OSCILLOGRAPHY - BPA SYSTEM

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INTRODUCTION

The Bonneville Power Administration has long recognized the automatic oscillograph as an invaluable tool in monitoring equipment performance, relay operations, system performance during abnormal conditions, major system disturbances, and calculating fault locations.

> Oscillogram evaluation has resulted in: The inspection of a circuit breaker which had unsuspected internal damages and had been placed back in service; the inspection of a circuit switcher which had the wrong type of grease in the brain causing slow operation; the replacement of a low accuracy CT which was saturating and could possibly cause relay misoperation or failure.
>
> Oscillograms have proved simultaneous line faults, thus eliminating the suspicion of a relay misoperation. They have also proved the lack of simultaneous faults and the ensuing discovery of relay problems.
>
> Oscillograms recorded during system disturbances have proved proper relay operations (some improper) and helped determine the sequence of events during system wide breakups.
>
> Before the advent of a complex fault locating system, oscillograms were a necessity in determining fault locations. The oscillogram information resulted in reduced outage times for permanent faults.

The purpose of this paper is to outline the installation guidelines for automatic oscillographs on the BPA system and to demonstrate the effectiveness of the automatic oscillograph as a tool for power system disturbance monitoring.

INSTALLATION GUIDELINES

In the early 1970's, a Task Force was formed within BPA to establish guidelines for the installation of automatic oscillographs on the system. The guidelines take advantage of several items as follows:

1. Availability of oscillographic data from adjacent stations.
2. Avoidance of redundancy between oscillographs.
3. Availability of fault studies to extrapolate additional data.
4. Voltage level of the substation.
5. Importance of the substation to the system.

Georgraphic location was originally proposed as one of the considerations but was later dropped. The geographic location as relating to isokeraunic level was not considered because equipment defiencies with consequent failures are the same system wide, and major load areas west of the mountains are just as important as the eastern portion of the system where high isokeraunic levels and large concentrations of generation exist.

The following items are used as guideline when contemplating the installation of an oscillograph:

1. Sixteen channels is the maximum number of traces considered usable for a machine assuming 12 inch paper (this number is based on a trace calibration to allow accurate measuring for fault location calculations).
2. Each line breaker requires a minimum of two traces (residual and one phase current). In addition to the requirements per line breaker the following station quantities should also be recorded: Rectified 3 phase voltage from two sources and polarizing current.

3. In the case of transformation at 345 KV and above each transformer bank shall be considered as 2 line positions when considering a 230 KV station. For transformers below 345 KV each transformer bank shall be considered as ½ line position. This will provide for monitoring 500 KV quantities at locations where no 500 KV PCB's are installed and it will also provide a limited number of traces for recording critical circuits at 115 KV or 69 KV
4. Substation Voltage
    - I. 500 KV Stations
        - a. 500 KV stations should have at least three breakers to meet the minimum requirements for a station automatic oscillograph.
            1. Between three and up to and including six breakers, one machine.
            2. Up to and including 12 breakers, two machines.
            3. More than 12 breakers, three machines.
    - II. 230 KV Stations
        - a. 230 KV stations should have four line positions to meet the minimum requirements for a station automatic oscillograph.
            1. Between four and up to and including seven line positions, one machine.
            2. More than seven line positions, two machines.
    - III. Stations with both 500 KV and 230 KV

      Stations having both 500 and 230 KV should follow the individual requirements for the two voltages as outlined in one and two above.
    - IV. Below 230 KV

      Stations below 230 KV must be justified on an individual basis.
5. As with any usable guideline, the above is subject to change to adapt to new and changing conditions.

SAMPLE ANALYSES

During the infancy of the NW-SW a-c intertie, one particular relay false trip occurred that went unexplained for several years. At that time, we were using distance relays to provide reactor differential backup protection. Several unexplained tripouts encouraged us to add time delay to the distance relay scheme and discouraged our further use of distance relays for reactor protection. Several years following, we were energizing a 230 KV, 180 megavar shunt reactor group at Monroe Substation. The layout of the substation allowed us to energize the reactor with a circuit switcher or with a gas blast circuit breaker.

Examples of the energization transients are shown in Figure 1. The upper figure shows the reactor energized with a circuit switcher. The lower figure shows energization with the circuit breaker. Note that the circuit breaker is more likely to close at other than a voltage peak thus giving varying amounts of d-c offset in the current wave. The d-c current in the reactor causes partial saturation and a resulting decrease in the inductance of the reactor. In this case, the resulting transient inrush current approaches 1.9 per unit making it virtually impossible to apply a common distance relay or overcurrent relay to a shunt reactor and still provide a reasonable amount of protection. The oscillograph in Figure 1 dramatically illustrates that fact.

The response of current transformers is increasing in importance in EHV systems because of the increase in fault magnitudes, system time constants and incidence of offset faults because of high closing speed of air and gas blast breaker contacts. The configuration of most EHV stations requires paralleling of CTs to provide line relay currents. Different magnitudes of currents in the parallelled CTs cancause different CT performance, with resulting error currents in the protective relays. Figure 2 illustrates this occurrance, traces one and two represent the two parallelled CTs and trace three represents the resulting current to the relay set. Note the distorted wave form of trace three. This kind of CT performance has caused low set permissive directional ground relay misoperations on the BPA system.

It is sometimes desirable for isolation reasons to use an auxiliary current transformer when paralleling CTs. This can create error currents, particularly if the auxiliary CT does not have adequate relay accuracy rating. In Figure 3 a one line to ground fault is being fed through one power circuit breaker of a ring bus station. The other circuit breaker is open which should keep the current in the auxiliary CT at zero. Trace number one shows the current supplied by the main CT and trace number two shows the actual relay current. Note the distorted wave of the relay current. Apparently the auxiliary current transformer saturated and provided a low impedance path in parallel with the relays.

Still another example of poor current transformer performance with parallel CTs is shown in Figure 4. At this substation the polarizing current for the ground relays is derived from three different transformer banks. The three individual currents and the total polarizing is shown in the figure. In a station this size, we normally monitor only the total polarizing and we added the individual contributions in this case to try and determine the reason for the distorted wave form of the total polarizing current. Displaying the three sources separately indicated a problem in bank three current transformer. That current transformer turned out to be an accuracy class of C100. The others were 400 or better. We replaced the bank three C100 current transformer with one of a C400 rating and waited for the next fault. This is shown in the figure. Being able to monitor different quantities at different times by the basic design of our oscillograph cubicle allows us to get the maximum benefit from a minimum number of installed oscillographs. The example sited above did not cause a relay misoperation because the total polarizing current still was in the proper phase relationship.

Further saturation from higher magnitude faults could cause ground relays to misoperate and worse yet could cause failure of a ground relay to operate on a faulted line.

Normal clearing of faults in double breaker bus schemes can cause departures from expected excursions of current. This is illustrated in Figure 5. The upper trace in the figure is the fault current flowing through a power circuit breaker without tripping resistors. Note the excursions of current as the main current path shifts first from the resistor breaker to the other breaker then, when the other breaker opens, the current path is back through the resistor's of the resistor breaker. This can cause some rather violent current reversals in ring buses and through bus ties on double breaker arrangements. We are not aware of any relay misoperations on the BPA system as a result of these current reversals.

Figure 6 illustrates two separate faults occurring almost simultaneously on two parallel lines. These two lines are not on double circuit towers. The three phase rectified voltage trace indicates the fault is c to ground throughout. The initial fault is on the number three line and 3½ cycles later the same phase of the number five line became faulted. At 5¼ cycles the number three line cleared and at 8½ cycles the number five cleared. Without an oscillograph operating at this time, proper operation of the two line relays could not have been verified.

Figure 7 shows subharmonic currents of approximately 30 Hz that occur following fault clearing on the 500 KV NW-SW intertie. The fault is near Grizzly Substation on the Round Butte line. The 500 KV lines north to John Day and south to Malin are 50% series capacitance compensated with shunt reactors at Grizzly on one John Day line and one Grizzly line.

Figure 8 is the polarizing voltage derived from the line CCVT on a faulted 500 KV line during a lightning storm. The record shows the fault, the clearing and reclose of the line. It appears that lightning struck either the line or very close to it a total of six times during the approximately 30 cycles of dead time. This line does not have overhead ground wires.

On November 27, 1979 at 1433 hours PST, the WSCC region experienced a wide-spread disturbance which resulted in the region separating into seven islands. Figures 9 and 10 are copies of two oscillographs from the BPA system during this disturbance.

Figure 9 is from an oscillograph at Dworshak Substation. Two units at Dworshak (one a 92 MVA unit and the other a 220 MVA unit) were connected to the system by a 500 KV line, 143 miles long to Hot Springs. The voltage distortion before the first swing is where Hot Springs became isolated from the Montana system. The swing ending at the end of the oscillograph is where the 220 MVA generator tripped.

Figure 10 is from an oscillograph at Hot Springs showing system time, 1 phase current, a residual current, and a line voltage on the Hot Springs - Anaconda 230 KV line. There is no transfer trip on this line so when Anaconda relayed by Zone 2 the Hot Springs end of the line did not open. On the oscillogram the reduction of I_A from load current to line charging current is where the Anaconda breaker opened. Six and one-half cycles after the Anaconda breaker opened, the I_R current, without a reduction in line voltage, caused us to suspect the breaker at Anaconda flashed across the contacts because of the out of step voltage across the breaker. Subsequent inspection of the breaker revealed oil on the ground from BØ and extensive internal damages, including the resistors being blown apart.

A line reactor neutral instantaneous overcurrent relay operated during line fault clearing. This was one of two parallel 500 KV lines with 75% series capacitive reactance compensation. The faulted line has shunt reactors at both ends and the parallel circuit has reactors at one end. Figure 11 shows the reactor neutral current during three cycles of fault followed by the somewhat violent de-energization transient. The instantaneous element of the neutral relay was set at about 4 per unit phase current and operated approximately 73 milliseconds after fault inception as indicated by the event recorder data in the figure. This illustrates that event recorders and oscillographs complement one another, each is useful because it supplies different information.

A 3-phase fault occurred on the 125 miles, 115 KV, Redmond-Harney line. Without the aid of an automatic oscillograph, we would still be wondering what actually happened and would, no doubt, have wasted a lot of time checking the relays.

The three-phase fault occurred approximately three miles from Redmond (this was an estimatedlocation from the oscillograph at Redmond). The Redmond end relayed by Zone 1, all three phases, and reclosed successfully in 10 seconds. The Harney end of the line did not open. A line patrol found insulators flashed on all three phases at Structure 5/4 with one unit broken on positions 2 and 3. The crossarm was damaged and there was considerable evidence of prolonged arcing on the structure.

Fortunately, we had installed a temporary oscillograph at Harney to monitor PCB performance on the Redmond line. By analyzing that record, we determined the following sequence. Initially, the fault impedance seen from Harney was 104 ohms. Zone 2 is set at 122 ohms, 0.5 second. However, at 30 cycles the fault impedance from Harney measured 131 ohms. There was a rather gradual decrease in current until at 140 cycles the impedance measured 180 ohms. Zone 3 is set at 150 ohms and 2.5 seconds.

At approximately 200 cycles, C-phase current decreased to approximately 50 amperes line charging and tapped load current. At 210 cycles, B-phase current was approximately 50 amperes, and 220 cycles, A-phase measured 50 amperes. This current was constant to the end of the record.

There was no operation of the PCB at Harney, but it is clearly evident from the oscillograph that the fault "went out." The oscillograph ran for approximately another 4 seconds. The Redmond PCB then reclosed at approximately 10 seconds. Figure 12 is only the portion of the record that shows the fault extinguishing. Incidentally, this record is from a PM - 13 oscillograph that was retired in 1979 after 30 years of service.

In order to reduce the number of traces required on the oscillographs, we use a three-phase rectified voltage trace instead of 3 separate traces. Figure 13 is the circuit in use to rectify the voltage before connecting it to the shunt box. The diodes are 1 Amp, 1000 PIV and the resistor is a 200 ohm 5 watt wire wound resistor with axial leads. The size of the resistor can be increased to decrease the deflection of the A phase trace. A phase is depressed for identification of phase information.

On most oscillographs, we use only one three-phase rectified voltage trace. On a breaker and one half bus or a ring bus the voltage trace is from voltage transformers connected to a line. If that line is out of service, the voltage monitor is lost. Therefore, the circuit shown in Figure 14 was devised, which provides two line voltage sources to the oscillograph. The time delay is necessary to delay the transfer until after the line, which is considered the main supply, has a chance to reclose.

One relay current circuit from each breaker and one relay potential circuit from each potential transformer in the yard is routed through the oscillograph cubicle. In the cubicle, they are connected to superior type test switches. With all the current and voltages available in the cubicle and using flexible leads from the galvanometer shunt boxes, we have the flexibility to change traces to help trouble shoot problems. This is shown in Figure 15.

CONCLUSION

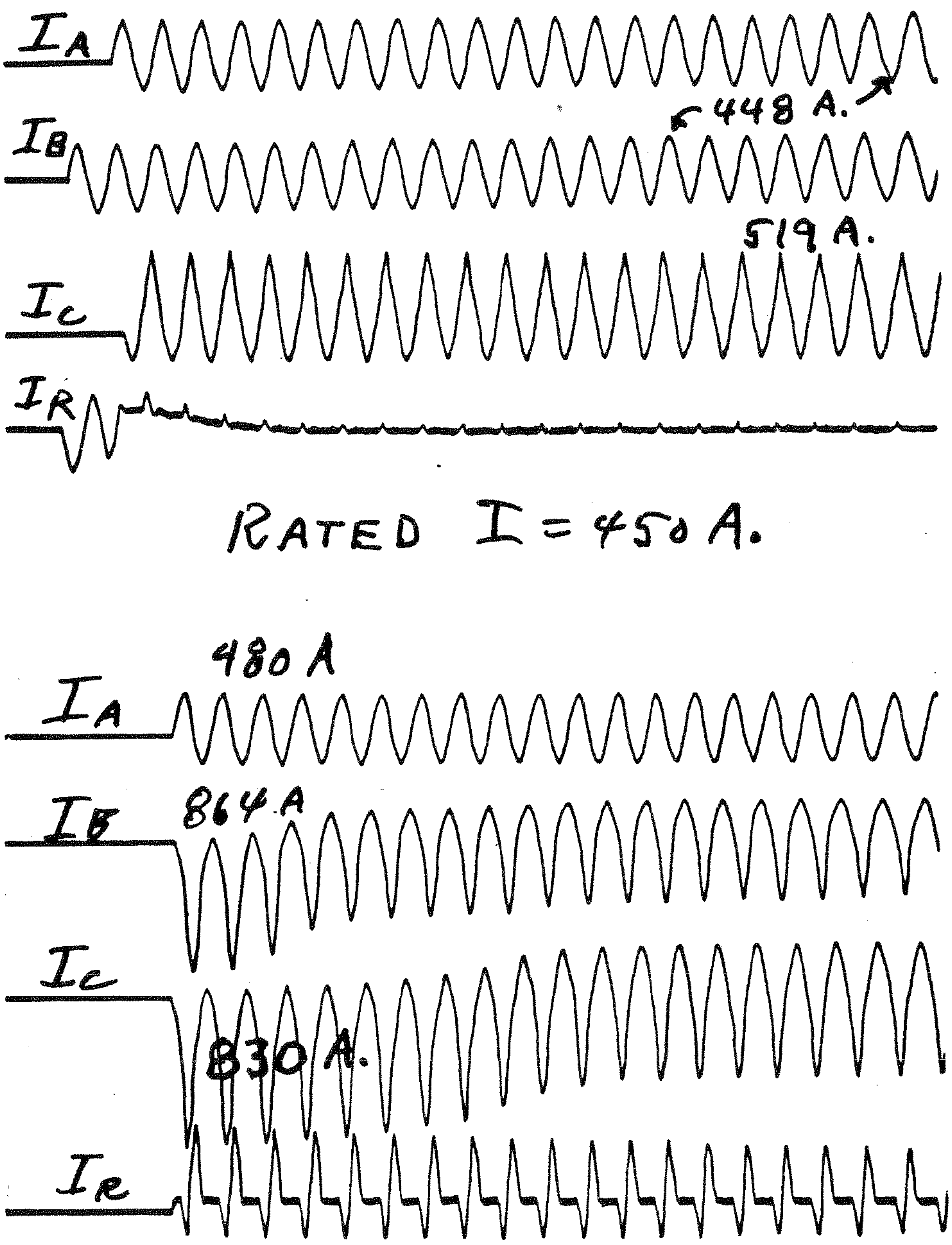
The Bonneville Power Administration has long recognized the automatic oscillograph as an invaluable tool in monitoring equipment performance, relay operations, system performance during abnormal conditions and major system disturbances, and calculating fault locations. The performance of circuit breakers as recorded on station oscillographs has been valuable in the past and will become increasingly important as equipment becomes more complex. This is particularly true of the EHV circuit breakers designed to limit switching surges, since breaker timing must remain within specified tolerances in order to meet the required switching surge levels. As more and more emphasis is placed on high speed clearing (2 cycles or better) fast automatic start oscillographs become inadequate and prefault data becomes essential. The installation of single pole relay schemes will require additional channels as well as event recorders to adequately monitor the system performance.

The exclusion of event recorders from this discussion is certainly not intended to minimize their importance to power system performance analysis. On the other hand, the two devices supplement one another. This is because certain types of data are unique to each device. The event recorder provides information on a change in contact status but it does not monitor circuit breaker and system electrical performance.

The event recorder tells when an event occurred but does not explain why it occurred. The oscillograph information can explain why an event occurred. Future high speed transducers may change that fact.

The BPA guidelines for oscillograph installation require about the same number of oscillograph elements per station as has been used on the system for many years. Experience has shown that this is generally adequate for analysis of disturbances which affect a large area or those which cause unusual conditions within a station. In a number of cases, this analysis would become impossible with fewer oscillographs or fewer elements per station.

Without oscillographs major system disturbances would be impossible to reconstruct in detail. Information on system performance during faults and swings both stable and unstable provide valuable data to system planners on the validity of computer studies. Proper as well as improper operation of many facets of system performance can be determined through the use of automatic oscillographs. The automatic oscillograph is a vital tool to the smooth running of a complex power system.



RATED I = 450 A.

Figure 1. Energization transient of a 230 KV, 180 MVAR shunt reactor bank. Energized with a circuit switcher (upper traces) and a circuit breaker (lower traces).

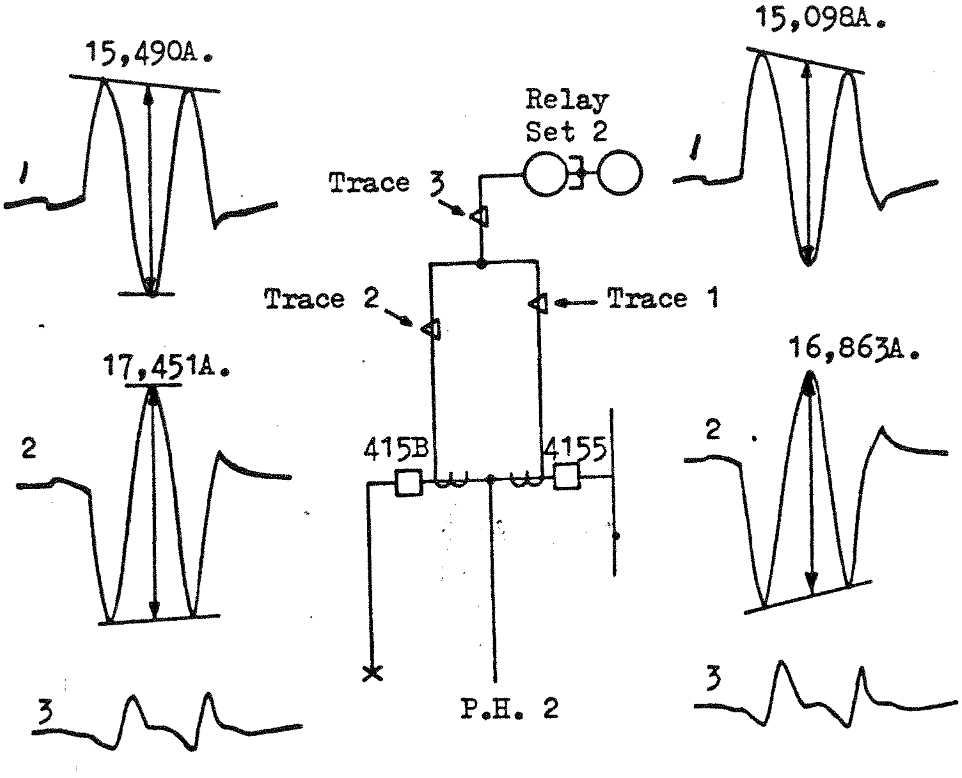


Figure 2. Parallel CT performance during two successive fault tests showing relay current distortion.

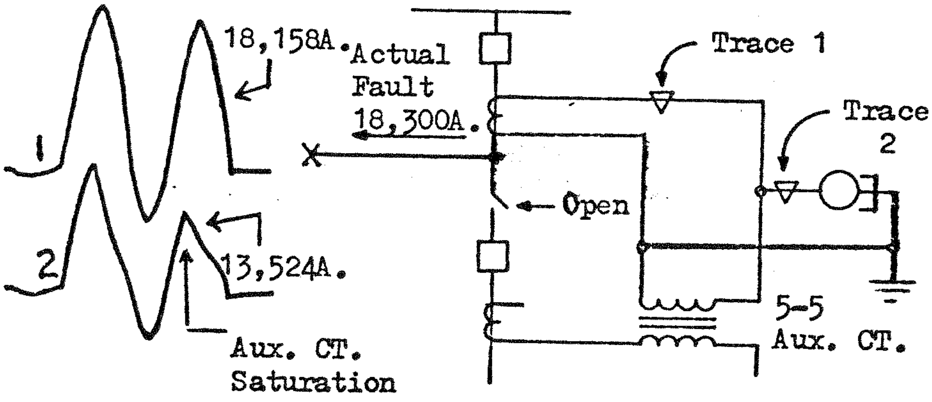


Figure 3. Auxiliary CT saturation.

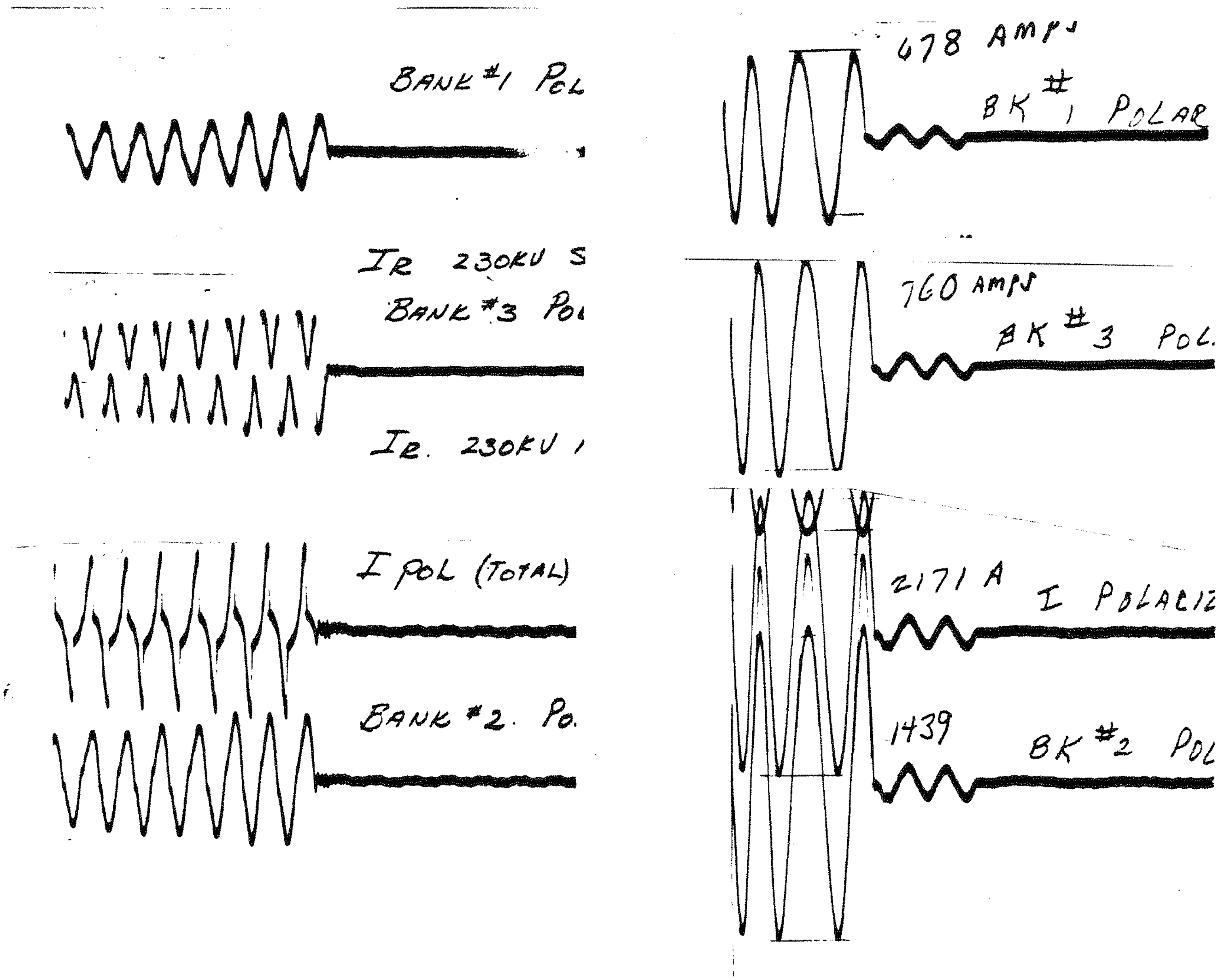


Figure 4. Current transformer saturation in a current polarizing circuit with a C100 bank 3 CT (left hand record) and with the bank 3 CT replaced with a C400 rated CT. (right hand record)

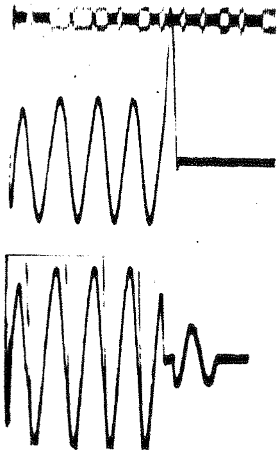


Figure 5. Normal fault clearing in a ring bus station with low ohmic resistors in one breaker.

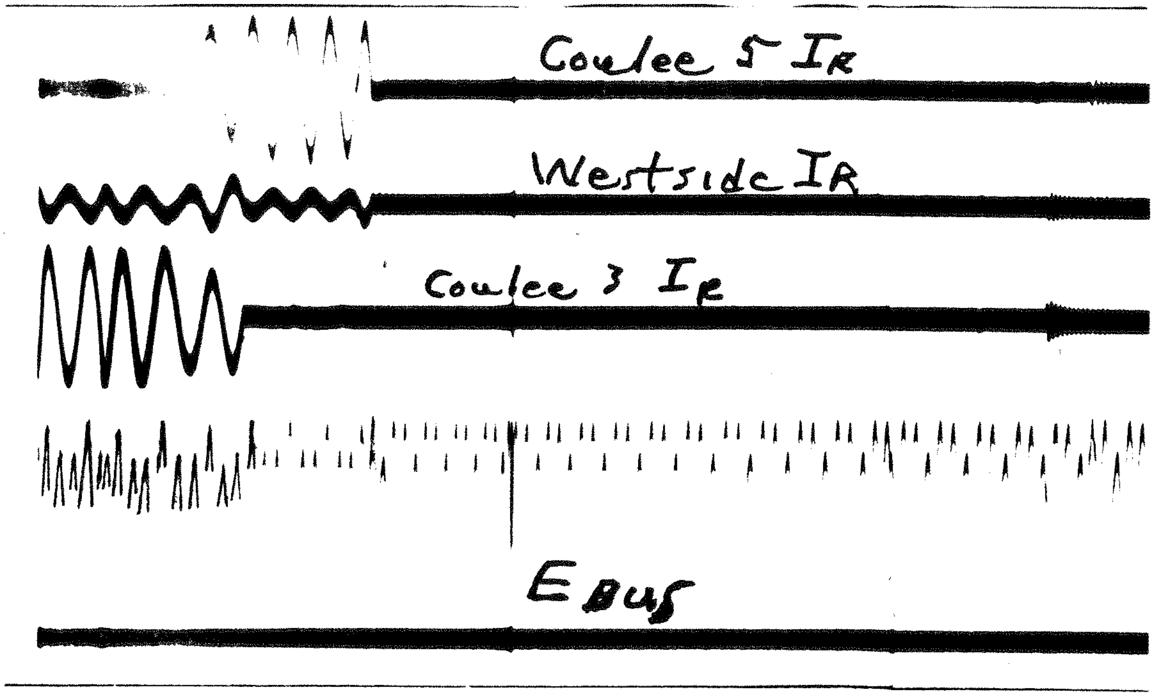


Figure 6. Bell Substation - near simultaneous faults on the Coulee No. 3 and No. 5 lines.

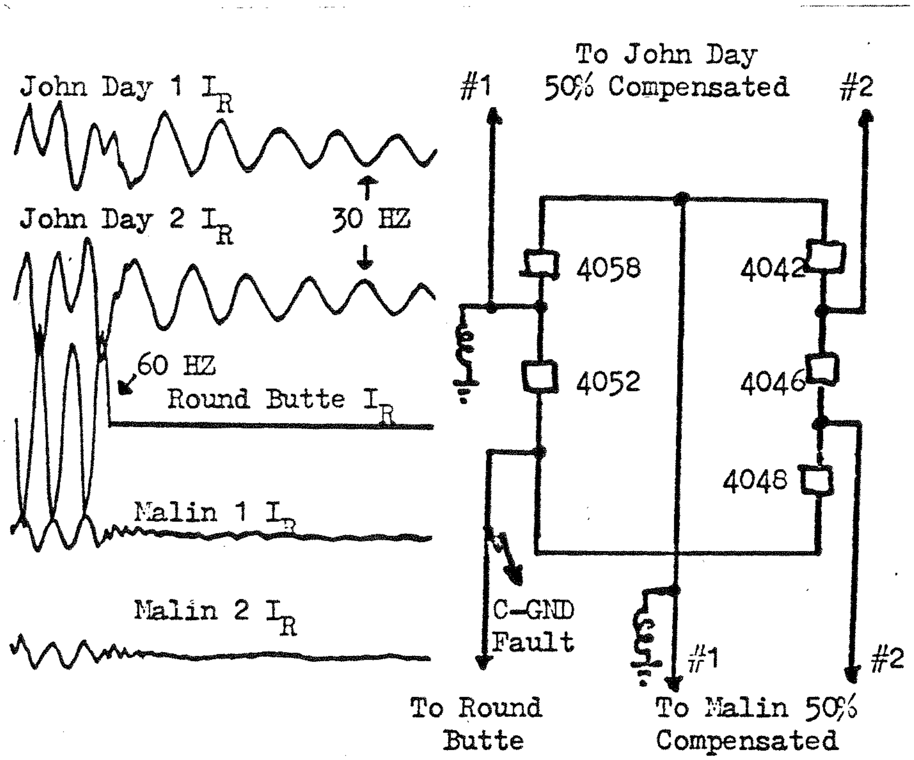


Figure 7. Subharmonic currents on lines with series capacitors.

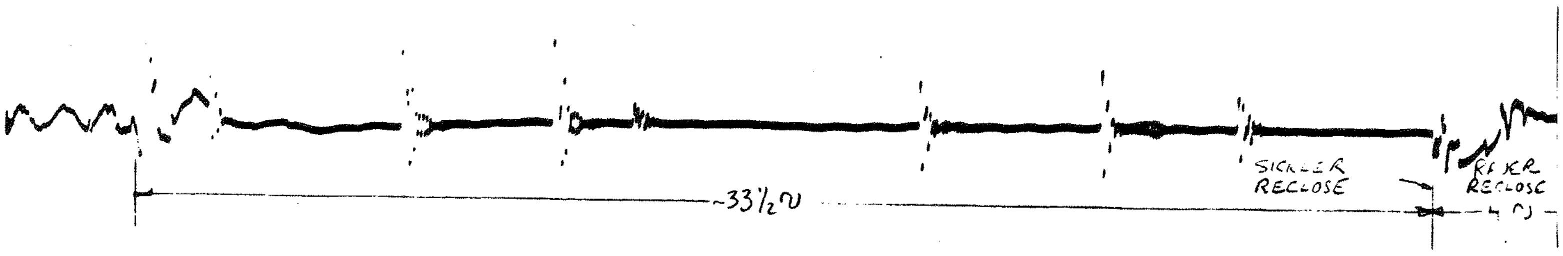


Figure 8. Line polarizing potential showing multiple lightning strikes.

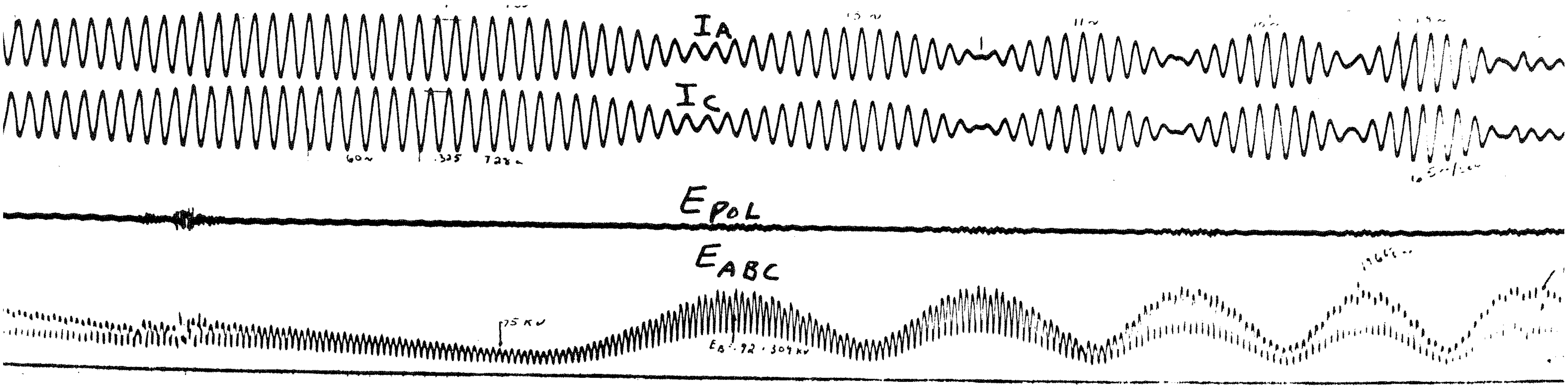


Figure 9. Loss of synchronism of a large hydro unit during a system **disturbance**.

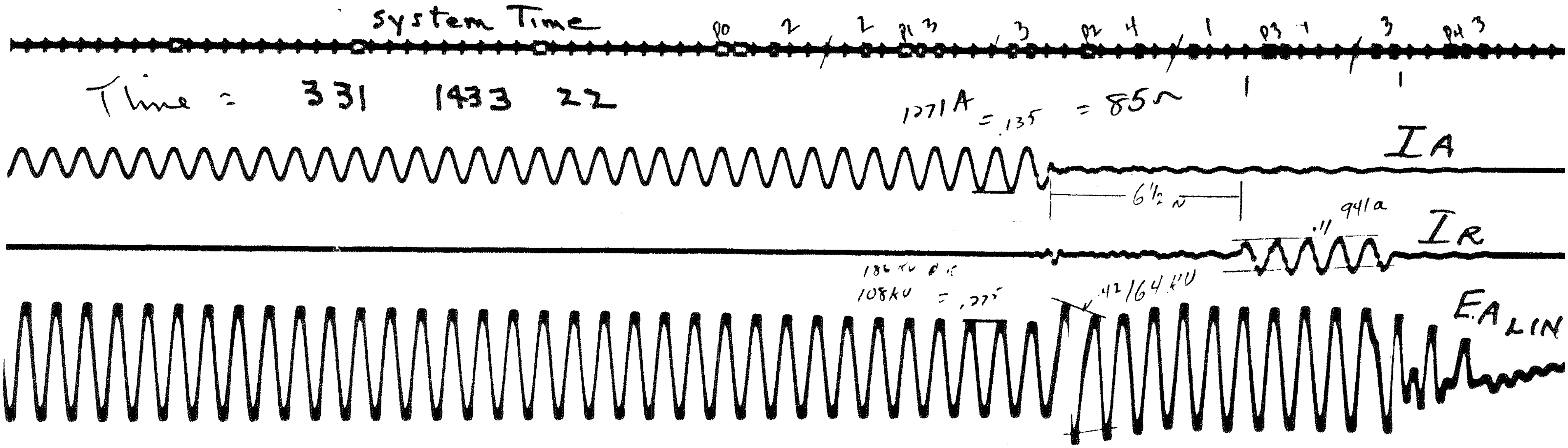
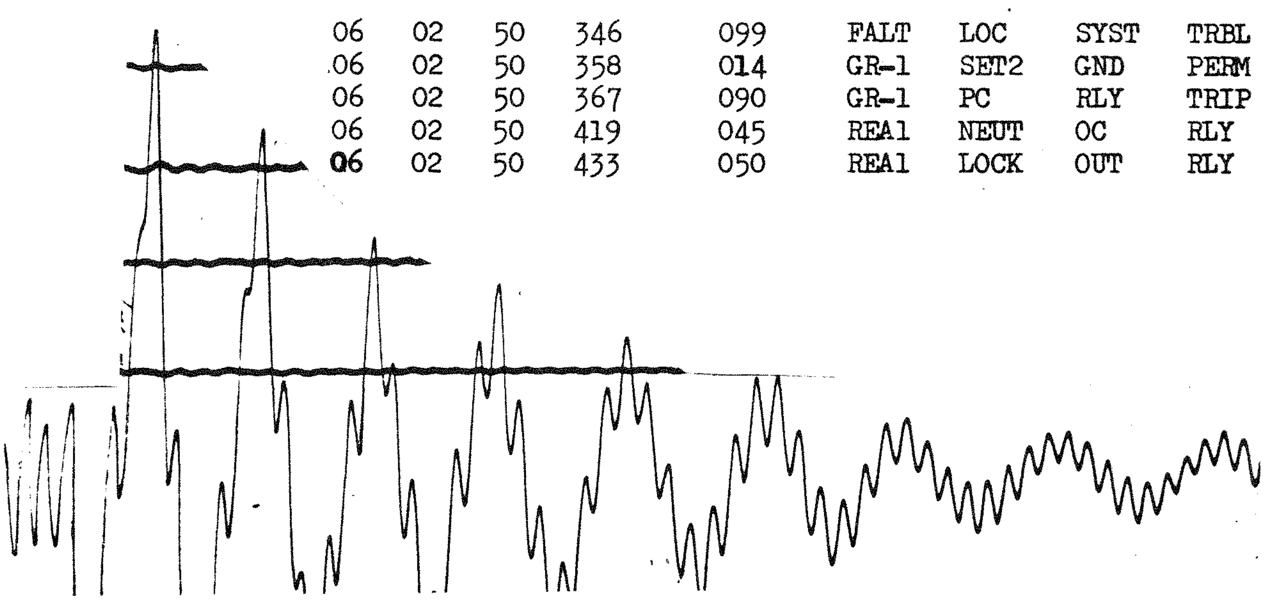


Figure 10. Failure of a 230 KV oil circuit breaker to interrupt on a system separation.



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06   02   50   346     099    FALT   LOC    SYST   TRBL
06   02   50   358     014    GR-1   SET2   GND    PERM
06   02   50   367     090    GR-1   PC     RLY    TRIP
06   02   50   419     045    REA1   NEUT   OC     RLY
06   02   50   433     050    REA1   LOCK   OUT    RLY
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Figure 11. Fault clearing and line reactor neutral current de-energization transient with sequential event printout.

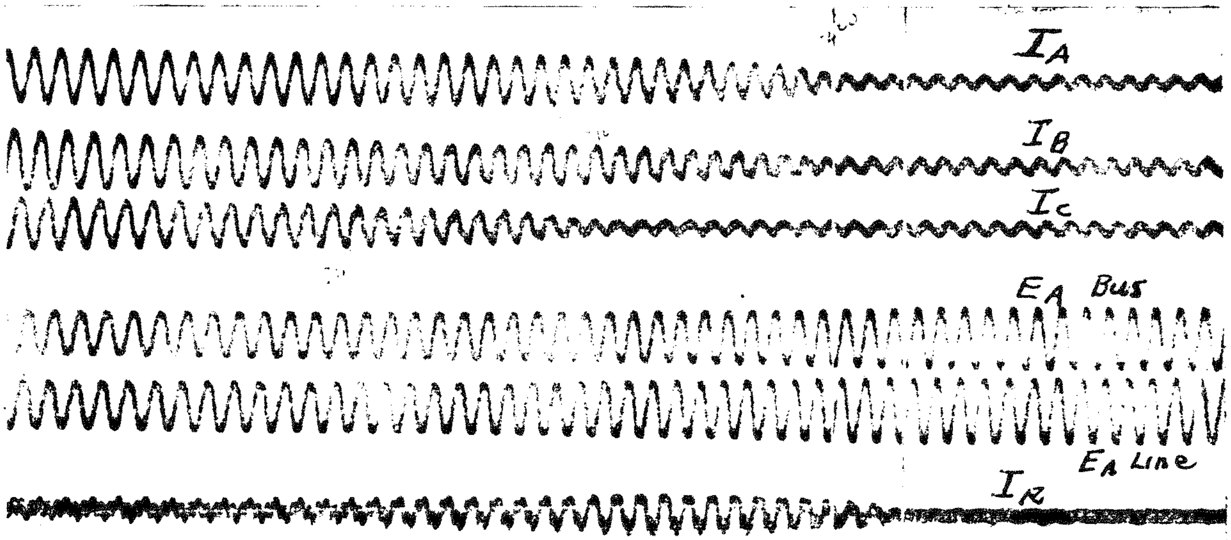
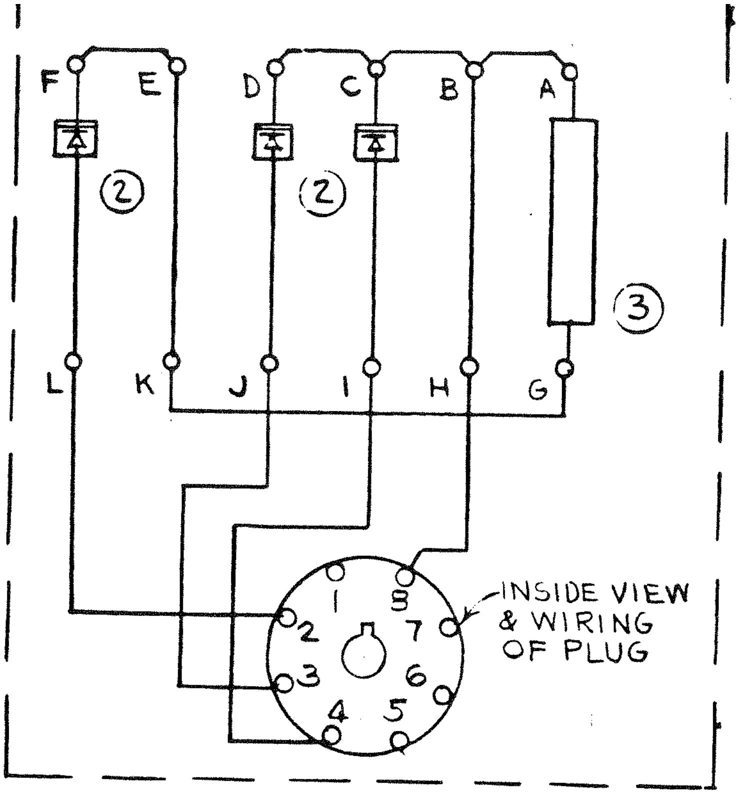
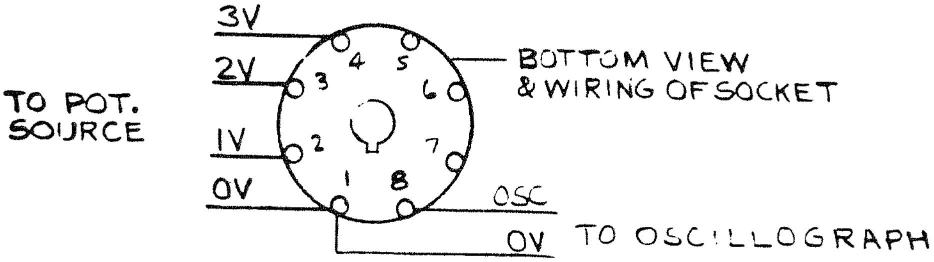


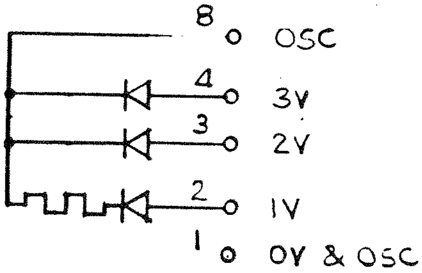
Figure 12. The fault that "went out."



WIRING DIAGRAM
PLUG-IN BOX

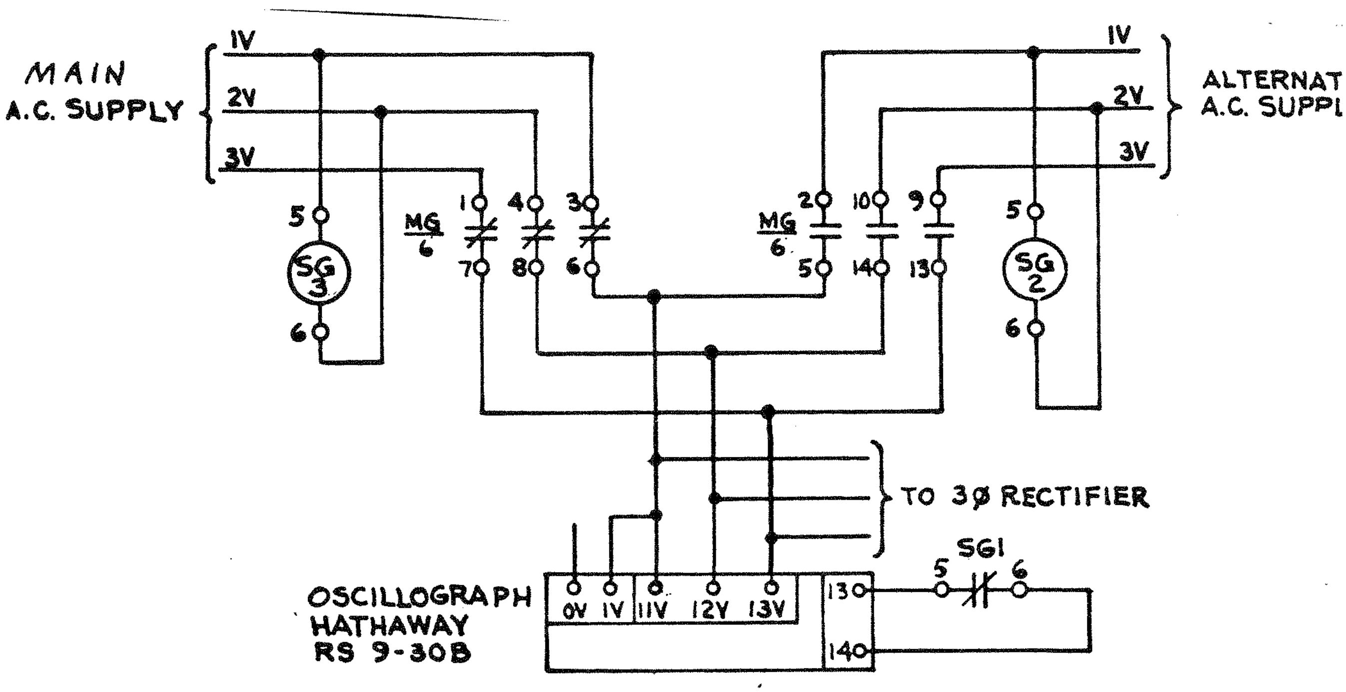


WIRING DIAGRAM
SOCKET

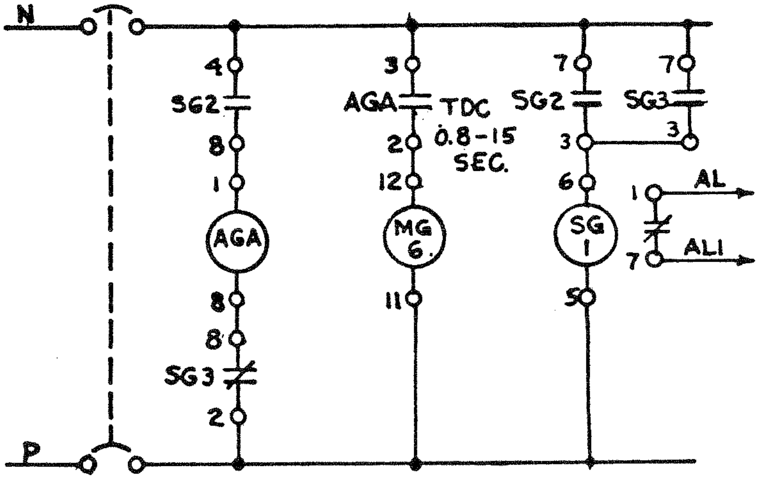


SCHEMATIC

Figure 13. Three phase potential monitor circuit to display all three phase voltages on one trace.



A. C. SCHEMATIC



D. C. SCHEMATIC

Figure 14. Schematic diagram of a-c voltage change over circuit for main/alternate supply.

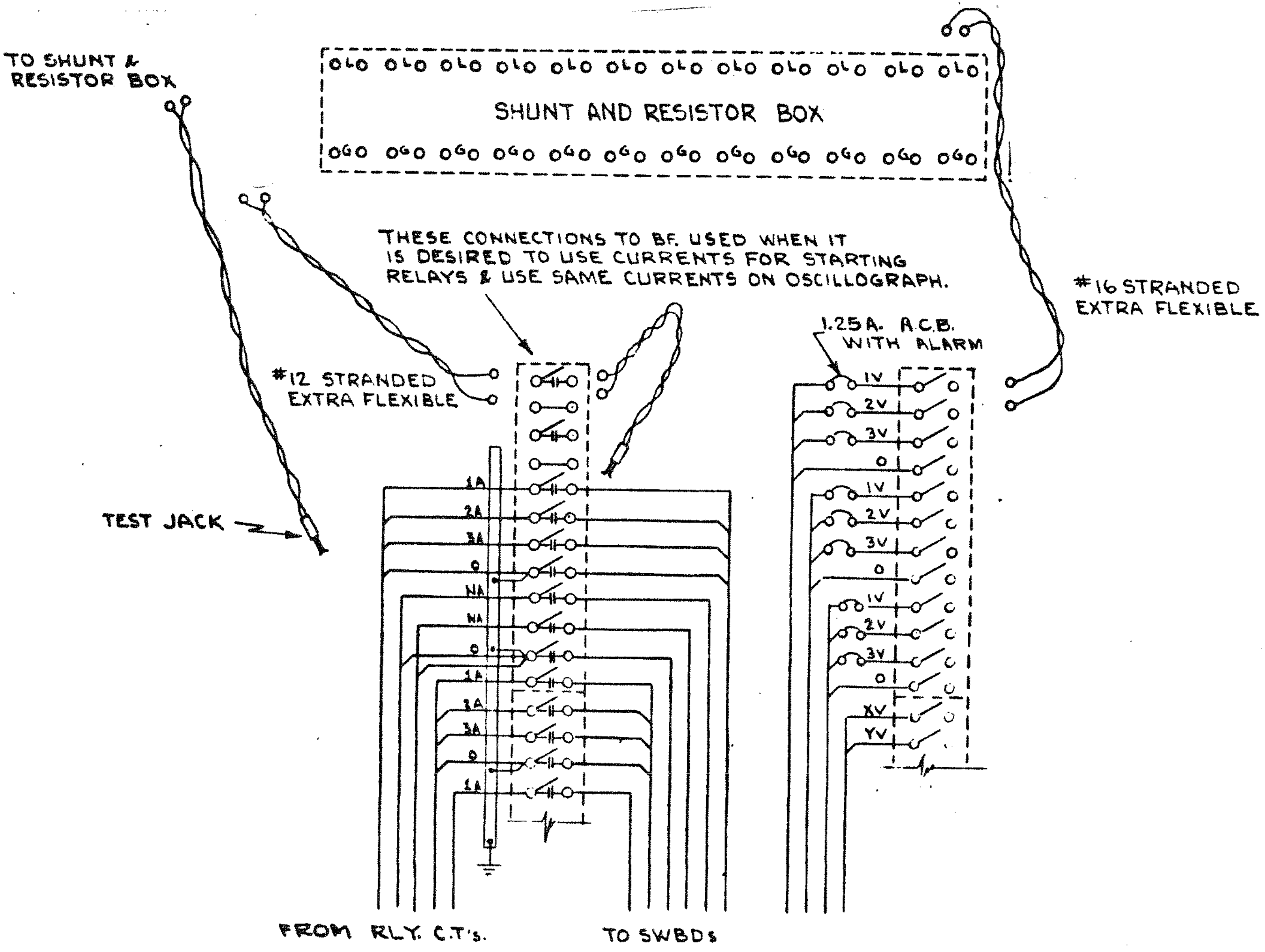


Figure 15. Wiring diagram of the potential and current circuits in an oscillograph cubicle.

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