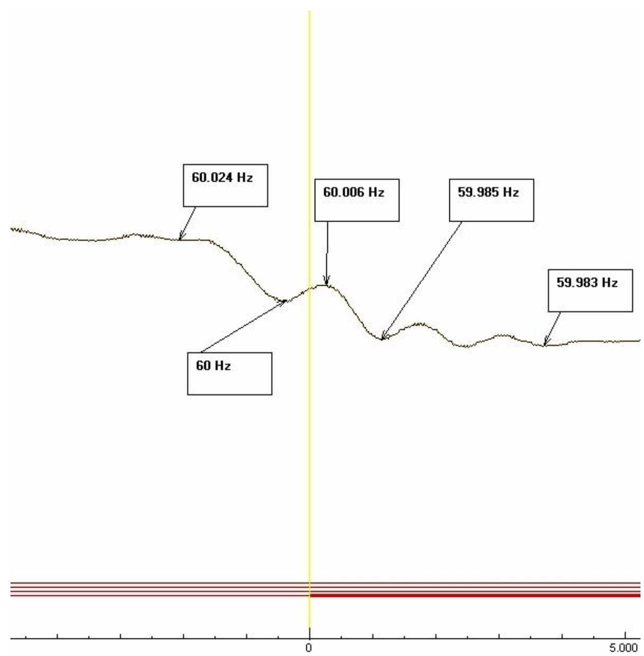


Figure 4
Slow Decline



It's interesting to note from the above examples that not all frequency excursions are alike. As shown in Figure 1, excursions associated with a sudden loss of a large generating unit yield a relatively sharp frequency decline; particularly sharp when the unit is nearby. In contrast, a stepped decline is shown in Figure 2, which is typical of a sequential loss of several units.

It's also interesting to note that several other types of system events in addition to loss of generation produce sudden changes in frequency. In Figure 3, the cycling of a pumped-storage hydro facility produced a relatively sharp frequency increase, associated with the sudden loss of load. Another event which typically produces frequency records is the change in hourly wholesale energy transactions (or changes in Area interchange schedules). These changes, which can greatly affect the generation dispatch across an Area or Region, typically occur at the top of the hour and produce the greatest frequency excursions at peak hours such as 05:00 or 22:00.

Figure 4 illustrates a relatively slow decline, which is typical of a mechanical trip of a nuclear unit which yields a relatively slow loss of the unit and a correspondingly slow or stepped frequency decline. In this case, most frequency triggers, particularly a strict rate of change trigger, will not catch the event.

A similar effect to the schedule changes is synchronized human behavior. The most common example occurs during the Super Bowl, which illustrates that instances of synchronized behavior can result in rapid load changes and thus rapid frequency changes. Other similar television events which have an unusually large audience also have this effect. The rapid frequency changes occur at moments such as beginning or end of commercials, beginning or end of half-time show, etc. Although the number of triggers and records varies from year to year, we expect that the Super Bowl will produce roughly 20 to 30 assertions of a properly adjusted Delta Frequency trigger. On rare occasions, other televised events have resulted in a smaller number of assertions. This effect does not really cause an operational problem on the system, and it can actually be a good opportunity to compare trigger performance. Keep in mind that recorders with limited storage capacity obviously may fill during the Super Bowl.

Another interesting observation in comparing frequency records across an Area or Region is the small difference in observed frequency. For most events, the frequency response is identical across the synchronized interconnection; however, as previously documented, certain events can cause a slightly different response such as larger or smaller swings. In all cases, the frequency eventually settles out identically across the interconnection. This needs to be taken into account when determining frequency trigger settings for specific recorders and locations.

- The End -

The Microprocessor Digital Frequency Recorder (MDFR)

By Jim Ingleson, NYISO

Introduction

The Microprocessor Digital Frequency Recorder (MDFR) is an obsolete device, but it had a very good Delta Frequency trigger. Through these triggered recordings made with our MDFRs beginning in 1986, many of us in the Eastern Interconnection learned a lot about power system dynamic response. Following the brief sections on history and general description, which can be skipped, we will concentrate on the frequency and trigger algorithms.

Units

Frequency in this section in expressed in Hz, and in MHz (megaHertz) and mHz (milliHertz).

History

The MDFR project was conceived by a working group of the Northeast Power Coordinating Council (NPCC). The principal supporters of the original project were Ontario Hydro, the New York Power Pool, and New England Power Exchange. The design and construction were by Ontario Hydro Research Division. Since then, these entities have all reorganized under different names. Each of these principal supporters received 2 MDFRs. Later, a very small quantity of additional MDFRs was manufactured by an outside vendor. At various times, MDFRs have been operated in the states of Maine, Arkansas, and New Hampshire, in addition to the original deployment in Ontario, New York, and Massachusetts.

General Description

The MDFR was a lunchbox-sized device which produced triggered recordings of frequency only, and was addressed though an RS-232 port, which was usually connected to a telephone modem. (Continued)

The communication speed was limited to 1200 Baud; however this was adequate, since the MDFR held only a total of 6 minutes of recorded frequency at a data rate of 10 Hz. The MDFRs were normally set up for 12 recordings, each recording of 30 seconds duration, of which 5 seconds was pre-trigger. The internal real-time clock was not capable of being externally synchronized.

<u>Frequency Algorithm</u>

The MDFR counted zero crossings until it reached 6 cycles, and then measured that time period using a 4 MHz clock. The result was approximately 10 frequency values per second, exactly 10 values per 60 power system cycles, with a resolution of 1 mHz and an uncertainly of 2 mHz. Thus each frequency value developed was an average taken over 6 power system cycles. Our experience was that MDFRs agreed with each other, and with other precision frequency measuring devices, within 1 mHz or less.

<u>Delta Frequency Trigger Algorithm</u>

Thus each new frequency value developed was actually an average taken over 6 cycles. The MDFR compared each new value to a pre-disturbance rolling average. If the difference between the new frequency value developed and the pre-disturbance rolling average exceeded the threshold frequency for 2 consecutive frequency readings, and if the deviations were in the same direction both times, trigger was asserted, a record initiated, and alarm contacts closed.

<u>Threshold Frequency</u>

This trigger threshold could be set to any integral mHz setting from 5 mHz to 1000 mHz. The most common setting was 25 mHz. Keep in mind that the MDFRs were used in the Eastern Interconnection. Interconnections of smaller capacity would likely use threshold settings much greater than 25 mHz.

<u>Pre-Contingency Average Length</u>

This total length of the pre-contingency average period was variable from 5 to 15 seconds, and was normally set at 10 seconds.

<u>Post-Contingency Average Length</u>

This was fixed at 6 cycles, the length of a frequency measurement period, which seemed to be satisfactory. It could be helpful to have the option of changing this period.

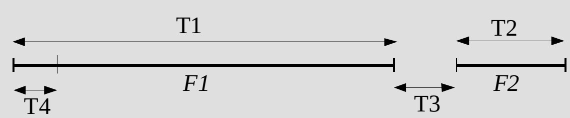
Pre-Contingency Average Displacement

One very interesting aspect of the trigger was that the pre-contingency rolling average was displaced back in time by a period of time variable from 1 to 10 seconds. This was normally set at 5 seconds. So, the pre-contingency rolling average period ended 5 seconds before each frequency value to which it was compared.

We believe that some backward displacement is helpful; however it would also be helpful to be able to set displacement to zero, to duplicate the performance of triggers without this feature. As far as we know, no other frequency change trigger algorithm has this displacement feature.

<u>Trigger Algorithm Re-statement</u>

Assuming the most common settings, each frequency value developed was compared to a 10 second rolling average frequency which ended 5 seconds before. If the difference exceeded threshold setting for two consecutive power system cycles, and also provided that the sign of the difference was the same both times, trigger was asserted, a record was initiated, and external contacts closed.



Graphical depiction of the parameters of the delta frequency trigger

<u>Trigger Parameters</u>

T1=User specified interval over which to average the first set of frequency measurements.

T2=User specified interval over which to average the second set of frequency measurements.

T3=User specified interval where no measurement is taken (“dead band”).

T4=Time for one frequency measurement (T1, T2, and T3 are specified in multiples of T4). T4 can also be how far to slide the window to perform the next set of trigger calculations.

F1=Average of frequency measurements taken during T1.

F2=Average of frequency measurements taken during T2.

Some example settings for this trigger would be
T1=10 seconds
T2=0.1 second
T3=5 seconds
T4=0.1 seconds
Threshold=0.025 Hz

Performance

Our results over many years were that all the MDFRs, all of which shared the above settings, would all reliably detect a loss of about 800 MW or more of generation which occurred anywhere in our interconnection. After gaining confidence in the trigger performance, the MDFR alarm contacts, which closed upon record initiation, were successfully used as control room alarms in New York and New England, for many years. The data rate of 10 Hz was sufficient to observe power system oscillations in the range where they occur in the Northeast, which has been between 0.2 to 0.8 Hz.

Conclusion

We believe the MDFR frequency trigger is very good at reliably detecting a loss of generation of a given MW level without regard to the distance from the lost generation to the recorder. We believe the variable backward displacement time as described above is significant in this, and we have never had another frequency trigger offered to us that included this feature. All settings were arrived at quickly, and none of them were critical. It was convenient that the threshold setting was approximately equal to the minimum frequency change that would trigger a record. Nuisance (undesired) triggers did not occur.

References

"A Microprocessor-Based Power Line Frequency Recorder," James D. Bruce, Ontario Hydro Research Division Report 85-63-K, March 13, 1985

"Microprocessor Digital Frequency Recorder Instruction Manual," James D. Bruce, Ontario Hydro Research Division Report 86-23-K, April 18, 1986.

The Qualitrol (Previously LEM) BEN500/BEN5000

By Robert Orndorff, Dominion

Overview

This Delta Frequency trigger has the following settings: Threshold, Window length, and Np. Also relevant is the Master Clock setting. This trigger uses 32 frequency measurements that are each "window length" long. These 32 measurements are divided into two averages. The Np setting determines how the 32 measurements are divided. Np has a range of 1 - 31. The average frequency is taken over (32-Np) windows and then again over (Np) windows. The difference between these two averages is the operating quantity for the trigger. If the difference is above the threshold, then the trigger will activate.

Our initial setting was a threshold of 0.020 Hz, window length setting of 0.050 seconds, and Np of 16. This setting was our interpretation of the settings implemented at the NYISO. This trigger captured many of the larger events, including the August 14 blackout. However there were many events that did not trigger with this setting.

To translate these settings into a "real world" slope and duration requires some math. First we wanted to see what the original settings were equal to in frequency change over time. We assumed a master clock setting of 6000 Hz, threshold of 0.020, window length of 300, and Np of 16.

Window length in seconds = 300/6000= 0.050 seconds

Np of 16 means that the two averaging periods are each 16 "window lengths" long. The first one is (32-Np) and the second is Np.

16 x 0.050 = 0.8 seconds.

The frequency is averaged over 0.8 seconds and then again over 0.8 seconds and if the difference exceeds 0.02 then the trigger will activate.

If we assume that the rate of change is relatively linear, then the average frequency of each time period falls in the middle of the averaging period. That would mean that the measurements are 0.8 seconds apart.

0.020 Hz/0.8 s = 0.025 Hz/sec rate of change.

The latest settings are Threshold of 0.019, Window Length of 1333, Master Clock of 4000 Hz, and Np of 3.

Window length in seconds = 1333/4000 = 0.333 seconds
Np of 3 means that the first averaging period is (32-Np), or 29, "window lengths" long.
29 x 0.333 = 9.66 seconds.
The second averaging period is Np, in this case 3, "window lengths" long.
3 x 0.333 = 0.999 seconds
The frequency is averaged over 9.66 seconds and then again over 0.999 seconds and if the difference exceeds 0.019, then the trigger will activate. Again we assume a linear rate of change and that the average frequency occurs in the middle of the averaging period. The difference in time is equal to the sum of each period divided by two.

(9.66/2)+(0.999/2) = 5.33 seconds.
0.019 Hz/5.33 seconds = 0.00356 Hz/sec rate of change.

This second trigger setting is much more sensitive than the original, and it is plain to see why the Dominion DFR would not always trigger when the NYISO DFR did.

Reference:
BEN 5000 Technical Reference Manual Rev C

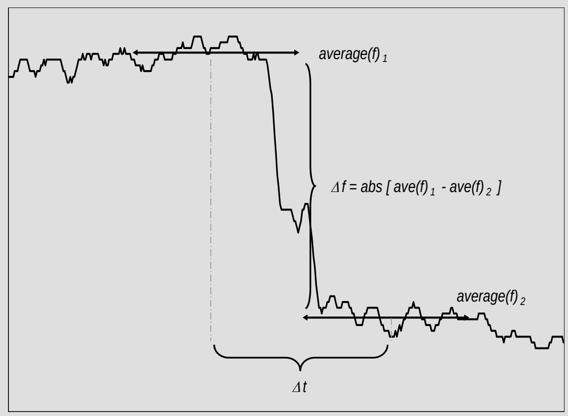
The Qualitrol (Previously LEM) BEN600/BEN6000
By Dean Ellis, NYISO

Background

Qualitrol offers a "Magnitude Variation" dX/dt trigger which can be used to detect change in a variety of quantities such as voltage, current and frequency.

The Magnitude Variation trigger in the BEN6000 series is very similar to the Delta Frequency trigger in the BEN5000 series; that is, two sliding averages are computed, and the absolute value of the difference is divided over a user-defined time period to calculate the rate of change. See figure 1 below.

Figure 1



The magnitude of the frequency variation is detected over a total time period of twice the user-defined value of Δt (Δt - a.k.a the "Time Window"). For purposes of analyzing the frequency, the total time period is divided into 20 smaller windows (the BEN5000 series uses 32 windows). The 20 individual smaller windows have a length of the "Time Window" (Δt) divided by 10:

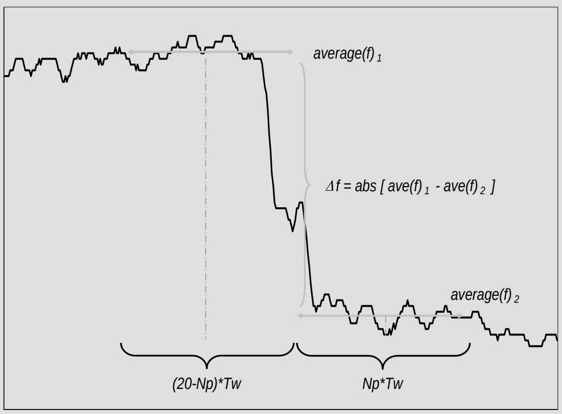
Individual Window Length (a.k.a. "Tw") =
Δt (a.k.a. Time Window) / 10

For example, if the user defines the Time Window (Δt) as 5 seconds long, then the frequency is analyzed every 0.5 seconds (Tw). Said a different way, the duration between each averaged value (or detection step) is 0.5 seconds.

As mentioned previously, the Time Window is defined by the user, and the signal is analyzed over a total time period of twice that Time Window. Since the total time period is divided into two averaging windows, the sum of the two averaging windows equals the total time period.

The relative size of each averaging window can be defined by the user thru the parameter Np (a.k.a. "Number of Detection Steps"). The first averaging window is the length of (20-Np)*Tw, and the second is Np*Tw. If Np is set to 10, then the duration of the first averaging window is exactly the same as the second. See figure 2 below.

Figure 2



The BEN6000 manual states that in order to approximate df/dt with Δf/Δt, Np should be equal to 10. The manual also suggests the duration of the second window, Np*Tw, should be less than half the period of the fastest expected variation. And finally, the duration of first window, (20-Np)*Tw, should be long enough to smooth out fast variations.

The user must define the frequency step (or change) which will be considered a trigger threshold. The "Threshold" represents the change in frequency, which if exceeded over the "Time Window", will trigger a record. The "Threshold" is entered in units of Hz.

The last user-defined variable is the "Hysteresis". The "Hysteresis" represents an increase or decrease in the triggering threshold after the initial threshold is crossed. This parameter prevents multiple triggers when the input signal remains near and oscillates around the threshold. The "Hysteresis" is entered in units of Hz.

Example Setting

The NYISO has had good experience with the following settings on our BEN6000 series recorder, and these settings most closely replicate our settings on the BEN5000 series:

Time Window = 5.333 secs.
Np = 2
Hysteresis = 0.002 Hz
Threshold = 0.019 Hz/sec.

With these settings, the frequency variations are detected over a period of twice the time window, or 10.667 secs. Also, the time between detection steps is 0.533 secs. (a.k.a. "Tw"), the duration of the first averaging window is 9.60 secs., and the duration of the second averaging window is 1.07 secs.

It did take some trial and error to replicate our BEN5000 frequency trigger settings in the BEN6000. This was mainly due to the fact that the BEN5000 series requires the user to enter the individual window length ("Tw", the time between detection steps) rather than the "Time Window". Additionally, the BEN5000 window length is entered in number of samples, which has to be divided by the master clock speed in order to convert it to seconds. This window length then needs to be multiplied by 16 to come up with the equivalent BEN6000 "Time Window".

	BEN500	*BEN600*
Master Clock Speed	*4000 Hz*	
Window Length	*1333 Samples*	
Np	*3*	*2*
Hysteresis	*0.002 Hz*	*0.002 Hz*
Threshold	*0.019 Hz*	*0.019 Hz*
Time Window		*5.333 secs.*

References:
LEM BEN6000 Manual, MAN018E, Rev. B

USI Model 2002 DFR
By Robert Orndorff, Dominion

The USI Model 2002 DFR has the ability to perform rate of change triggering. As implemented in this DFR, the frequency trigger is a rate of change trigger that also has a "Duration" setting. The duration setting is a user settable time that the rate condition must exist. We may not be interested in a rate of 3 milliHertz/second that lasts for one second, but we certainly would if it existed for 10 seconds.

They also perform continuous recording of frequency, RMS, and phase angle. These continuous recordings go back 30 days. If another DFR triggers for an event, it's possible to retrieve data for that event even if the DFR did not trigger.

We decided to experiment with triggering the USI for frequency events. Several events were examined for slope and duration. It appeared that the events all lasted about 10 seconds and had a slope of about 0.003 Hz/sec or greater. The trouble was that the USI only allowed 2 decimal places in the frequency setting. I then sent the example records and my calculated settings to USI to see if they could come up with a trigger that would capture these events. USI then did some testing and determined that the DFR was capable of measuring with an accuracy of 0.001 Hz. The software was changed to allow three decimal places.

According to USI, the DFR calculates frequency every 5000 samples, so any duration setting would be limited by the sample rate setting. We have the sample rate set at 4800 Hz, which works out to one frequency measurement every 1.04 seconds. Available sample rates for the USI are 1200, 2400, 4800, 9600, and 19200 Hz.

With the new USI software installed on all the recorders, we then implemented a trigger with a setting of 0.003 Hz/sec and a duration setting of 3.125 seconds, or three successive frequency measurements. A duration setting of less than 3.125 seconds resulted in many "nuisance" triggers. We eventually settled on a setting of 0.003Hz/sec with a duration setting of 6.25 seconds. This setting eliminates most of the unwanted triggers and captures most of the events that are of interest to our planning department.

The first night that we had implemented the new trigger, it caught an event that turned out to be a generator tripping at Belew's Creek. We also captured frequency rises due to pump storage facilities shutting down their pumps.

After a few days, I decided to go back and look at some of the older recordings captured by the BEN recorders and see if the characteristics of those events matched what we had been seeing recently. It turns out that many did, but a few did not. Many of those events that did not match were of much shorter duration, lasting about one or two seconds, and also had a sharper slope. It appears that the currently implemented USI trigger would miss these events due to the duration setting being longer than the event. I didn't want to change the current trigger settings, but what we could do was add a second trigger to the same channel.

The "Fast" dF/dT Trigger

This trigger has the philosophy of setting the duration as short as possible and then raise the slope setting so that it is above the "nuisance" trigger threshold. The original trigger philosophy was to set the slope as low as possible and raise the duration setting to the point that it avoided nuisance triggers. So we now have two dF/dT triggers - one that we call dF/dT slow (the 0.003 Hz/sec for 6.25 seconds) and the other called dF/dT fast.

We originally set this fast trigger to a rate of 0.009 Hz/sec and left the duration setting to zero (which should be "as fast as possible"). This setting had too many nuisance triggers, so I continued to adjust the settings until it was only triggering for valid frequency events. The final setting was 0.019 Hz/sec with a duration setting of 1.04 seconds.

Differences in Trigger quantities versus Displayed quantities

Some triggers did not seem to have a corresponding change when I looked at the continuous frequency record. These triggers on the USI recorder were sent to the vendor for analysis. The explanation was that the frequency displayed in the continuous frequency record is not the same as the frequency that is measured for triggering. The frequency that is **displayed** is still based on a 5000 sample sliding window, but the continuous frequency sample rate is 600 Hz. This means that each displayed data point is the average over 8.333 seconds. The frequency **trigger** is based on the transient record sample rate, which we have set to 4800 Hz. This averages the frequency over 1.04 (5000/4800) seconds.

There is an alternative to the continuous frequency record. The DFR also makes a longterm oscillography record for each trigger. We have this set to one minute pre-fault and two minutes post-fault at a sample rate of 600 Hz. The USI Master Station software has the ability to convert a waveform to frequency using a sliding window calculation. The size of the window is user settable. By using a 60 cycle sliding window, you can get a higher resolution frequency plot than is available in the continuous frequency recording.

References:
USI Model 2002 User's Guide Rev 1
Thanks to the people at USI for providing detailed information not available in the User's Guide

APP 501 DFR

By Robert Orndorff, Dominion

The APP-501 recorder has implemented a Delta Frequency trigger based on the MDFR trigger explained in this paper. This trigger has three user settable times – T1, T2, and T3. T1 and T2 are frequency measurement time intervals with T1 being the first measurement and T2 the second. T3 is the amount of time between the two measurements; this is sometimes called the "dead band". This trigger divides the total time into 50 "slices", each slice is equivalent to T4 in the MDFR section. T4 is calculated based on T1, T2, and T3. T4=(T1+T2+T3)/50. The whole measurement window advances by T4 to begin the next set of trigger calculations.

This trigger does not calculate the frequency by averaging multiple measurements over the period of T1 and T2, instead it uses the entire time window to measure frequency.

Our settings for this trigger closely match the settings used in the Ben 5000. The settings are: T1=9.5 seconds, T2=1 second, and T3=5 seconds. These settings result in a T4 of 0.310 seconds. The threshold is set at 0.022 Hz.

Our experience with this trigger is limited (about two weeks at the time this was written), however, it does seem to be more sensitive than triggers without the "dead band". The additional events that cause this trigger to activate seem to be of a longer duration.

References:
Thanks to APP Engineering for providing the information on their trigger operation.

Macrodyne PMU Delta Frequency Trigger

By Jim Ingleson, NYISO

In New York, the New York Power Authority (NYPA) in cooperation with NYISO, has deployed now a total of eight (8) phasor measurement units (PMUs). These are Macrodyne Corporation Model 1690. In addition to continuously forwarding data to a central data concentrator, these PMUs make 72 second recordings which are initiated by various trigger algorithms, and are stored locally for batch pickup. One of the algorithms is a Delta Frequency Trigger, as described in this paper.

The algorithm makes use of two 'running or moving' averages, a long frequency average (calculated every 5.6 sec), and a short frequency average (calculated every 0.35 sec). The long table and the short table are both centered about the trigger point. If the difference between the short and the long calculated average frequencies exceeds the set frequency threshold, this trigger is asserted. This frequency threshold is presently set at 20 mHz, and can be varied in a range about that setting.

The short average frequency is computed by summing 256 frequency estimates, which are produced by the frequency calculation algorithm 12 times per cycle, every .35 seconds. (256 * 1/720= 0.35). The long average frequency is computed by using a moving average of 16 of the short average frequencies, every 5.6 seconds (0.35sec * 16 = 5.6). The absolute value of the difference between the long and short averages is calculated each time the short average is recalculated. This difference is then compared to the trigger threshold and, if it exceeds the threshold setting, a trigger is asserted. The normal 16.66 sec of pre-trigger record length and 72.66 sec of total record length assures successful and sensitive capture of system events, based on this frequency triggering algorithm.

The performance of this algorithm is comparable to other Delta Frequency triggers described in this paper. This algorithm is relatively somewhat more sensitive to nearby events and somewhat less sensitive to distant events.

Mehta Tech, Inc.

By Jim Ingleson, NYISO

Mehta Tech, Inc. has implemented a delta frequency trigger described as follows. Analog inputs are run through a filter and processed in a DSP to produce a Phasor. Frequency is determined by calculating the angle between this phasor and the last one. The output is a number representing the angle of phase advance in this time period (i.e. frequency). This number, less the current value, is exponentially averaged to attenuate the noise in the result and the value is compared to the frequency set point. The change of the value is also compared to the frequency Rate of Change set point.

The delta frequency trigger exponentially averages the frequency again with an even smaller time constant to develop a base frequency which is compared to the "instant" frequency.

We have not yet had experience with this algorithm so we can't as yet relate our preferred settings and experience.

AUTHOR BIOGRAPHIES

Robert M. Orndorff currently works in the Fault Analysis group at Dominion Virginia Power, and has held this position since November 1997. His responsibilities include:

- The retrieval and analysis of data from DFR's, SER's, "smart" relays, and other devices for the entire Dominion system;
- The maintenance, testing and troubleshooting of modem and network communications to substation devices;
- The testing and implementation new technologies. (substation automation);
-DFR configuration and setup;
-Anything else he's asked to do...

Robert previously worked as a field relay technician for 11 years. Responsibilities included the installation, maintenance and testing of protective relay systems, SCADA, and power line carrier. Robert holds an AAS Degree in Electronics from J. Sargeant Reynolds Community College. His hobbies include Amateur radio and computer programming. He can be reached at *robert_m_orndorff@dom.com*.

James W. Ingleson began his electric power career with the municipal electric utility in his hometown, Jamestown, New York. He received his B.S. and M. Eng. degrees in Electric Power Engineering from Rensselaer Polytechnic Institute in 1970 and 1975. He worked for General Electric Company in various capacities, including design and construction of substations, generating plants, HVDC projects, and in system protection engineering. Jim is now with New York Independent System Operator, Inc. (NYISO) as Senior Operations Engineer. He is a registered professional engineer, a senior member of the IEEE, has been an active member of the IEEE Power System Relaying Committee (PSRC) since 1979. He is currently Chairman of PSRC’s Relaying Practices Subcommittee (PSRC). He can be reached via *ingleson@nyiso.com.*

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