REPORT ON OPERATION OF 60 KV TRANSMISSION SYSTEM IN THE FORT WORTH AREA 1940 - 45

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By

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REPORT ON OPERATION OF 60 KV TRANSMISSION SYSTEM

IN

THE FORT WORTH AREA

1940-45

Prepared by Texas Electric Service Company Power Department April, 1945

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REPORT ON OPERATION OF 60 KV TRANSMISSION SYSTEM IN THE FORT WORTH AREA

HISTORICAL

Continued growth of load in the Fort Worth area following the depression motivated the making of load studies in 1938-39 from which required capacity in power supply could be estimated. Load requirements were outstripping installed generating capacity in Fort Worth, and consideration was given to augmenting this supply. Thought was given to installing additional generating capacity in Fort Worth, but the development of Federal financed hydro power projects in North Texas indicated that the wiser policy to be followed was to derive the needed additional power from these hydro sources through the 60 kv transmission system.

This necessitated a stiffening of the channels for getting power from the 60 kv transmission system into Fort Worth and its environs. Briefly, this led to the following improvements:

- 1. Extensive revamping of the 60-12.5 kv substation at the Fort Worth plant in 1940
- 2. Application of carrier pilot relaying to the Fort Worth-Norwood 60 kv line in 1940
- 3. Application of distance relaying to the Fort Worth-Cleburne line in 1940
- 4. Construction in 1940-41 of a 15,000 kva 60-12.5 kv substation known as Bryan Avenue for augmenting the power supply to the distribution system in the South Side of Fort Worth
- 5. With the extension of service to the Consolidated-Vultee Aircraft plant in 1941, 60 kv sectionalizing oil circuit breakers were installed at the White Settlement Switching Station (from which the Consolidated plant is served) in 1943, and pilot relaying applied to the Fort Worth-White Settlement 60 kv line.

These improvements were all carried out in keeping with good engineering practice, but great industrial activity in the Fort Worth area resulting from war production caused loads to outstrip anything which had been contemplated. This abnormal load growth forced operating techniques to be adopted different from those conceived in the carrying out of improvements outlined above. This has led to operating difficulties which this report will review. It should be pointed out that in addition to strengthening the transmission system as already described, generating capacity in the Fort Worth area was augmented by installation of a 10,000 kw steam turbine at the Handley Plant in 1941-42. This unit has been very successful in operation and has in no way contributed to operating difficulties referred to; on the contrary, it has been most helpful.

THE PROBLEM

Reference should be made to Plate II which shows in simplified form the transmission system in the Fort Worth area. As originally conceived, each of the three transmission lines, namely, Norwood, Cleburne and Mineral Wells, was to terminate in a three-phase 60-12.5 kv transformer of 14,500 kva capacity with control oil circuit breaker on the 12.5 kv side of each transformer. In other words, each transformer was a part of its connecting line and the line terminated in a single 12.5 kv oil circuit breaker. Operation under this arrangement, however, was soon found impossible for two reasons:

- 1. The loading of lines often exceeded the capacity of terminal transformers
- 2. The high impedance of these transformers (approximately 10%) resulted in voltage conditions which were intolerable. This made it necessary to operate with 60 kv oil circuit breakers #56 and #1600 closed. This in turn meant that the Norwood and Mineral Wells lines terminated in two oil circuit breakers instead of one, and the Cleburne line in three oil circuit breakers rather than one. This called for the cross-connection of current transformers and controls between these breakers (which is indicated by Plates III and IV) and resulted in a wiring scheme which became very complex.

In brief, difficulties in operating with the existing arrangement of line terminals at the Fort Worth plant consist in the following:

- 1. Operation of relays is frequently uncertain or incorrect.
- 2. The complex switching arrangement is confusing to switchboard operators and to dispatchers.
- 3. A great amount of time and effort on the part of the relay engineers and testers is required for servicing this intricate control equipment.
- 4. Conductor burn-downs frequently occur on the Cleburne line due to three-ended line relaying.

PURPOSE OF THIS REPORT

This report is not a reflection on the judgment and skill of those who conceived the switching arrangement at the Fort Worth plant. Had it been possible to have operated the system as originally planned, it would doubtless have enjoyed a good performance record. However, as pointed out in the previous section, it has become necessary to change the plan of operation from that originally conceived.

This report simply attempts to review the performance of the 60 kv transmission system in the Fort Worth area in order that it may be evaluated in connection with proposed alterations to and extension of the 60 kv transmission system in this area following the war. It seems appropriate to do this at a time when the expenditure of considerable funds is being considered. It is hoped that this report will point the way toward overcoming some of the existing difficulties.

SCOPE OF THIS REPORT

The table of contents indicates the scope of this report. An effort has been made to include all data as to physical equipment and its arrangement and a complete log showing the operating record of the three transmission lines since the present relaying schemes were applied. The section devoted to Technical Discussion goes in more detail as to the matters discussed in this brief, while exhibits in the form of charts, wiring diagrams and drawings are, for the reader's convenience, grouped together behind the text of the report.

RELATIONSHIP BETWEEN TRANSMISSION FACILITIES AND EXPECTED LOAD TRENDS IN FORT WORTH AREA

Plate I indicates graphically the progressive dependence from year to year of the power supply for the Fort Worth area on the transmission system. Termination of the war will undoubtedly reduce the requirements for a short time, but it is the general belief the load will recover quickly in a post-war era and that the demands on the electric power supply system will be even greater than at present. Unless substantial increases are made in generating capacity, this would mean that the transmission facilities will continue to be taxed and should therefore possess a high degree of reliability. The principle that simplicity in layout works toward reliability of operation should be kept in mind.

THE OPERATING RECORD

Section 4 of this report outlines in detail the operating record of the 60 kv system in the Fort Worth area. Summaries covering the performance of each of the three transmission lines are given at the end of this section.

While some of the earlier difficulties have been overcome, the record indicates that performance is not altogether as good as it might be. Taking the year 1944 and the first three months of 1945, on the Norwood line, three operations were incorrect and one questionable, out of a total of eight. On the Cleburne line for the same period three operations were incorrect and two questionable, out of a total of nine; two cases of conductor burn-downs which can be attributed to three-ended line relaying occurred during this period. On the White Settlement or Mineral Wells line eight incorrect operations occurred and two questionable, leaving only one operation during this period that was considered clear, and this in spite of the fact that relaying on this line was extensively revamped late in 1944.

While it is true that none of these incorrect operations has caused serious impairment to service in the Fort Worth area, at the same time operation as uncertain as this is not conducive to reliable support to the Fort Worth load from the transmission system.

PRINCIPLE CAUSES OF POOR RELAYING PERFORMANCE

On the premise that good relaying is essential to reliable transmission system operation, it is well to consider the basic reasons for relatively poor performance of relays associated with the Fort Worth 60 kv network. A study of the operating record coupled with malfunctions as they occurred indicates the four following principal cuases of these difficulties:

- 1. Deviation from two-ended line operation as originally planned
- 2. Cross-connection of current transformers and control following Cause 1
- 3. The great diversity of fault currents (referred to later as distribution of fault currents)
- 4. Transformers at the Fort Worth plant in series with and part of the lines.

Each of these is discussed more fully under Section 5 of this report devoted to Technical Discussion.

CONCLUSIONS

A logical conclusion to this study would be that the performance of the 60 kv lines in the Fort Worth area is not good and that steps should be taken to improve it. It is not, however, the purpose of this report to make recommendations but to point out difficulties that may be taken into consideration on future additions so that prevailing troubles may be worked out. The following points warrant consideration:

- 1. This report together with recent load studies definitely points to the desirability of a firm 60 kv bus at Fort Worth. The same principle holds for future 60 kv buses at Forest Hills and Handley.
- 2. For clear-cut operation of lines with simple reliable control and relaying, this study points toward use of conventional two-ended lines.
- 3. The practice of paralleling current transformers connected to the high and low sides of transformer banks for the purpose of operating line relays definitely introduces a great many hazards to relay operation.
- 4. Large grounding banks, wye connected on the 60 kv side with tertiary as now in service on the Cleburne line, cause severe burning of the conductor with our present or even with possible future pilot relaying.
- 5. It seems definite that the neutrals of the Bryan and Jennings 60 kv windings should be ungrounded until such time as the Bryan and Jennings substations might be connected to Forest Hill bus through a radial 60 kv line. Incidentally, the GE Company has given approval to the operation of these banks with neutrals ungrounded, provided the neutral is insulated with the equivalent of 7 inches of oil.
- 6. Simplification of the control wiring seems highly desirable along with simplification of switching.
- 7. The conclusion might be erroneously reached that most of the difficulties with the present arrangement have been corrected or may be corrected in the near future. The basic reasons for most of these troubles do not support this view.
- 8. Finally, it seems definite that consistently correct operation of carrier current and pilot wire relays cannot be expected so long as differentially connected current transformers are used at Fort Worth on the Norwood and White Settlement lines; also that very poor performance of the Cleburne line will result so long as it remains in effect a 60 kv bus 32 miles long with transmission line exposure.

DESCRIPTION OF FORT WORTH PHYSICAL INTERCONNECTION TO 60 KV SYSTEM

CIRCUIT ARRANGEMENT

A glance at the one line diagram brings out the following:

- A. Transformers and Circuit Breakers
 - a. The Fort Worth Plant is connected at 12.5 kv to three 14,500 kva wye-wye banks (without tertiary) stepping up to 60 kv through individual oil circuit breakers for each bank.
 - b. Bank #1 is part of the Norwood line which also connects through 60 kv OCB #56 to the Cleburne line.
 - c. Bank #2 is part of the Cleburne line which also connects through 60 kv OCB #56 and #1600 to the Norwood and White Settlement lines.
 - d. Bank #3 is part of the White Settlement line which also connects to the Cleburne line through OCB #1600.
 - e. White Settlement Substation connects through the Mineral Wells line to Mineral Wells, which like Norwood and Cleburne is part of the 60 kv interconnected system.
 - f. Load on the lines is tapped at:
 - Bryan Avenue and Jennings by means of three 60-12.5 kv 7500 kva wye-wye (with tertiary) banks to the Cleburne line. Bryan Avenue low side connects normally to the 12.5 kv system through two feeders.
 - (2) American Mfg. Co. 60-12.5 kv delta-wye 5000 kva bank to the Norwood line.
 - (3) Tarrant Air Base 60-12.5 kv delta-wye 1500 kva bank to the White Settlement line.
 - (4) The Convair load consists of 2 banks rated 10,000 kva each, connected 60-4.1 kv delta-wye. These tap the White Settlement bus between 60 kv OCB #610 and #620.

B. Current transformer connections used in this setup are shown on Drawing TSD-22146 (Plate III) which shows the following:

- a. For the Norwood line:
 - 1 set GE Co. wound type K48 rated 800 to 5 ampere 15,000 volts.
 - 1 set PEM Co. wound type 300 to 5 ampere in 60 kv OCB #56.
 - 1 set balancing transformer GE Co. WSF #304081.

b. For the Cleburne line:

- 1 set GE Co. wound type K48 rated 800 to 5 ampere, 15,000 volts.
- 1 set PEM Co. 69 kv wound type OM 1, 300 to 5 ampere inside 60 kv OCB #56.
- 1 set PEM Co. bushing type inside 60 kv OCB #1600.
- 1 set balancing transformers WSF #304081.

c. For the White Settlement line:

- 1 set GE Co. wound type K-48 rated 800 to 5 ampere, 15,000 volts.
- 1 set PEM Co. 69 kv wound type OM 1, 200 to 5 ampere inside 60 kv OCB #1600.
- 1 set GE Co. type W12 rated 20 to 5 ampere 4500 volt.

These latter current transformers are used for changing the effective ratio of the 800 to 5 ampere current transformers to 1000 to 5 ampere.

LINES

A. Norwood 60 kv

6 conductors #1, 3 strand copper (prevailing) on steel towers approximately 26.7 miles total length from Fort Worth to Norwood.

B. Cleburne 60 kv

6 conductors #1, 3 strand copper (prevailing) on steel towers approximately 31.88 miles in length between Fort Worth and Cleburne. A 3 mile section of this line has insulated wire.

C. White Settlement 60 kv

Wood pole line 4/0 ACSR 5.28 miles Wood pole line 2/0 ACSR 3.85 miles

Total length

9.13 miles from Fort Worth to White Settlement.

CONTROL

A study of wiring diagram (GE Co. Drawings No. TT-6101098 and KK-6173981 and our Drawing TSE-22399 not included in this report due to their bulkiness) will indicate far more than the usual complications for control wiring. These complications are required in order to control two or more breakers per line terminal for manual and automatic switching. Control buttons for switches on a particular line may be on different panels, the relays may or may not be on the same panel and in the case of the Mineral Wells line, relays are found on separate panels.

As an indication of complexity the blocking rectifier diagram is shown on Plato IV. It shows in simplified form, the requirements for tripping all of the 5 oil circuit breakers involved in the Fort Worth connection to the high line, both for manual and automatic operation. The type PAA relay is a bellows type time delay relay furnished by the GE Co. Its purpose is to prevent sealing in the relay contacts due to back-feed through the relays. The sealing in effect originally caused locking out the circuit, burning of relay contacts, etc. before the PAA relay was installed.

In order to obtain reliable information as to relay performance it was necessary to make up a complete check-off sheet for relays for the operator to use after each tripout of a high line breaker. This is designated as Plate VII and is shown merely to indicate the problem of operating the relays and getting correct information after 60 kv line tripouts.

LIST OF RELAYS AND THEIR FUNCTIONS AT FORT WORTH PLANT

Cleburne Line

- 1 General Electric Type GCX distance relay.
- 3 General Electric Type IAC overcurrent relays rated 4-15 amperes with instantaneous attachments.
- 1 General Electric Type IAC overcurrent relay with instantaneous attachment.

The GCX relay was originally intended to provide one cycle tripping over approximately 76% of the distance to Cleburne, Zone 2 (tripping in approximately one second) set to reach halfway between Cleburne and Hillsboro and Zone 3 tripping in $2\frac{1}{2}$ seconds beyond this point to the Hillsboro bus. Addition of Bryan Avenue and later Jennings Avenue Substations with grounding banks had the effect of shortening this distance and also caused operation of the GCX relay for ground faults. Potential for the GCX relay was provided from potential transformers connected to the 12.5 kv side of Bank #2 with a later provision made for manual throwover to Bank #1 potentials. The IAC overcurrent relays with instantaneous attachments were originally set for approximately the same protection to the Cleburne line as the GCX relay.

The IAC ground relay provided approximately the same protection for ground faults and was the only protection for these faults.

There was also provided one Type IAC ground relay for tripping OCB #56 for ground faults in either direction.

Norwood Line

- General Electric Type GCX distance relay for use with carrier current or back-up distance relaying.
- 1 General Electric GFC relay for directional ground protection with carrier.
- 1 General Electric Type HDX fault detecting relay.
- 3 General Electric Type IAC overcurrent relays rated 4-15 amperes.
- 1 General Electric Type IAC relay rated 2-6 amperes.

The GCX, with carrier pilot and fault detection by HDX relay, provides 1 cycle tripping for internal phase faults or back up tripping of 90% of the distance to Norwood with Zone 2 reaching into the Dallas bus or well out on other lines from Norwood. Zone 2 trips in 45 cycles. Zone 3 was set at approximately 2 seconds.

The GFC relay provides 1 cycle tripping for internal ground faults with carrier.

Induction relays were set for instanteous and overcurrent back up protection.

White Settlement Line

- 2 General Electric Type IA 201 relays for phase protection rated 4-10 ampere.
- 1 General Electric Type IA 201 relay for ground protection
- 1 General Electric Type PYC instanteous relay rated 10-40 ampere
- 1 General Electric Type CPD pilot wire relay

The induction relays are used for back up protection all the way to Mineral Wells and are set for longer timing than OCB #620 relays at White Settlement.

The PYC relay is for back up protection with pilot wire relay and set to reach within 2 miles of White Settlement.

The pilot wire relay provides 1 cycle tripping for phase and ground faults between Fort Worth and White Settlement. Transferred tripping is provided through the pilot wire alarm relay for tripping OCB #610 at White Settlement when there is insufficient current from Mineral Wells to pick up the pilot wire relay at White Settlement.

3 X 4 X X X X

The PQ relay for reclosing OCB #1600, by means of sealing in, is so arranged that it will reclose OCB #1600 only when it is tripped by the relays for the line to White Settlement. Incidently, this reclosing scheme has worked out very well.

OPERATING RECORD

RELAY SYMBOLS USED IN HISTORIES OF SWITCHING PERFORMANCE

Symbol	Interpretation					
	Fort Worth 60 kv					
A, B or C AI or CI LG IG	Induction overcurrent relay for phase designated Instantaneous relay phases A or C Ground relay with light setting Ground relay with instantaneous setting					
PW AF, BF or CF GB GC	Pilot wire relay Fault detector relay for phase indicated Induction relay used as back up ground protection Ground relay for use with carrier current					
Z 1, Z 2 or Z 3	Zone designation used with distance relay Note 1: Zone designation followed by A, B or C indicates zone and phase. Example: (Z 1 A) indicates GCX relay operated on					
	Zone 1 phase A Note 2: Induction relays on Cleburne line have only one target to indicate LG or IG operation.					
	Bryan Avenue 60 kv					
IG LG	Same as above Same as above					
A, B or C	Same as above except directional to Hiline					
	White Settlement 60 kv					
PW TT DIF	Same as above - for OCB #610 Transferred tripping by pilot wire - for OCB #610 Differential ground - for OCB #610 and #620					
A, B or C LG IG	Same as above - for OCB #620 Same as above - for OCB #620 Same as above - for OCB #620					
	Norwood 60 kv					
Z 1, Z 2 or Z 3 GB	Same as above Same as above					
	<u>Cleburne 60 kv</u>					
A, B or C	Same as above					

SWITCHING DIFFICULTIES AND TROUBLES

A - Clearances for Maintenance

A study of the one line diagram (Pla te II) indicates that the Fort Worth setup is quite flexible for switching. However, with heavy load on either the Norwood or Mineral Wells line, it usually develops that voltage drop is excessive if either of the 60 kv breakers (#1600 or #56) is opened, due to the heavy IZ drop through the transformers. It has also been found that excessive voltage drop occurs to load on either of the lines, for clearances on line sections adjacent to Fort Worth during normal loaded conditions.

B - Equipment Failures

Trouble has been experienced with the operating mechanism of both 60 kv breakers which resulted in failure to open electrically. This would be a serious situation anywhere, but it was doubly so here, as the fault then appeared to be external to the other line, also the 12.5 kv bus and through the bus to the third 60 kv line. To clear the fault it was then necessary to open, manually, whatever breakers that had not opened and depend on all of the 60 kv lines to clear at the far end. (See Plate II.)

An outage of a 60 kv breaker is likely to overload a transformer bank as the load on the Norwood and Mineral Wells lines occasionally exceed the rating of one bank.

Failures occurring on the 12.5 kv leads to the yard transformer or in the 12.5 kv winding would present a very meager fault indication to the far end of the line. There is considerable exposure for this fault, but it has not occurred in four years.

Current transformer secondary circuit failures (grounds, shorts or open circuits) may cause several incorrect operations before they are suspected. The problem of locating such a fault is rendered extremely difficult by reason of its inaccessibility. (See Plate III.)

C - Emergency Conditions

Switching facilities have not ordinarily been satisfactory during system disturbances, overload conditions, etc., for protecting the load. The usual system disturbance, of serious nature, requires opening 12.5 kv breakers #172 and #224. This leaves the 60 kv load separated from the Fort Worth plant and on the transmission system. OCB #378 usually opens automatically, leaving Bryan Avenue load on the 12.5 kv system.

It has not been found practical to open any one line quickly, as this also requires opening one transformer bank leaving the Fort Worth plant tied to the system through one bank with resulting instability.

In general it has been found that the switching is over complicated and conducive to errors during the stress of system trouble.

D - Improvements and Corrective Measures

By way of explanation and in fairness to the present arrangement, an attempt is made here to list most of the corrective measures for incorrect operation due to errors, defects, lack of information, etc. The exact time of making changes was not ordinarily recorded, but dates have been fixed quite accurately in most instances.

(1) Carrier Current Relaying - Norwood Line

As originally furnished, the GCX relay would trip on inadvertent loss of voltage regardless of whether current was in excess of ordinary load current. This was soon corrected by installing (inside the GCX relay) "PHC" units, furnished by GE Company about January 1, 1941.

Considerable trouble was experienced with the original carrier equipment, due principally to the incorrect use of the Type 807 vacuum tubes as originally used in the carrier current transmitter. To correct this trouble material was purchased, and the transmitter-receiver equipment was rewired complete to use ordinary radio receiver type tubes and to be like the Leon carrier current equipment. This job was completed about the middle of 1942 and resulted in eliminating practically all troubles with the carrier channel. Previous to this time the carrier channel would go in trouble on an average of about every three weeks.

The original settings for distance relays were calculated in 1941 by Mr. A. R. Van Warrington of the GE Company, who was present at Fort Worth and Norwood and before Bryan Avenue was placed in service. These settings seemed to be good as checked by normal operation and also by some short circuit tests at Fort Worth. However, at a later date load was added to the Cleburne line at Bryan Avenue and Jennings. Since these fairly large banks are 60 kv grounded nuetral and have tertiary windings, they cause ground faults on the Cleburne line to appear as phase-to-phase faults in Zone 3, both at Fort Worth and Norwood. Originally it had not been necessary to grade Zone 3 timing between theses relays, as Zone 3 did not overlap. It so happened that timing on the GCX relay at Norwood was faster than the GCX relay on the Cleburne line at Fort Worth. The result was that the Norwood breakers would occasionally trip ahead of or with the Cleburne line breakers.

Voltage for GCX relays is furnished by potential transformers located between the 12.5 kv bank breaker and the bank. This means that to take out of service either Bank #1 or #2 would remove potential from the GCX relay on one line with resultant incorrect operation for faults. This defect was corrected in 1942 by installing a throwover switch for selecting voltage for both sets of relays from either source, along with potential lights to show that the GCX relays have potential at all times. This is a compromise to the extent that potential for Cleburne GCX is furnished from the Bank #1 potentials, which are subject to the same outage as the Norwood line. Transformer drop compensators for correcting 12.5 kv potential to 60 kv potential were not furnished by the GE Company. So far, the additional complication and expense have not been considered worthwhile.

(2) Distance and Back-Up Relaying - Cleburne Line

The remarks made above for the Norwood line GCX relay apply to the Cleburne GCX relay. The original GE Company drawings had numerous errors for ground relay connections. All of these with the exception of one was cleared up at the time of installation. This one was only detected recently. It has the effect of doubling the setting of one back-up ground relay.

Blocking rectifier feed back trouble developed soon after we started tripping three breakers to clear the Cleburne line from Fort Worth. This was soon corrected by use of an instantaneous relay for bypassing the protective relay contacts. The relay has time delay reset by use of bellows and prevents protective relays sealing in due to back feed.

Bell alarm troubles developed due to the great diversity of trip currents depending on which breaker is tripped and how many breakers are required to trip. No provision was made by the GE Company for bell alarm on the back-up relays. This was first corrected by using a series type HG relay with very low pickup value. This, however, in addition to targets and seal-in relay gave too much drop in series with trip coils. The problem was finally solved by using the sealing relay only for this purpose with fairly satisfactory results.

To clear the Bryan Avenue 12.5 kv breaker for 60 kv faults on the Cleburne line was a problem from the start. The GE Company made no provision for detecting 60 kv ground faults other than phase relays on the 12.5 kv side. One of the overcurrent relays for 12.5 kv phase fault protection was rewired for ground fault detection. However, this proved unsatisfactory due to fault current distribution; so 60 kv neutral current transformers were furnished by the GE Company along with a ground relay. These were installed early in 1944 and have resulted in much better clearing of 60 kv ground faults from the Bryan Avenue 12.5 kv source.

(3) White Settlement Line Relay

Phasing out the Fort Worth-White Settlement line for proper connection of the relays in August, 1943, proved to be rather difficult for various reasons. Due to the heavy load fed from this station (Consolidated Aircraft) and also an intermediate load at Tarrant Air Base, it was not possible to clear the line. Indirect methods of checking were used. To add to the confusion one relay was later found with phases reversed internally between the terminal black and the relay element. The result of the above was incorrect installation and some incorrect operations during the first month. These mistakes were found and cleared up, but some incorrect operations continued even after that.

- 5 -

In July, 1944, Mr. R. E. Cordray from the relay section of the GE Company at Philadelphia came by Fort Worth to discuss pilot wire relay operation. His conclusion was that the principal difficulty was in the use of a balancing transformer between the 12.5 kv and 60 kv current transformers. (See Plate XII.) This balancing transformer was not designed to carry the burden of the pilot wire relay for ground faults. His recommendation was that the balancing transformers be eliminated by the use of some auxiliary transformers connected in the secondary of the 12.5 kv current transformers for changing the effective ratio to 1000/5 for 12.5 kv current transformer. For more sensitive performance, the 60 kv current transformers were changed from 250 to 200 amperes in OCB #1600, #610 and #620, even though this does overload some current transformers slightly. He also recommended the addition of transfer tripping so that the Fort Worth pilot wire relay would trip the White Settlement breaker over the pilot wires for minimum faults close in to Fort Worth.

It was necessary to make relay changes in the factory; therefore one of the relays was returned to the factory where it was kept for some four months for making the changes.

The pilot wire relays were placed in service again in January, 1945, with settings which were calculated and seemed correct. However, soon after that there were some two or three incorrect operations. In reviewing the setting, it was found that literature on the relay indicated that the particular combination of taps selected was not recommended.

Accordingly, in March, 1945, other taps that seemed satisfactory for the particular condition were selected. These do not conflict with GE instructions. Although the summation does not indicate good performance, it is the opinion now that these relays are giving fairly good service for the following reasons:

- (1) Most of the through faults are being cleared by the proper relays external to this line
- (2) Internal faults have been cleared properly
- (3) Out-of-step block was demonstrated when the relays rode through a case of instability.

Staged tests should, no doubt, be made to determine causes of remaining incorrect operations. These would, perhaps, determine some defects in the arrangement or equipment other than the principal difficulty with the Fort Worth switching arrangement. HISTORY OF SWITCHING PERFORMANCE FORT WORTH-NORWOOD 60 KV LINE

January 1st, 1941 to April 1st, 1945

Time and Length of Interruption to Line - Switches which Tripped

Comments

- 1941 -

May 4 7:59 PM - No interruption

OCB #56, #172 (GCAFHG) at Ft Worth #662 at Norwood. (#662 and #172 reclosed successfully) Correct operation. Flashover on Hurst transformer blew 60 Kv fuses at Hurst. Relays operated before fuses cleared.

May 20 4:27 - No interruption

#56 (LGAF) #172(AF) at Ft.Worth #662(GC) at Norwood. (#662 and #172 reclosed successfully)

May 22 1:30 PM - 7 Minutes

#56 (C) and #24 (C) at Ft. Worth #662 (23) Norwood; #662 reclosed and tripped before CCB #378 was opened by hand.

June 11 7:02 AM - No interruption

#56 and #172 (GC) at Ft Worth #662 (AFGC) at Norwood (#172 and #662 reclosed successfully.

Aug. 12 3:45 - No interruption

#56 #172 (GCA) at Ft Worth #662 (FCAF) at Norwood (#172 and #662 reclosed successfully)

Oct. 1 11:21 AM - No interruption

#56 (HG) #172 and #56 (GCAF) at Ft Worth, #662 (GC) at Norwood (#172 and #662 reclosed successfully.) Staged test at Bryan Avenue on 60 Kv Ft Worth-Cle burne line. Fault would not clear with reasonable setting of relays on OCB #378. Cleared by hand after #662 tripped.

Correct operation.

Correct operation.

Correct operation.

Correct operation.

Comments

- 1942 -

April 20 2:32 AM - No interruption

#56 (CIG) #1600 (CIA) #124 (CIG) at Ft Worth #378 at Bryan #40 at Cleburne #662 (CZ3) at Norwood (OCB #662 reclosed immediately)

April 23 3:11 PM - No interruption

#56 (HG) #172 (ZICF) at Ft Worth and #662 (BFGC)(#172 and #662 reclosed successfully)

June 15 2:26 AM - No interruption

#56 & #172 (GC-LG) at Ft Worth #662 (AFGC) at Norwood (#172 and #662 reclosed successfully)

July 4 6:12 AM - 1 Minute

#56 and #172 (AFGC) at Ft Worth #662 (?) at Norwood #662 and #172 closed automatically and tripped)

Sept 17 8:01 PM - 4 Minutes

#172 and #56 (BFGC) at Ft Worth #662 (NF) at Norwood (OCB #662 reclosed and tripped)

Oct. 15 3:37 AM - No interruption

#172 and #56 (GC) at Ft. Worth #662 (AF) (#172 and #662 reclosed successfully)

Oct 16 12:44 PM - No interruption

#172 and #56 (AFBF-GC) at Ft Worth #662 (B-AI)(#662 and #172 reclosed successfully) Incorrect operation of Norwood GCX relay. Insulators shattered at Tower 449 disabling the Cleburne line. Mineral Wells line open 2 minutes while #2 bank was being placed in service.

Correct operation for internal fault.

Correct operation for internal fault.

Apparently correct operation for multistroke of lightning.

Operation was apparently correct for fault which did not clear before the line was recharged. Closing coil burned up due to mechanical trouble. Buzzard found on line.

Correct operation for internal fault.

Correct operation for internal fault.

Nov. 4 7:53 AM - No interruption

#56 and #172 (NF) at Ft Worth #662 (B-ZI) at Norwood (#662 and #172 reclosed successfully)

Correct operation for internal fault.

Comments

- 1943 -

May 27 9:37 AM - No interruption

#56 and #172 (GC) at Ft Worth #662 (AFGC) at Norwood #202 at Possum Kingdom (#662 and #172 reclosed successfully)

June 29 9:32 AM - No interruption

#1600 and #56 (CHG) at Ft Worth #662 (AFGC) at Norwood (#662 reclosed successfully)

Sept 3 5:20 PM - 1 Minute

#56 and #172 (GC) at Ft Worth #680 at Norwood and #948 at Denton. apparently incorrectly.

#202 at Possum Kingdom tripped

Apparently incorrect operation of OCB #662 for fault on Cleburne line.

Incorrect operation of Fort Worth breakers. Apparently due to failure of Norwood carrier to block Ft Worth relays.

Sept 4 6:34 AM - No interruption

#662 at Norwood opened and reclosed automatically.

This breaker tripped incorrectly when OCB #56 at Ft. Worth was closed charging into a fault on Cleburne line.

Sept 4 10:42 AM - No interruption

#1600, #56 and #224 (C-IAC) at Fort Worth, #610 (PW) at White Settlement, #2190 (G) at Mineral Wells, #662 (23) at Norwood Apparently incorrect. Incorrect operation of #662 at Norwood when Air Switch #69 was closed charging bad string of insulators on Cleburne line. - 10 -

Time and Length of Interruption to Line - Switches which Tripped

Comments

- 1944 -

April 29 12:50 PM - 9 Minutes

#56 and #172 (AF-BF-CF-ZI-BC) at Ft. Worth, #662 (AF-BF-CF-Z3) at Norwood, #977 at Payne, #1120 at Royse, #40 at Cleburne, #1300 (A) at Decatur, #948 at Denton, #1170 at Oran, #203 at Possum Kingdom and #378 at Bryan Avenue.

May 24 11:14 PM - No interruption

#56-1600 (C&A) at Ft. Worth, #378 at Bryan Avenue, #40 at Cleburne and #662 (23) at Norwood.

May 24 11:15 PM - No interruption

#662 (23) tripped when #56 charged into fault on Cleburne line.

Aug. 17 3:32 PM - 36 Minutes

#172 and #56 (AFCFZIABC) at Ft. Worth, #1300 at Decatur, #1150 (BC) Wichita Falls, #662 (AFBFCFZ3ABC) Norwood, #40 at Cleburne, #166 at Hillsboro, #378 at Bryan.

Sept. 5 1:47 PM - No interruption

#172 and #56 (CF-ZI-BC) at Fort Worth and #662 (F-ABC) at Norwood (172 and 662 closed automatically.) This is correct performance of relays as we do not have out=of-step blocking.

Apparently incorrect operation of #662 at Norwood for permanent (?) fault on Cleburne line.

Apparently incorrect operation of #662 at Norwood for permanent fault on Cleburne line.

System shutdown.

Correct operation for fault on Norwood line.

Comments

- 1945 -

Jan. 16 3:42 AM - 8 Hr. 8 Minutes

#224 and #1600 (IG), #56 and #172 (AG-IG-GC) at Ft Worth #662 at Norwood and #378 at Bryan Avenue tripped when "C" phase of the south 60 kv line broke in two between Towers #654 and #655 and fell to the ground.

This story is incomplete. It seems evident that OCB #1600 and #224 tripped when OCB #56 was tried one time as it would not have tripped on LG with the original surge. Even so this operation is incorrect for the Mineral Wells line but correct for Norwood line.

Feb. 27 9:50 AM - 1 Minute

#172 and #56 at Fort Worth, #662 (ZIB) at Norwood, #2190 (BC) at Mineral Wells, #40 at Cleburne and #378 at Bryan (#172 and #662 reclosed automatically but tripped)

March 29 8:48 AM - 9 Minutes

#1600 and #56 (Z3) at Fort Worth #662 (ZIZ3) at Norwood, #2190 at Mineral Wells and #40 at Cleburne. Operation of relays for this line is probably correct as there was ice on the line at this time. Cleburne and Mineral Wells opened up on instability.

Incorrect operation of OCB #662 at Norwood caused Fort Worth plant to sink on overload, tripping at Cleburne and Mineral Wells.

HISTORY OF SWITCHING PERFORMANCE FORT WORTH-CLEBURNE 60 KV LINE

Time and Length of Interruption to Line - Switches which Tripped

Comments

- 1941 -

Jan. 14 3:32 AM - 1 Minute

#56 (LG), #124 (LG), #1600 (AHG) at Fort Worth This evidently was an incorrect operation but we do not know where the fault was, (OCB #56 and #124 probably should not have tripped.)

Jan. 15 5:30 - 1 Minute

Same action

Apr. 14 6:03 AM - 1 Minute

#124 (AC), #172 and #56 (BFAFGCXZ?) at Fort Worth plant, #662 (BFCFGF) at Norwood and #40 (A₂B₂) at Cleburne.

Apr. 17 6:06 PM - 3 Hrs. 43 Min.

#56(B), #124(B) at Fort Worth, #40 at Cleburne, #2190 at Cleburne. Ditto.

Evidently incorrect. Operation of CCB #40 at Cleburne seems questionable.

Relay operation correct. OCB #1600 had trouble in the operator and refused to open the breaker. Cleburne line was out for repairs 3 hours 43 minutes.

Apr. 25 1:34 PM - 1 Minute

OCB #56 and #124 at Fort Worth

Staged test and line cleared correctly as radial feeder out of Fort Worth plant.

Apr. 25 5:10 PM - 3 Minutes

Ditto

Ditto.

May 2 8:40 AM - 7 Minutes

OCB #378 at Bryan Avenue

May 22

June 2 12:28 AM - 1 Hr. 20 Min.

June 18 4:47 AM - 5 Minutes #56, #124, #1600 (A-HG-IHG)

July 4 7:54 - 8:27 AM - 9 Min.

OCB #378 tripped four times

July 8 11:35 AM - 2 Minutes

#56(HG), #124(HG), #1600(AHG), #2190(G), #1600 closed automatically and tripped.

July 11 7:44 AM - 1 Minute

#40 at Cleburne, #166(C) and #790 at Hillsboro. OCB #378 at Bryan Avenue tripped incorrectly for system swing caused by trouble in Leon area. Momentary outage of transformer and slightly low voltage.

Staged tests at Bryan Avenue cleared as radial feeder OK from Fort Worth but would not clear from Bryan Avenue with equipment, provided by G.E. Co. at that time.

OCB #378 at Bryan Avenue tripped by lightning and was open for 1 hour and 20 minutes due to signal trouble.

OCB #2200 at Mineral Wells was open at this time. We have no information as to where the fault was.

There were no surges. Operation seems questionable.

The trouble may have been on the Cleburne line or the Mineral Wells line. We do not know when OCB #2190 opened. Operation is incorrect but we do not know which performance was wrong.

OCB #790 apparently should not have operated.

Comments

July 23 9:40 PM - 54 Minutes

OCB #378(A) at Bryan Avenue.

Aug. 12 5:03 PM - 18 Minutes

#124(HG), #56(HG), #172(GC), #662, #1600 HGBI

Comments

No cause known (perhaps incorrect.)

This separated Fort Worth from the 60 kv system but it is difficult to isolate the faulty operation now (1945).

Aug. 21 10:34 AM - 4 Hrs. 11 Min.

#56 (BZIB), #124, #1600 at Fort Worth, #40 at Cleburne, #378 at Bryan Avenue. Two conductors broke or burned down near Fort Worth. OCB #1600 was reclosed manually on this trouble resulting in 6 minutes interruptions to the Mineral Wells line as OCB #2190 at Mineral Wells tripped.

Aug. 24 1:39 AM - 1 minute

OCB #56(CI)(CI), #124(ZIBC)(ZIB), #1600(CI)(CI) at Fort Worth plant, #378 at Bryan, #40 at Cleburne.

Aug. 24 1:56 AM - 1 Minute

Same action

Sept. 22 6:01 AM - 2 Minutes

#56(HG), #124 and #1600 HGBI, #1600 closed automatically and tripped. Apparently correct operation for fault on Cleburne line.

Ditto.

OCB #2190 was open at this time. It is assumed that the fault was on the Mineral Wells line. If so, OCB #56 and #124 should not have tripped.

Comments

- 1942 -

Jan. 17 7:03 AM - 1 Minute

#56 (H&LG), #124(H&LG), #1600 HG at Ft. Worth and #2100(G) at Mineral Wells.

Jan. 30 2:40 AM - 1 Minute

#56 (BC), #124 (BC), #1600 (BC) at Ft. Worth #378 at Bryan, #40 at Cleburne, #662Z3 at Norwood.

Feb. 13. 8:26 AM - 1 Minute

#56 HG, #124 HG, #1600 (IHHG) at Ft. Worth, #2190 G at Mineral Wells and #948 (G) at Denton.

Feb. 15 4:36 PM - 1 Minute

#1600, #56 and #124 (Z₁B) at Fort Worth, #40 at Cleburne and #378 at Bryan.

Feb. 20 2:32 AM - 1 Hr. 41 Min.

#56 (IG), #124(CIG), #1600(CIA) at Fort Worth plant, #378 at Bryan Avenue, #662 (CZ3), #662 reclosed automatically, #124 tried and tripped #3 Bank on at 2:34 AM. Insulators found shattered on both east and west lines at Tower 449.

April 27 11:17 PM - 1 Minute

#56 HG, #124 (?), #1600 (HGBI) at Fort Worth, #2190 (G). This seems to be an incorrect operation of OCB #124 and #56.

This appears to be a fault on the Cleburne line which is a Zone 3 fault on the Norwood distance relay. Operation of OCB #662 (23) is incorrect.

This appears to be a fault on the Mineral Wells line with the Cleburne line clearing incorrectly due to current transformers characteristic of paralleled CT secondaries.

Apparently correct.

Incorrect operation of OCB #662 at Norwood which sees faults on Cleburne line as Zone 3. It trips on Zone 3 ahead of our ground relays.

Incorrect operation of #56 and #124 at Fort Worth due probably to CT characteristics and balancing transformers.

Comments

Normal operation changed to No. 3 Bank in service in place of No. 2 Bank at Fort Worth Plant.

May 18 12:36 AM - 22 Minutes

#56 and #1600 (Ph AZ1) at Fort Worth, #378 at Bryan, #40 at Cleburne, #56 tried and tripped. (conductor burned down.)

May 18 4:20 PM - 4 Minutes

#56 (LHG-ZIB), #224 and #1600 (IEHG) at Fort Worth, #898(C) at Denton.

June 5 12:55 - 1 Minute

#224 and #1600 IAIBIC at Ft. Worth, #898 (B) at Denton tripped OCB #1600 reclosed correctly placing fault on 60 kv Ft. Worth-Norwood line and #56 tripped.

June 13 7:21 AM - 1 Hr. 47 Min.

#1600 and #56 (BLG), #378 at Bryan, #166(G2) and #790 (G2) at Hillsboro.

June 14 5:32 AM - 1 Minute

#166 (IA, #168(IB)

July 8 5:41 PM - 1 Hr. 43 Min.

#56 and #1600 (A) at Ft. Worth, #378 at Bryan, #166(A2-B2) at Hillsboro. Relay action correct. However, arc probably held on thru OCB #378 long enough to burn down the conductor.

Incorrect operation of #56 and #898.

Operation was correct to clear fault on Mineral Wells line but change in fault current (after OCB #224 cleared) put heavy current thru OCB #56 and it tripped incorrectly.

Incorrect operation of OCB #790 at Hillsboro otherwise correct performance (OCB #40 at Cleburne out of service.)

At this time the breaker at Cleburne was bypassed. The arc was evidently near Hillsboro and went out of its own accord.

Correct operation at our end. Fault was on 12.5 kv feeder to Steel Mill from Jennings; and oil circuit breaker contacts stuck due to weak opening spring and wedging action of contacts.

July 26 5:42 AM - 1 Minute

#56(LG(LG), #1600 and #224(HGIB) (HGIB), 1600 closed automatically but tripped. This operation is questionable and undoubtedly incorrect but we have no way of knowing where the fault was.

Aug. 11 4:14 AM - 1 Minute

#56 and #1600 (C) at Ft. Worth

Probably correct operation as the arc was apparently blown out by the wind when these breakers opened.

Correct operation (Insulator

disconnect at Fort Worth Plant).

flashed over on line side

Nov. 27 2:40 PM - 2 Hrs. 42 Min.

#56 and #1600 (BHG) at Ft. Worth, #378 at Bryan Avenue, #40 at Cleburne.

Nov.	15	1:37	PM	-	1	Minute
		1:44	PM			11
		2:01	PM			11
		3:35	PM			11

#56 (?), #1600 and #224(HGBI) (HG-BI)(HGBI(HGBI) at Ft. Worth, #2190(G)(A)(A)(A) at Mineral Wells, #40 at Cleburne. #378 at Bryan Avenue found open at 5:04 and closed. This action evidently caused some unnecessary interruptions to service. The story seems to be incomplete but it appears

that OCB #56 and #40 should not

have tripped.

- 1943 -

June 4 11:51 PM - 1 Minute

#56 and #1600 (ZIBCA) at Fort Worth and #378 at Bryan Avenue.

June 29 9:32 AM - 1 Minute

#56 (C-HG) and #1600 at Fort Worth and #662 at Norwood. Correct operation assumed.

This operation seems questionable. The log does not indicate targets for OCB #1600.

Comments

Sept. 4 6:33 AM - 24 Minutes

#56 and #1600 (ZI PhB, 6) at Ft. Worth #40 at Cleburne, #378 at Bryan Avenue, Arlington Heights #1 (NF) and Rolling Mill #2 (IA) at Fort Worth 12.5 Kv bus.

Sept. 4 10:42 AM - 41 Minutes

#1600 and #56, and #224(C-IAC) Ft. Worth, 610 PW at White Settlement, #2190(G) at Mineral Wells and #662 (Z3) at Norwood tripped when Switch 69 at Fort Worth was closed and a string of insulators flashed over on Tower 631 of the Cleburne line.

Oct. 1 11:46 AM - 1 Minute

#56, #1600 (NF) at Fort Worth and #2190 at Mineral Wells.

- 1944 -

Feb. 25 12:16 AM - 1 Minute

#1600 and #56 (Z3) at Fort Worth, #378 at Bryan, #40 at Cleburne.

February 27 3:38 PM - 2 Hrs. 45 Min.

#1600 and #56 (Z1-B-IB-B) at Ft. Worth, #378 at Bryan and #40 at Cleburne.

May 3, 10:39 AM - 1 Minute

#40 at Cleburne, #378 at Bryan.

One conductor burned in two on Cleburne 60 kv line between Towers 618 and 619. Unnecessar trip of 12.5 kv feeders at Fort Worth.

From targets reported it seems difficult to analyze performance. OCB #224 does not trip with same relays that trip #56. Net result was incorrect performance on all three lines.

This seems to be an incorrect operation of OCB #56 however no targets were reported.

Correct operation.

Correct operation. However 2 phases burned down between Towers 608 and 609.

These breakers tripped for trouble on T. P. & L. system.

Comments

May 24 11:14 PM - 1 Hr. 7 Min.

#56, #1600 (C&A) at Fort Worth, #378 at Bryan Avenue, #40 at Cleburne, #662 (Z3) at Norwood (#662 reclosed automatically).

July 12 5:51 PM - 1 Minute

#1600 and #56(C) at Ft. Worth, #378 at Bryan Avenue and #40 at Cleburne.

Aug. 17 3:32 PM - 26 Minutes

#172 and #56 (AF-CF-ZI-ABC), #224
(?) at Ft. Worth (#662 AFBF-CFZ3ABC) at Norwood, #40 at Cleburne,
#378 at Bryan Avenue, #1300 at
Decatur, #1150 at Wichita Falls
(#662 at Norwood and #172 at Ft Worth
reclosed but tripped.)

(Dester also

- 1945 -

Feb. 27 9:50 AM - 1 Minute

#172, #56 (AFBF) at Ft. Worth, #662 (ZIB) at Norwood, #2190 (BC) at Mineral Wells, #40 at Cleburne and #378 at Bryan (#172 and #662 closed automatically and tripped.)

May 19 6:50 AM - 1 Minute

#56 and #1600 (A) at Ft. Worth, #378 at Bryan Avenue and #40 at Cleburne.

Mar. 31 11:17 PM - 1 Minute

#1600, #56 (NF) at Ft. Worth, #2190 (AG) at Mineral Wells.

Comments

(Interruption to Jennings Sub.)

One conductor burned down near Burleson.

Correct operation.

60 kv system shut down due to lines over the system but away from Fort Worth relaying out, overloading the Ft. Worth plant operation of relays questionable.

Load was heavy in Ft. Worth area. Outage due to loss of Norwood line. Operation of relays probably correct.

Correct operation.

OCB #1600 and #56 evidently tripped on light ground relay by residual current from Bryan Ave. and Jennings 60 kv transformers.

HISTORY OF PILOT WIRE RELAY PERFORMANCE FORT WORTH TO WHITE SETTLEMENT AUGUST 21, 1943, to APRIL 1, 1945

- 20 -

September 4, 1943 - 10:10 a.m.

Lightning tripped oil circuit breaker #610 at White Settlement, #1600 and #224 at Fort Worth. #610 and #1600 closed automatically. Oscillograph indicated three phase fault at bypass switch on line side of #610. (Correct operation)

September 4, 1943 - 10:44 a.m.

Oil circuit breaker #1600, #56 and #224 (C, Inst. A, and Inst. C) Fort Worth, #610 (PW) White Settlement, #2190 (G) at Mineral Wells and #662 (Z3) Norwood, tripped when air switch #69 closed in on bad string of insulators close in on Cleburne line. (Apparent incorrect operation of OCB #610 (PW), Fort Worth current transformers saturation, may be explanation.)

September 8, 1943 - 3:23 p.m.

Oil circuit breaker #610 (PW) tripped while workman was patching corrugated roofing on building which caused slight jar through steel framework and pipe supports, to switchboard and relays. (Incorrect operation)

September 9, 1943 - 9:24 a.m.

Oil circuit breaker #610 (PW) tripped when Weston portable 150 volt AC voltmeter was connected across leased pair, used as pilot wires, at White Settlement. (Incorrect operation)

October 1, 1943 - 5:43 p.m.

Oil circuit breaker #610 (PW) tripped when bypass switch #612 was opened and one phase dragged out. (Undesirable but correct operation)

October 18, 1943 - 10:46 a.m.

Oil circuit breaker #610 (PW) at White Settlement and #203 at Possum Kingdom tripped. (Apparently incorrect)

November 12, 1943

Oil circuit breaker #610 trip counter showed two tripouts. (No explanation)

April 20, 1944 - 10:13 p.m.

Lightning tripped oil circuit breakers #1600-224 (IACPW) and #662 (Z3) at Norwood; #1600 and #662 reclosed, but #1600 tripped again, apparently on PW. (Incorrect operation in that #610 apparently should have operated)

May 1, 1944

Target found on PW relay for oil circuit breaker #610, and #610 showed one trip which probably occurred with #620 and #2190 at 3:40 p.m. (Assumed incorrect)

May 31, 1944 - 6:13 p.m.

Oil circuit breakers #1600, #224 (PW), #56 (LG) and #2190 (G) tripped. (This did not cause an interruption but was apparently incorrect and undesirable. #2190 and #56 probably operated after #610 and #1600 tripped and reclosed.)

January 3, 1945 - 8:25 p.m.

Oil circuit breakers #2190 (BG) at Mineral Wells, #620 (IC-G) and #610 (PW) at Fort Worth tripped. #1600, #610 and #620 reclosed successfully. (Incorrect operation)

February 8, 1945 - 10:39 p.m.

Oil circuit breakers #610 and #620 (DIFF) at White Settlement tripped when a crane backed into tap line. (Correct operation)

February 20, 1945 - 9:50 a.m.

Lightning tripped oil circuit breakers #1600 and #224 (PW) at Fort Worth, #2190 (G) at Mineral Wells, #610 (PW) and #620 (G) at White Settlement. #610, #620 and #1600 reclosed successfully. (Incorrect operation)

March 11, 1945 - 4:27 p.m.

Oil circuit breakers #224 (PW) at Fort Worth, #610 (PW) at White Settlement and #2190 at Mineral Wells tripped; #610 reclosed automatically but tripped again. #1600 did not trip because tripping toggle failed to release tripping mechanism. (Incorrect operation)

March 11, 1945 - 4:55 p.m.

Oil circuit breaker #224 (PW) at Fort Worth, #610 (PW), #620 (IA-IG) at White Settlement tripped; #610 and #620 closed automatically but tripped again. Note: #1600 was open at this time to repair tripping mechanism. (Questionable)
March 29, 1945 - 5:34 p.m.

Lightning tripped #1600 and #224 (NF) at Fort Worth, #1170 at Oran, and #203 at Possum Kingdom. (Questionable)

March 30, 1945 - 12:23 a.m.

Lightning tripped #610 (PW) at White Settlement, #1600 and #224 (PW) at Fort Worth, and #2190 (A) at Mineral Wells. #1600 and #610 reclosed successfully. (Incorrect operation)

March 30, 1945 - 7:24 a.m.

Lightning tripped #610 (PW) at White Settlement, #1600 and #224 (PW) at Fort Worth, and #2190 (G) at Mineral Wells. #1600 and #610 reclosed successfully. (Incorrect operation)

Note: Between the dates of August 21, 1943, and June 1, 1944, there are recorded in the log book at White Settlement 20 tripouts of OCB #620 for faults between Mineral Wells and White Settlement. These are apparently correct operations for this section of line and prevented interruptions, either momentary or for one minute to the bomber plant. Dispatcher's logs do not show these, as supervisory control was not in service at that time.

SUMMARY OF SWITCHING PERFORMANCE

FOR 60 KV LINE FAULTS

NORWOOD LINE

									1945		Total	
	191	+1	191	42	19	+3	19	44	3 M	05.	No	• %
Correct operation	4		7		1		2		2		15	59.0
Incorrect operation	2		1		4		2		1		10	37.3
Questionable operation	0		0		0		1		0		1	3.7
Total	6		8		5		5		3		27	100.0
Conductor burned down Total momentary outage	0		0		0		0		0		0	0.0
(Automatic Reclosure)	5		6		4		3		0		18	69.3
Total momentary outage												
(1 minute each)	0		1		1		1		1		4	15.3
Total prolonged outages	1		1		0		1		2		5	19.0
Total time of prolonged												•
Outages	0	Hr.	0	Hr.	0	Hr.	0	Hr.	8	Hr.	8	Hr.
	*7	Min.	4	Min.	0	Min.	*9	Min.	17	Min.	37	Min.

*External to this line.

CLEBURNE LINE Total 1945 1941 1942 1943 1944 % 3 Mos. No. 6 32 4 1 27.2 Correct operation 1 15 97 3 12 1 27 49.0 Incorrect operation Questionable operation 3 1 1 1 13 23.8 6 19 5 Total 22 3 55 100.0 Conductor burned down or broken 2 0 1 2 0 5 9.0 Total momentary outages 7 32 33 30 54.5 (1 minute each) 14 30 25 45.5 Total prolonged outages 15 5 Total time of prolonged 8 Hr. l Hr. 4 Hr. 24 Hr. Outages 10 Hr. O Hr. 26 Min. 18 Min. 5 Min. 18 Min. O Min. 7 Min.

WHITE SETTLEMENT LINE

			1945	Tot	Total	
	1943	1944	3 Mos.	Noe	%	
Correct operation	1	0	1	2	10.5	
Incorrect operation	6	3	5	14	74.0	
Questionable operation	1	0	2	3	15.5	
Total	8	3	8	19	100.0	
Conductor burned down	0	0	0	0	0.0	
(Reclosed automatically)	5	2	6	13	69.0	
(1 minute)	3	1	1	5	26.0	
Total prolonged outages	0	0	î	1	5.0	
Total time of prolonged						
Outages	O Hr.	O Hr.	O Hr.	O Hr.		
	O Min.	0 Min.	12 Min.	12 Min.		

TECHNICAL DISCUSSION

DISTRIBUTION OF FAULT CURRENT

The following is quoted from Silent Sentinels:

"A knowledge of the conditions existing on the system during faults is necessary to provide suitable relay protection, since it is the abnornal quantities, occuring as a result of the faults, which are used to actuate the relays."

Fault at Fort Worth

A study of Plate VIII will indicate a total ground fault current of 4950 amperes for a 60 kv bus fault to ground at Fort Worth, and 4200 amperes for a 3 phase fault. It is of interest to note that Bryan and Jennings combined furnish 600 amperes residual current for this fault, and that Cleburne furnished only 72 amperes.

The significant thing about this distribution of fault currents is the heavy flow of ground faults near Fort Worth on the Cleburne line. Even though the line is cleared by fast relay action from Fort Worth and Bryan, heavy ground current (sufficient to burn the conductor down) continues to flow until OCB #40 at Cleburne trips. However, OCB #40 has very little reason for tripping in its present location. Assuming that a breaker were located on the Fort Worth side of Bryan Avenue Tap, it would see ample fault currents for fast operation, as fault currents are heavy in this section of line.

Fault at Cleburne

Similarly a fault at or near Cleburne as shown on Plate IX draws heavy residual current from Bryan Avenue and Jennings but very little from Fort Worth, indicating the need of a breaker on the south side of Bryan Avenue Tap for best fault protection.

Fault at White Settlement

A fault at White Settlement draws very heavy current through OCB #1600, which is the resultant of current through Bank #1, current from Norwood and current from the Bryan-Jennings transformers. The effect of this, or a fault closer in on the White Settlement line, is to saturate current transformer in OCB #1600. Proper allowance must be made for this as well as the heavy flow from the south to prevent OCB #56 tripping incorrectly. Incorrect tripping of OCB #378 for faults close in on this line as well as the Norwood line is considered a necessary evil. The reason for this is that Bryan and Jennings feed more fault current to the Fort Worth bus than they do to the Cleburne bus due to the greater distance to Cleburne.

Maximum and Minimum Conditions

The effect of maximum and minimum fault conditions at Fort Worth is quite interesting. It might be expected that minimum conditions exist when #0 Generator is off. As a matter of fact #0 being off only reduces fault current on the 60 kb system at Fort Worth 15%. The effect at Cleburne is neglegible.

The actual minimum condition occurs when a breaker is closed on a fault after a line trips out. This is due to the fact that it is only possible to charge with one of the two or three breakers normally connecting the line to the Fort Worth plant. Since only one breaker can be used, there will be only one transformer with consequent doubling of transformer impedance above the first fault. In addition, other lines are open so that their contribution is cut off.

The above means that the relay setting should be changed to approximately one-half before charging a line for test. Obviously, this would be impractical. The result is that relay action may be entirely different for a fault at the same location on the line as is always the case with a permanent fault.

Effect of Large Grounding Bank

Plate XI, Figure 1, shows the normal condition of ground current flowing from Bryan and Jennings with arrows showing flow also from Cleburne.

Figure 2 shows the effect on the ground current of removing the grounds from 60 kv windings

RELAY CHARACTERISTICS

It was discovered several years ago that percentage type relays were highly desirable for use even with <u>matched current transformers</u> used for differential protection of transformers. The setup at Fort Worth is similar in that current transformer secondary circuits are parallel and should not operate on through faults. In addition, three different types of current transformers are used. Relays, therefore, necessarily operate directly from the sum (or difference incorrectly) of secondary currents. Relays having characteristics suitable for ordinary line protection are used.

Pilot wire relays previde differential protection for all types of line faults in the protected section. They are dependent only on current for indication from the two ends. Due to the parallel arrangement of 12.5 kv and 60 kv current transformers with balancing transformer at Fort Worth, the amount of secondary current from Fort Worth has been decidedly variable with respect to secondary current at White Settlement for through faults. Bushing type current transformers were a wartime requirement at White Settlement. However, relay burdens at White Settlement were held to a minimum by proper selection of relays. As a result, it appears that the total relay burden there is not excessive, and current transformer performance should be good. Distance relays are in effect ohm measuring devices for measuring the reactance to the fault. This is determined by voltage drop on 2 phases and current flowing to the fault in the third phase. As pointed out above, the reactance from the Fort Worth 12.5 kv bus to the fault is greatly affected by the number of transformer banks in service.

Carrier pilot relaying at Fort Worth depends on the distance relay as described above for phase fault location and a directional ground relay, polarized by 12.5 kv residual voltage, for ground fault location on the 60 kv line.

Back-up relays are of the usual variety of induction relays with instantaneous trip attachments and have no unusual characteristics.

CURRENT TRANSFORMER CHARACTERISTICS

Plate XIII shows characteristics of the various types of current transformers used in this setup. These are for the normal burdens imposed by leads and relays at the Fort Worth plant. These curves are based on the assumption of symmetrical sine wave current. Tests made at Houston in 1938 and recent A.I.E.E. papers show conclusively that the DC component of an offset wave does saturate the core where the burden is heavy so that a current transformer puts out only a fraction of the normal secondary current during the first several cycles. Either kind of saturation may make very little difference where only one set of current transformers are used for a single line. In the present case at Fort Worth, or in any differential scheme, saturation causes incorrect performance unless corrected or else tripping delayed for serveral cycles.

The following is quoted from Mr. A. R. Van Warrington's comments:

"A fault at the bus on the Cleburne line may saturate the current transformer on the tie breaker and cause a preponderance of current in the tripping direction, if the GE (12.5 kv) current transformer in parallel with it does not also break down in ratio, and hence close the starting unit, stopping carrier and tripping both ends of the Norwood line."

Following is description of the various current transformer characteristics:

a. Bushing Type

The usual bushing type current transformer for relaying purposes has good ratio characteristics for heavy fault curronts provided the burden is kept low.

With long leads to the GCX and IA relays, the burden is in the order of 69 volt amperes at 5 amperes secondary (2.4 ohm). From the characteristic curve (Plate XIII) it may be seen that the ratio breaks down badly beyond 500% rating. This suggests trouble for close in faults. The effect is worse when Bank #2 is in service instead of Bank #3.

b. Wound Type

There are two makes of wound type current transformers:

- (1) GE Company 12.5 kv current transformers have ample cross section of iron, and the ratio holds good for both heavy burden and high over current.
- (2) PEM Co 60 kv Type OMl current transformers are mounted inside the 60 kv oil circuit breaker where the space is limited. This along with possible other consideration means that the iron core is small. At any rate its ratio begins to break down at approximately eight times normal. There are two sets of this type in OCB #56 rated 300 ampere and one set in OCB #1600 rated 200 ampere.

c. Balancing Transformers

Balancing transformers used are GE Company Catalog #K-3661843G4 with characteristic curve shown on Plate XII.

From the curve it may be seen that the transformer builds up to 42 volts with 5 amperes flowing; also that the curve has very nearly flattened out at that point. It appears that not more than approximately 45 volts would ever be impressed on any burden connected to any of its taps. The burden on the Norwood current transformers is in the order of 128 volt amperes at 5 amperes or 5.1 ohms. Dividing 45 by 5.1 gives only 8.8 amperes as a maximum secondary current to the relays which is only about 25% of the requirement for balancing off the 60 kV current for a fault close in on the Cleburne line. Evidently this action may well account for some of the incorrect operations.

Fortunately the balancing transformer on Bank #2 current transformers usually do not enter into the picture as Bank #2 is normally out of service. It is also fortunate that balancing transformers on Bank #3 were eliminated from relay operation in August of 1944 to correct pilot wire troubles due to excessive burden from the pilot wire relay for ground fault currents.

d. Interconnection of Secondaries

Problems which arise from the interconnection of current transformer secondaries increase rapidly when two or more sets are paralleled. By reference to Plate III showing current transformer connections, it may be seen that the original drawing which was made up after installation was completed, has had some six revisions. These have all been necessary to keep up with load growth and other necessary changes which have all been made after considerable thought. In fact, this particular problem has required a great amount of continuous study and engineering talent, all out of proporation to the usual relaying and switching problems arising due to current transformers.

As indicated in various parts of this report, the problems due to current transformer secondary interconnection at Fort Worth are by no means all solved at the present time.

THREE-ENDED LINE PROBLEM OF PROTECTION

The following statement seems to be borne out by theory, study and practice:

The proper action of directional overcurrent and distancetype relays for three-ended lines is much more difficult than two-ended lines because of two principal reasons:

- The relays necessarily should be set at the same value at each terminal as in any differential scheme. However, the impedances to remote terminals are unequal. This results in settings that are below load currents which, of course, is not permissible.
- (2) "Mutual impedance effects" or the effect of IZ drop of one path on the other for load and fault current entering or leaving at a tap may cause one relay to fail to "see" the fault.

Blocking type pilot schemes may be used in some cases but are not satisfactory if there is a paralleling external path.

It seems that the Westinghouse Company would recommend their type HCB pilot wire relay for short three-ended lines, provided the pilot wires are sheathed in cable and have several other provisions to insure a continuous circuit at all times. It seems also evident that paralleled current transformers as at Fort Worth would not be permissible.

Assuming that all requirements are met for proper clearing of a three-ended line for internal faults, the problem usually remains of what will be the effect on the system when a three-ended line does clear. The answer is likely to be instability where the three-ended line is between two plants located near each other like Fort Worth and Handley.

OPERATING DIFFICULTIES WITH THE FORT WORTH AREA CONNECTION TO THE TRANSMISSION SYSTEM (CONDENSED REASONS)

1. Switching is complicated and conducive to errors during system disturbances.

2. The hazard of overloading Banks #1 or #3 at Fort Worth may occur due to outage of either 60 kv breaker. All 60 kv faults on Norwood and White Settlement lines require the operation of a 12.5 kv bus room breaker which is an increased hazard.

3. Operation is not clean cut. In a great many cases of incorrect operation it has been impossible to determine the order of switch operation, manual switching done or the relays that tripped certain breakers.

4. Control wiring of trip circuits, blocking rectifiers, interlocks, balancing transformers, current transformers, polarities, etc., is so complicated that only a very few people in the organization have any degree of familiarity with it. In fact, the actual determination of correct polarity and wiring of the twelve interconnected current transformers used in the protection of the Fort Worth-Cleburne line has never been checked definitely by other than very indirect methods.

5. Current transformer characteristics are such that they do not parallel satisfactorily. This sometimes causes relays to operate incorrectly on the difference of current between two current transformers on through faults.

6. Current transformer connections are such that it is practically impossible to periodically check ratio, continuity of circuit or grounds on leads. This is regularly done on other high voltage breakers and has resulted in finding a great many defects in current transformers and their leads.

7. Residual current for operating ground relays for faults near Cleburne is meager. This is due to the effect of the heavy grounding banks at Bryan Avenue and Jennings being connected directly to this line. The Fort Worth transformers, having no tertiaries and high impedance, limit fault currents.

8. Characteristics of the GCX reactance relays for distance relaying are such that they depend on drop in 12.5 kv voltage for indication of distance to faults on the 60 kv system. Since one of these, on the Cleburne line, is graded with a similar relay at Norwood with 60 kv potentials, the grading has not been satisfactory. 9. Fault conditions of lines vary over extreme ranges. Depending on the number of line and transformer breakers that are closed at any one time, fault currents may be extremely high or low. This means that relay settings must be too near load for safe operation. In the case of a permanent fault the fault current is approximately one-half as much on the second tripout.

10. Banks #1 and #3 must normally be charged as part of the line. Settings must be arranged to prevent tripping on this heavy inrush current. In the case of pilot wire relays, a method of desensitizing was found necessary at the Fort Worth end and probably should be used at White Settlement.

CHARTS AND DRAWINGS

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Plate I

This plate shows graphically the gradual change in the Fort Worth area annual load peaks from 1938 to April 1, 1945.

The green part of the graph shows that in 1938 there was a surplus of capacity to be sold even on the peak. In 1939 the peak equalled the capacity, but since that time there has been a growing shortage even with the Handley addition in 1942. PEAK NET CONSUMED COMPOSED OF NET GENERATED AT SAME HOUR AND NET INTERCHANGE.



PLATE NO. _I

Plate II

This plate seems self-explanatory. Such details as conductor size, spacing configuration, transformer sizes and impedance, etc., are given in Section III under "Description of Physical Interconnection."



Plate III

This plate is included to show the complex interconnection of current transformers of various kinds and at different voltages.

Reference is made, at various points throughout the report, to this application of current transformers and balancing transformers. It is definitely true that current transformers have been the cause of a great amount of incorrect operation.



Plate IV

Schematic Diagram of Trip Circuits Showing Use of Blocking Rectifiers

This plate is included merely to show the complexity of wiring necessary to provide tripping of individual breakers by pull button and yet to provide multiple tripping of breakers by relays.

Troubles soon developed due to back feed resulting from a small amount of current flowing against the arrows which indicate the normal flow.

Trouble shooting is made difficult due to continuous interconnection of so many direct current circuits.

The PAA bellows type relay was provided to furnish a time delay bypass on the Cleburne relay contacts and seal in coil.

There is some lack of confidence in this whole arrangement for the following reasons: (1) No provision is made for bypassing the Norwood or Cleburne relay contacts. (2) The PAA relay is a bellows type relay. (3) The life of the copper oxide rectifiers may be short when subjected to heat and vibration. (4) Some damage was done to rectifiers in 1940, when the relays sealed in on two or three occasions, the rectifiers became overheated before the trouble was discovered.



Plate V

Comparative Performance, Norwood, Cleburne, and White Settlement Lines Showing (1) Outage Time, (2) Number of Prolonged Outages

This chart shows definitely bad performance of the Cleburne line. This is no doubt due to grounding banks being directly connected to the line which with multiple connections at Fort Worth and the Cleburne 60 kv tie make it in effect a 5 or 6 ended line or practically a 60 kv outdoor bus 32 miles long.

A short section of this line has insulated wire. However, only one of the 12 prolonged interruptions was caused by conductor failure in the insulated section.

The greater part of the Norwood line outage was due to a conductor failure as a result of a gunshot conductor. COMPARISON TOTAL OUTAGES FORT WORTH 60 KV LINES DUE TO LINE TROUBLES



OUTAGE TIME (HOURS) NUMBER OF PROLONGED OUTAGES

PLATE NO. _I



Plate VI

Comparison is made here of questionable, incorrect, and correct operation of the three 60 kv lines and other high voltage lines over the TESCO system.

It may readily be seen that the record for lines in the Fort Worth area is far behind the usual standards.

This chart is made up from tabulations to be found at the latter part of the Operating Record section. COMPARATIVE SWITCH OPERATION FORT WORTH GO KV LINES WITH OTHER GO KV LINES FOR ISOLATING FAULTS





JAN 1 1941 TO APR 1, 1945 JAN. 1941 TO APR.1, 1945 SETTLEMENT SEPT. 1943 TO APR. 1, 1945 ENDED LINES TESCO SYSTEM AVERAGE PERFORMANCE

PLATE NO. I

Plate VII

Check Off Sheet for Relay Operation

This check off sheet was worked out in 1944 to permit getting correct information as to relay action.

By checking off the relays which operate at any time, the switchboard operator has a quick way of making a record which he later reports to the dispatcher who also has a copy of this sheet. The result is ordinarily that the dispatcher gets correct information for the interruption report.

By studying this sheet, interruption reports and automatic oscillograms, the Relay Engineer has some basis for correct analysis of performance.



Plate VIII

Short Circuit Current Distribution for Three Phase and Single Phase Faults on Cleburne Line at Fort Worth Plant

Red = Residual Current at 60 kv Black = Current in Faulted Conductor at 60 kv Blue = 3 phase Fault at 60 kv

This chart is included to show distribution of fault currents for 60 kv faults at Fort Worth under the present conditions.

It is interesting to note that of the 4950 amperes residual current resulting from a ground fault on the 60 kv system at Fort Worth a current of only 72 amperes flows from Cleburne and 90 amperes from White Settlement. Obviously, ground relays at Cleburne or at White Settlement receive very little indication of a ground fault at Fort Worth either at 60 kv or 12.5 kv.

The 399 amperes from Bryan Avenue is sufficient current to cause instantaneous tripping of OCB #378, since installation of the 60 kv neutral current transformers at Bryan Avenue. However, the opening of OCB #378 does not remove the principal sources of zero sequence current which originates in the Bryan and Jennings transformers.

It will be beneficial to open the neutrals at Bryan and Jennings to the extent that the residual current coming from Bryan and Jennings will be reduced to zero. Other problems will be introduced as a result, and the Cleburne line will remain multiple ended.



Plate IX

Short Circuit Current Distribution for Faults on Cleburne Bus

Red = Residual Current Black = Current in Faulted Conductor Blue = 3 Phase Fault

This chart indicates preponderance of residual current being fed from the Bryan and Jennings Substations. Even as far away as Cleburne there are 930 amperes flowing into a ground fault with 507 amperes flowing from Bryan.

These faults cannot all be cleared by fast relaying without a breaker to the south of the Bryan Avenue tap. With any appreciable time delay #3 copper would be expected to burn down. Operating records show that it does burn down for almost one third of the flashovers.

As pointed out elsewhere, it seems evident that 60 kv transformer neutrals should be ungrounded at Bryan and Jennings Avenue Substations.



Plate X

Fault Current Distribution For Faults on White Settlement 60 kv Bus

Red = Residual Amperes at 60 kv Black = Current in Faulted Phase at 60 kv Blue = 3 Phase Fault Current

OCB #1600 is automatic reclosing for faults on the White Settlement line. This means that it also recharges Bank #3 at the same time which had the usual distorted wave form during the first second. It was found necessary to desensitize the pilot wire relay to prevent tripping on inrush current for #3 bank.

It may also be seen that when OCB #1600 recloses on a permanent fault, the fault current is only about 60% of the original fault since 948 amperes come through OCB #1600 and 640 amperes through Bank #3 which is already open when OCB #1600 recloses automatically. These values are for residual amperes, and the other values are of similar proportion.

Various other information may be obtained from this and the previous distribution charts, such as the following: (1) 135 amperes, residual, flow from Bryan for a bus fault at White Settlement or 399 amperes for fault at Fort Worth and 342 amperes for fault at Cleburne. It is considered good practice to reach the full length to Cleburne and Fort Worth lines but not reach beyond White Settlement with instantaneous tripping. This means that the Bryan Avenue instantaneous ground relay should be set above 135 amperes but not over 342 amperes. (As mentioned elsewhere, the tripping of OCB #378 for faults beyond Fort Worth and Cleburne is considered a necessary evil.) (2) A study of this and Cleburne fault current distribution charts along with Plate XIII indicates that normal current transformer saturation should be no problem for faults at Cleburne and White Settlement, etc.



Plate XI

Diagram Showing Change in Ground Current on Cleburne Line

Figure 1 - Bryan and Jennings Transformer Grounded Figure 2 - Bryan and Jennings Transformer Ungrounded

The red and green arrows in Figure 1 indicate ground current flowing from Bryan and Jennings Substation transformers. Incidentally, Bryan Avenue provides practically twice as much ground current as Jennings.

Figure 2 shows no ground current from these transformers. Removing the neutral connection will improve relay action at Fort Worth and Cleburne, as well as remove this heavy source of ground current which burns down No. 3 stranded copper conductor in an extremely short time.

A 60 kv potential transformer and voltage relay may be considered desirable at Bryan Avenue for tripping OCB #378 on the low side of Bryan Avenue for permanent ground faults on the 60 kv line.



Plate XII

Reproduction of Sheet from General Electric Handbook Showing Characteristics of Balancing Transformer Used at Fort Worth

As seen from the description, this transformer is small and intended for light burdens. In itself it also imposes some burden on the current transformers.

Balancing transformers were removed from the pilot relay setup. This was done in order to eliminate definite trouble due to saturation caused by heavy burden of a ground fault as imposed by the pilot wire relay.

Due to the rather heavy burden imposed by long leads with the GCX and other relays it seems probable that some unbalancing may result from saturation of balancing transformer still used on Norwood and Cleburne relays. Switchgear Handbook7693Page 2Switchgear Data Book7693Page 102Industrial Handbook8874Page 7693-2

Apr. 24, 1939

General Electric Company Schenectady, N. Y RELAY

AUXILIARY AUTOTRANSFORMERS

SELECTION OF AUTOTRANSFORMERS









VOLT-AMPERE BURDEN

The volt-ampere burden of these devices is usually negligible and will never exceed 10 voltamperes at 5 amperes, 60 cycles if properly applied. It can be accurately calculated from the equivalent circuit diagram shown by Fig. 4. When used to step

* Dimensions are subject to change and should not be used for construction without approval.

up the current it must be remembered that the burden of the load increases as the square of the step-up ratio.



Fig. 4. Saturation curve and equivalent circuit diagram of auxiliary autotransformer Cat. No. 3661843G1 to G9

*DIMENSIONS



Fig. 5. Dimensions of auxiliary autotransformer



Plate XIII

Ratio Characteristics of Fort Worth Current Transformers for Ground Faults

This plate shows relative performance of the three types of current transformers used at Fort Worth with normal ground fault burdens.

It appears that the bushing type current transformers level off at approximately 8 times normal, the Pacific Electric wound type at 11 times normal, and General Electric wound type at approximately 20 times normal.

The expected result of such variation in performances is incorrect and inconsistent action for paralleled current transformers which provide current for line faults near the Fort Worth plant.


Plate XIV

Oscillograms Showing Instability of Possum Kingdom Following Permanent Fault on Cleburne Line and Test by Charging Line with 60 kv OCB #1600

This plate is included mainly to show: (1) The weakness of the tie with Possum Kingdom when operating through Bank #3. The proof of the weak tie is that a test on the Cleburne lineby using OCB #1600 set up an unstable condition which separated Possum Kingdom from the system. (2) It illustrates the great diversity of fault current from Fort Worth between the first and second of two tripouts in quick succession on the same line.

The original fault on the Cleburne line at 5:02 a.m. was cleared from Fort Worth in approximately 10 cycles and caused very little disturbance.

When the line was tested at 5:03, using OCB #1600 to charge from #3 Bank and the Mineral Wells line, there was very little drop in 12.5 kv voltage or flow of ground current through Bank #3. In fact, there was insufficient current flow or voltage drop to start the oscillograph. However, the 60 kv voltage did drop sufficiently to cause Possum Kingdom to get out of step. This in turn dropped the voltage sufficiently to start the oscillograph at 5:03 for the second run off.

The third run off shown at the bottom of the sheet and indicated as 5:04 perhaps started the oscillograph immediately after the second run off. It shows definitely out-ofstep conditions which separated Possum Kingdom from the system by tripping OCB #203 at Oran.



Plate XV

Oscillogram Showing Effect of DC Component Causing Saturation of Bushing Type Current Transformer

This oscillogram shows saturation occurring during first cycle with the result of reducing output in amperes to less than 25% during second cycle.

This oscillogram was not made on the TESCO system but was made under similar conditions of heavy burden consisting of long secondary leads, relays and meters.

The effect was to unbalance differentially connected current transformers causing differential relays to operate.

At Fort Worth bushing current transformers are used in OCB #1600 and are paralleled with 12.5 kv wound type current transformers (through balancing transformers) and PEM Co wound type current transformers in OCB #56. All of this is for protection of the Cleburne line. The effect of unbalancing is to cause current to flow through Cleburne relays for faults on White Settlement line. The effect is more pronounced when Bank #2 is in service instead of Bank #3 which was normal operation for some time. (See Plate III.)