

# ANALYSIS of OSCILLOGRAMS

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## I. INTRODUCTION

The purpose of monitoring the power system is twofold; (1) to check the speed and correctness of the protection systems and (2) to monitor the reaction of the power system to disturbances.

What goes into providing a good analysis of the data obtained from the system monitoring? An analysis of an oscillogram, whether consciously or unconsciously, includes the characteristics of the input transducers, the characteristics of the data conditioning, and interpreting the output. The interpreting is often a function of how well the interpreter understands; (1) the protection, control, and monitoring systems, (2) the operation of the power system, and (3) the characteristics of the major components of the power system.

The analysis of “analog” oscillograms is very direct and straightforward. The results, on paper, are generated directly from the input transducer. The only data conditioning is in the frequency response of the galvanometers.

The only component of analysis that differs with the “digital” oscillograph is the data conditioning.

The application of digital technology to oscillography provides a good opportunity to review the components of a good analysis and to consider the effect of each component on the analysis.

## II. INPUT TRANSDUCERS

Input transducers can be thought of as primary power system conditioners. They take the primary power system values and prepare them for use by the secondary devices to provide protection, control, and monitoring functions.

There are three major categories of input transducers; current, voltage, and event (contact).

### A. *Current Transducers*

Current transducers have good frequency response and normally do not require any special attention when operated in their recommended range of one to twenty times rated current and at rated burden or less. Perhaps the only unanticipated degradation in the input signal will be due to the capacitance of the cables. This can introduce errors in magnitude at several kilohertz and errors in phase angle at several hundred Hertz.

When harmonics are to be measured, it is much better to use current than it is to use voltage. Current circuits are low impedance paths that are less susceptible to induced signals or noise; whereas, voltage circuits are high impedance paths that are more susceptible.

Always use the fault current to select the current transducer ratio used for protective relay functions. Be sure that any auxiliary cts are selected (both ratio and classification) to assure that they do

not degrade the circuit.

In medium and large size substations, the burden on cts is mainly determined by the cable burden. The reduction of the relay burden with the use of digital relays is useful but usually the cable burden is the greater part of the ct burden, with either type of relays.

### *B. Voltage Transducers*

Voltage transformers do not have good frequency response, neither magnetic vts nor coupling capacitor vts. The capacitance of the cable will further degrade the input signal. But, depending on the frequency, this can be minimal compared to the errors due to the frequency response of the vt.

If harmonics are to be measured, it is much better to use current than voltage. In addition to being a lower impedance path, the output of the current transducer would represent the primary values with much better accuracy over a range of frequencies.

Select any auxiliary vts with a ratio and classification sufficient to prevent any further degradation of the voltage circuit.

*1) Magnetic Voltage Transformers:* The errors are generally due to interwinding capacitance and winding-to-ground capacitance. If the errors are to be limited to 10% (in magnitude or phase angle), then for harmonics or frequencies above 400-500 Hz. it is

advisable to perform a frequency response test on the particular magnetic voltage transformer to be used for the measurements.

*2) Coupling Capacitor Voltage Transformers:* The coupling capacitor voltage transformer uses a series tuned circuit (tuned to 60 Hz.) across a lower section of a capacitance divider to obtain a voltage proportional to the primary voltage. This voltage is transformed and compensated (for both magnitude and phase angle) to supply the specific attached burden. At frequencies other than 60 Hz., the ccvt can produce an output of 3 p.u. or more at some harmonics of the tuned frequency, with plenty of hills and valleys along the way. It is certainly not recommended that a ccvt be used to measure harmonics, without first performing a frequency response test on the particular ccvt to be used for the measurements.

### *C. Event Inputs (Contact Inputs)*

Event inputs are usually added to the disturbance recorder data in addition to, or instead of, the sequence-of-events recorder data. Although this input can be a simple contact, it is deserving of considerable attention because of the importance it can assume in the analysis process. Some of the items to be considered are:

*1) Interposing Relays:* All interposing (auxiliary) relays introduce some time

delay into the record. The amount can vary from relay to relay (microswitch to HFA/MG-6)(microseconds to 100 milliseconds). The amount of operate time is not as important as the fact that it exists. The pick-up time and drop-out time can be added to the data on the oscillogram, just as ct ratio and vt ratio are added.

2) *Open vs. Close Contacts:* It is usually clearer to indicate deviation from normal (breaker trip, low air pressure, hot spot temperature, loss of station service, etc.). In analyzing the data, it is helpful to know that going from normal to abnormal is the same for all event inputs. Some manufacturers allow the user the option of selecting an open or a close contact but other manufacturers specify which it shall be.

3) *Wet vs. Dry Contacts:* This is the statement of who will supply the voltage to the event logic. The “wet” contact has voltage supplied from the user. The “dry” contact has voltage for the logic supplied from the recorder.

4) *Logic Sensitivity (current requirements):* With “dry” contact logic, the amount of current required for a closed contact multiplied by the number of logic circuits determines the size of the manufacturer’s power supply. Heat dissipation can also become a problem. For “wet” contacts, a ground on the battery (dc supply) should not cause a false indication. In the case of the substation battery’s being used, the

requirements should include “battery on overcharge”. Another consideration should be “wet” cables. The current required to operate the logic input should be greater than the current that will flow between the cables going to the switchyard.

5) *Contact Bounce:* Contact bounce occurs whenever contacts close. It is the result of two contacts approaching each other, touching, and sliding (contact wipe) to their final location. From “contact first touch” to “contact at rest” may be a very short time, but the current flow may be interrupted “hundreds” of times. It is important that the contact bounce be ignored. Current should flow for a predetermined time period to be considered a closed contact. This time must be coordinated with the event resolution time of the recorder.

6) *Event Resolution Time:* This is the time from event input to output. This time can include or not include the anti-bounce time.

### III. DATA CONDITIONING

The application of digital technology to oscillography has resulted in a different set of items for data conditioning. The important thing to remember is not to try to “read” something into every blip and squiggle that you see on the output. Only try to explain that part of the output that the “system” is capable of handling. It is also

important that the “system” be coordinated and does not have one component that badly limits the capabilities of the “system”. The limits of the “system” should be clearly known and thoroughly understood. What this means is that you need to know what you are going to read and then select the proper device to read it.

#### *A. Input Signal Isolators*

Manufacturers can provide ac input isolators with good frequency response up to 10 kHz.

#### *B. Analog-to-Digital (A/D) Converters*

Present technology allows the use of converters that clearly exceed the needs of system. Some manufacturers provide 16-bit converters (sign  $\pm$  and 32,768 counts for full scale input)

#### *C. Sample Rates*

Sample rates are available up to 5,760 samples/second. This is 96 samples/cycle of 60 Hz. or 1 sample/3.75 electrical degrees of 60 Hz. or 1 sample/173.6 microseconds. These sample rates will allow the capture of any signal that is likely to appear at the input.

#### *D. Anti-Aliasing Filters*

Very good anti-aliasing filters are in

use that will prevent multiples of the sample rate from being interpreted as a signal with the frequency of the sample rate.

#### *E. Measurement Windows*

Some devices use a measurement window or the equivalent of a measurement window. This probably means that, at least the first sample in the first window is not accurate (ramp up value). Likewise, at least the last sample in the last window is not accurate (ramp down value). Depending on the sample rate and window length, it may be desirable to ignore more than one sample at the beginning and at the end of each input analog quantity. This makes slower sample rates less desirable because; 1) during analysis of all analog quantities, it is necessary to ignore the ramp up time of the quantity and the ramp down time of the quantity and 2) if data is analyzed from more than one device, it is necessary to keep up with the ramp up and ramp down times for the different devices and use the proper one with the proper device. The use of faster sample rates minimizes to insignificance the ramp up and ramp down times, therefore making it no longer necessary to ignore these times in the analysis.

## IV. INTERPRETING THE DATA

The final component in analysis of

the data is interpreting the data it's self. What is the reaction of the power system to the abnormal conditions that occur? The abnormal condition can be; a transmission line fault, a power transformer fault, a generator swing, a fault on an adjacent system, etc. It is important that the person analyzing the data have; a good knowledge or "feel" for the protection, control, and monitoring systems, a good understanding of the operation of the power system, and an understanding of the characteristics of the major components of the power system.

#### *A. Protection, Control, and Monitoring Systems*

It is very important that the person analyzing the data know, for example, that for a self-clearing fault on transmission line "13", breaker 1467 should open at station "A", in "W" time, and breaker 7641 should open at station "B", in "X" time. Breaker 1467 should reclose in "Y" time. After the transmission line is successfully energized for "Z" time, breaker 7641 should reclose. A similar scenario could be made for a power transformer, a generator, a capacitor bank, etc. These are fairly simple examples. The person analyzing the data must have a feel for these protection, control, and monitoring systems and what actions might take place if the fault occurs on peak, if the

reclose is not successful, if a tie to an adjacent utility is lost, etc. In other words, how these systems will react to various abnormal power system conditions. Power swings on transmission lines and on generators are much more complex and require considerably more data. The analysis of the data depends, to a large degree, on the expertise that the person doing the analysis has in protection, control, and monitoring. His importance becomes even greater when special, or unusual, or non-standard systems are use; or when questionable operations occur; or when wide area disturbances are involved.

While evaluating the speed and correctness of the protection systems, the following items will be considered:

- a) Did the protection systems operate as intended?
- b) Did the protection systems operate within the time limits?
- c) Determine the type of fault, the location, and possible causes.
- d) Did all protection systems react properly?
- e) Did reclosing operated as intended?
- f) Verify system calculations and relay settings.
- g) Use fault interrupting duty to determine maintenance schedule.
- h) Can any impending failures be detected?
- i) Etc.

## *B. Operation of the Power System*

An intimate knowledge of the operation of the power system is required. The person must know what power system components are involved and why the components are set up as they are. He must know what options are available and what procedures are necessary to initiate them. Without this intimate knowledge of the power system, it is extremely difficult for the person doing the analysis to place the disturbance into proper perspective. This could mean that the greatest benefit from the analysis might be lost.

## *C. Characteristics of the Major Components of the Power System*

The analysis of the disturbance requires a detailed understanding of the characteristics of the major components of the power system; i.e. circuit breakers, power transformers, generators, voltage regulators, power capacitors (shunt and series), power reactors (shunt and series, but not nuclear), transmission lines, etc. Without this understanding, you will not know that the interrupt time in oil circuit breakers varies inversely with current magnitude but in gas circuit breakers it does not. Or that a 13-kV, air insulated, shunt reactor has an air core and a very strong magnetic field for some distance around it, whereas a 500-kV, oil insulated, shunt reactor has a

gapped iron core and the tank completes the path for the magnetic field. These are in contrast to the magnetic path in power transformers where the magnetic field is contained by the closed magnetic path inside the transformer tank. It is the understanding of the detailed characteristics that enables the person to interpret the current interruptions, the charging currents, the discharging currents, etc. This adds to the analysis to make the interpretation more complete and more accurate.

While evaluating the reaction of the power system and the power system components to the disturbance, the following items will be considered:

- a) Current Transducers
- b) Voltage Transducers – VT or CCVT
- c) Power Transformers
- d) Circuit Breakers – Opening Resistors, Closing Resistors, etc.
- e) Generators
- f) Shunt Capacitors
- g) Series Capacitors
- h) Shunt Reactors
- i) Series Reactors
- j) Switching Surges/Surge Arrester Operations
- k) Protective Gap Flashes
- l) Ferroresonance
- m) Etc.

## V. SOME EXAMPLES

The following are some examples of system disturbances:

Figure 1: These are examples of surge arrester operations.

Figure 2: These are examples of power transformer magnetizing inrush current. Fig. 2a shows all three phase currents and the neutral current. The magnitude decreased for 4.6 seconds. For a large EHV power transformer bank, this time could be several times longer. Fig. 2b shows the dc decrement dying out very quickly, but the magnitude will continue for quite some time.

Figure 3: These are examples of coupling capacitor voltage transformer performance. Fig. 3a shows CCVTs being energized from the right. These distortions can continue for more than a second, suddenly having distortion reappear after being smooth for ten cycles or more. Fig. 3b shows CCVTs being deenergized. The decaying voltage output can still have 3-5% voltage at tens of cycles after "deenergization".

Figure 4: This an example of an extra that is available sometimes. EHV air-blast circuit breakers are equipped with opening resistors that are inserted as the main breaker contacts open and reduces the transient to the system (and to the breaker) when the breaker opens. This resistor can be monitored, thereby reducing the probability of the resistor being open when the breaker is called on to interrupt a large current. This could avert a catastrophic breaker failure.

Figure 5: These are examples of current transformer performance. Fig.

5a shows dc offset when the breaker is reclosed into a fault. Fig. 5b shows current transformer saturation.

Figure 6: These are examples of restrikes in power circuit breakers. Fig. 6a shows a restrike that was cleared. Fig. 6b shows a restrike that was not cleared and resulted in the destruction of the circuit breaker.

Figure 7: These are examples of a power circuit breaker closing to energize a transmission line. Fig. 7a, trace 6 shows a ringing at 21 cycles. If you can read the distance between the peaks of the ringing you can determine the line length. At 26 cycles, you see a dc decrement. Fig. 7b, trace A4 shows the dc decrement again. Here is an example of another extra, the contact closing dispersion of a circuit breaker.

Figure 8: This is a good example of an unsuccessful reclose (permanent fault). The fault occurs, the fault is cleared in a little under 4 cycles. The line is deenergized for about 11.5 cycles. The circuit breaker recloses into the fault, the fault is cleared in a little under 4 cycles.

Figure 9: This is an example of an unsuccessful reclose (dead time too short). The fault occurs, the fault is cleared in a little over 5 cycles. The remote end of the line recloses in a little under 10 cycles. The dead time of the line is insufficient to allow the arc path to de-ionize and the fault is reestablished. When the local circuit breaker recloses,

the fault is still present, and the breaker opens.

Figure 10: These are examples of ferroresonance. Fig. 10a shows voltages on a 500-kV line with shunt reactor compensation and flat line construction. When the line is disconnected from the system at both ends, the disconnected system rings at about 40 Hertz. Fig. 10b shows current transformer saturation. Figs. 10c&d show CCVT outputs.

Figure 11: This shows the same shunt reactor compensated line as Fig. 10a. This time the fault continues to reestablish (see trace 5) and reclosing is unsuccessful.

Figure 12a, b, &c: This data is from a digital swing recorder. This is a record from Northfield Substation, Mass. of the loss of both nuclear units (2200 MW) at Sequoyah Generating Station, Tenn on Dec. 31, 1992. Fig. 12a shows the frequency and voltage excursions. Please note the time scale is in seconds. Fig. 12b shows the MW & MVAR excursions on the New York to New England 345-kV tie line. Fig. 12c shows the R/X impedance diagram plot of the 345-kV tie line.

## VI. CONCLUSIONS

It is important to properly identify and isolate faulty equipment from the power system as swiftly as you can dependably do so. The need for speed is to improve stability, reduce the damage to the equipment, and improve the quality

of service. The increase in speed costs money. Monitoring the faster, more complex equipment is a necessary investment. This insures that the equipment does the job that you paid for. It also tells you when the equipment is not functioning as it should. After repairs and maintenance, you can tell if the equipment is back to doing the job it was purchased to do.

The increased speed of the circuit breakers means that faster relay and control systems are required. You do not want to have a 3-5 cycle relay system on a 2-3 cycle breaker. Faster fault clearing times require fast relay systems to be matched with fast circuit breakers. Fast fault clearing requires monitoring to verify that you do, in fact, have fast fault clearing.

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## **Power system monitoring:**

- **Checks the speed and correctness of the protection and control systems**
- **Monitors the reaction of the power system to disturbances**

## **Analysis of an oscillogram includes:**

- **The characteristics of the input transducers**
- **The characteristics of the data conditioning**
- **Interpretation of the output**

**Interpreting the output is a function of how well you understand:**

- **The protection, control, and monitoring systems**
- **The operation of the power system**
- **The characteristics of the major components of the power system**

# **INPUT TRANSDUCERS**

- **Current Transducers**
- **Voltage Transducers**
  - **Magnetic Voltage Transformers**
  - **Coupling Capacitor Voltage Transformers**
- **Event Inputs (Contact Inputs)**
  - **Interposing Relays**
  - **Open vs. Closer Contacts**
  - **Wet vs. Dry Contacts**
  - **Logic Sensitivity (Current Requirements)**
  - **Contact Bounce**
  - **Event Resolution Time**

## **DATA CONDITIONING:**

- **Input Signal Isolators**
- **Analog-to-Digital (A/D) Converters**
- **Sample Rates**
- **Anti-Aliasing Filters**
- **Measurement Window**

# **INTERPRETING THE DATA**

- **Protection, Control, and Monitoring Systems**
- **Operation of the Power System**
- **Characteristics of the Major Components of the Power System**

## **Evaluating the speed and correctness of the protection systems**

- **Did the protection systems operate as intended?**
- **Did the protection systems operate within the time limits?**
- **Determine the type of fault, the location, and possible causes.**
- **Did all protection systems react properly?**
- **Did reclosing operate as intended?**
- **Verify system calculations and relay settings.**
- **Use fault interrupting duty to determine maintenance schedule.**
- **Can any impending failures be detected?**
- **Etc.**

## **Evaluating the reaction of the power system to the disturbance requires an understanding of the major power system components**

- **Current Transducers**
- **Voltage Transducers – VT or CCVT**
- **Power Transformers**
- **Circuit Breakers – Opening Resistors, Closing Resistors, etc.**
- **Generators**
- **Shunt Capacitors**
- **Series Capacitors**
- **Shunt Reactors**
- **Series Reactors**
- **Switching Surges/Surge Arresters**
- **Protective Gap Flashes**
- **Ferroresonance**
- **Etc.**

## **CONCLUSIONS:**

- **Properly identifying and isolating faulty equipment from the power system as swiftly as you can dependably do so**
  - **Improves stability**
  - **Reduces damage to equipment**
  - **Improves the quality of service**
- **The faster, more complex systems cost more**
  - **It is necessary to monitor these fast systems to assure that they are doing the job they were purchased to do**
  - **Monitor to determine when the systems are not functioning properly**
  - **Monitor after repairs and maintenance to verify that the systems are back doing the job**

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