PROTECTIVE RELAY STUDIES FOR THE NIGERIAN NATIONAL ELECTRIC 330 KV TRANSMISSION SYSTEM

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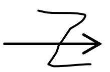
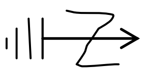
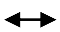
ABSTRACT

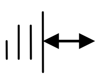
An indepth study and analysis has been performed on the 330KV transmission protective relay schemes of the National Electric Power Authority. Some of the basic considerations taken into account in the study to optimize the settings on the existing protective relay schemes are presented. Typical calculations are performed to illustrate the guidelines enumerated in the setting philosophy. These settings as calculated are presented and major defects existing in the protective schemes pointed out. The fundamental reasons for requiring these specific protective relaying features are also reviewed. Other protective relaying schemes that can accomplish the same basic protection objectives are presented. Based on the Nigerian special system characteristics, schemes to correct existing protection inadequacies are recommended.

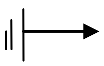
LIST OF SYMBOLS


= Phase distance relay at location indicated
Ground distance relay at location shown


= Ground distance relay at location shown


= Overcurrent relays at location shown


= Non-directional earth fault relay at location shown


= Directional earth fault relay at location shown

CB = Circuit breaker
CT = Current transformer
EHV = Extra High Voltage
FD = Fault Detector
HV = High Voltage
I = Current flow in line during indicated, fault.
LBB = Local Breaker Backup Scheme
T_2 = Time delay setting for the operation of the zone 2 element of distance relay.
T_3 = Time delay setting for the operation of the zone 3 element of distance relay.
Z_1 PR = Zone 1 element reach of distance relay in primary ohms and at line angle.
Z_2 PR = Zone 2 element reach of distance relay in primary ohms and at line angle. .
Z_3 PR = Zone 3 element reach of distance relay in primary ohms and at line angle.
Z_{400} MVA = Maximum relay setting in primary ohms and at line angle without tripping for expected load of 400 MVA.
Z_{800} MVA = Maximum relay setting in primary ohms and a line angle without tripping for expected load of 800 MVA.

1. INTRODUCTION

The simplified schematic diagram of the 330/132 KV network within Nigeria as at 31st December, 1984 is shown in figure 1. The generating stations are located in three different parts of the country, namely; Kainji Station in Niger State and Jebba Station in Kwara State to the North West, Sapele and Delta Stations in Bendel State to the West, and Afam Station in Rivers State to the East. Lagos which is the largest single load centre (over ,50% demand) receives its

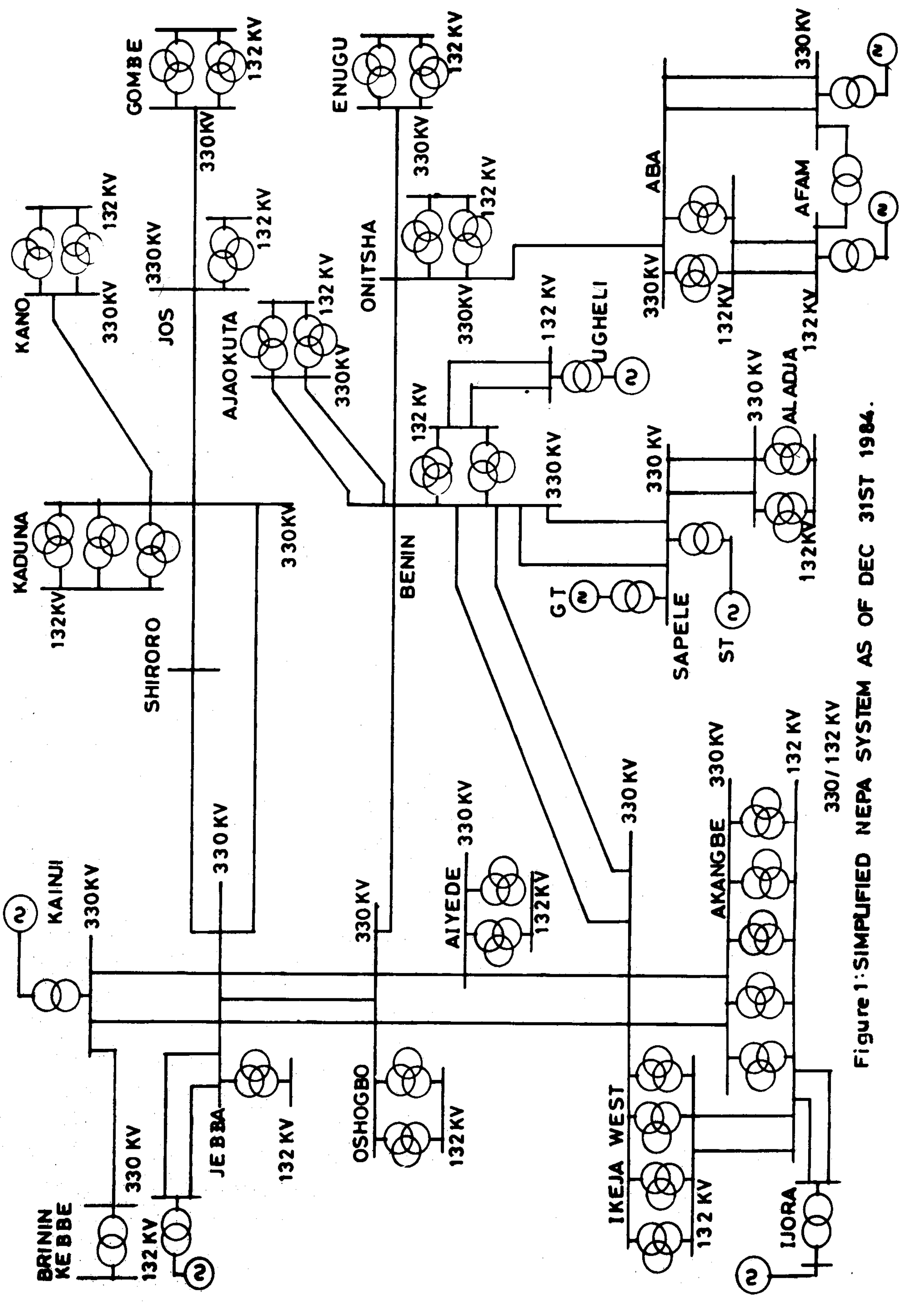


Figure 1: SIMPLIFIED NEPA SYSTEM AS OF DEC 31ST 1984.

power through an Eastern tie (Ikeja west - Benin 330 KV lines) and a northern tie (Ikeja West - Oshogbo, and Ikeja west - Uyede 330 KV lines). The status of the 330 XV loop network; Ikeja west - Oshogbo, Ikeja West - Aiyede, Aiyede - Oshogbo, Oshogbo - Benin, and Benin - Ikeja west is important in determining the ability of the network to supply power to Lagos area. An inadvertent drop of the whole Lagos load could lead to system high voltage conditions at some buses, high system frequency and total shut down of the system.

This study was embarked upon primarily to optimize the settings of existing protection schemes to improve system reliability and then to study defects on the systems and suggest remedies needed to improve system performance and avoid frequent partial or system blackouts.

2 EXISTING FAST PROTECTION SCHEMES

Two fast protection schemes now in use on the 330 KV network are the under-reaching direct transfer scheme and the permissive over-reaching scheme. These schemes are briefly discussed.

2.1 Under-reaching Direct Transfer Trip Scheme

This scheme, shown in figure 2, requires being able to set the under-reaching phase and ground elements short of the remote terminal so as not to overreach and trip falsely but yet have sufficient sensitivity as to provide a definite reliable over-lap that will ensure tripping for a fault anywhere on the line. For a fault on line AB within the reach of the relay located at terminal A and CB at A *is* tripped and a direct transfer trip signal sent to B terminal to ensure the tripping at that terminal if the fault *is* not within the reach of the relay elements at B. For a fault on line AB within the reach of the relay elements at B, the CB at B is tripped locally and a direct transfer trip signal similarly sent to trip the CB at A.

For a fault in the limited percentage of the line covered by A and B relays both, terminals will trip their respective CB's locally, but transfer trip signals, nevertheless, will still be transmitted to the respective remote terminals.

2.2 Permissive Over-reaching Relay Scheme

From figure 3, it *is* noted that basically the permissive scheme consists of over-reaching phase and ground elements at terminals A and B. For a trip to occur, the relays at the terminal must pickup and must also receive permissive signal to trip from the remote end of the line. For a fault beyond the B terminal (fault at D) relays at A will pickup to initiate a trip at A and will send permissive signal to terminal B. However, the B terminal trip relays which are directionally oriented will not respond and line AB CB at B will not trip. The A terminal CB will not trip because the relays at B in not picking up will not transmit a permissive signal to A. For internal fault on line AB (fault at C), the relays at terminals A and B will both pickup and send permissive trip signals to their respective remote terminals and their circuit breakers will operate to· clear the fault. Typical phase settings for this scheme are shown in figure 4.

Irrespective of which of the fast protective schemes is employed, the traditional settings of the three zone elements of the distance relays is not affected. This is because the different fast schemes is achieved by coupling the appropriate zone setting to the communication channels. For example, in the under-reaching transfer scheme, the zone one elements are coupled to the communication channels to achieve transfer trips at remote terminals. In the permissive overreaching scheme, the zone three elements are coupled to the communication channels to effect the sending of permissive trip signals to remote buses. In the application of both schemes, the zone one elements will still provide fast trips even when the communication system is out of service, while the zone two and zone three elements will provide time delayed protection for the remaining section of the Line not covered by the under-reaching zone one element and back-up protection for adjacent lines on the remote bus. It is therefore necessary, that the zone three elements do not pickup to trip the associated CB

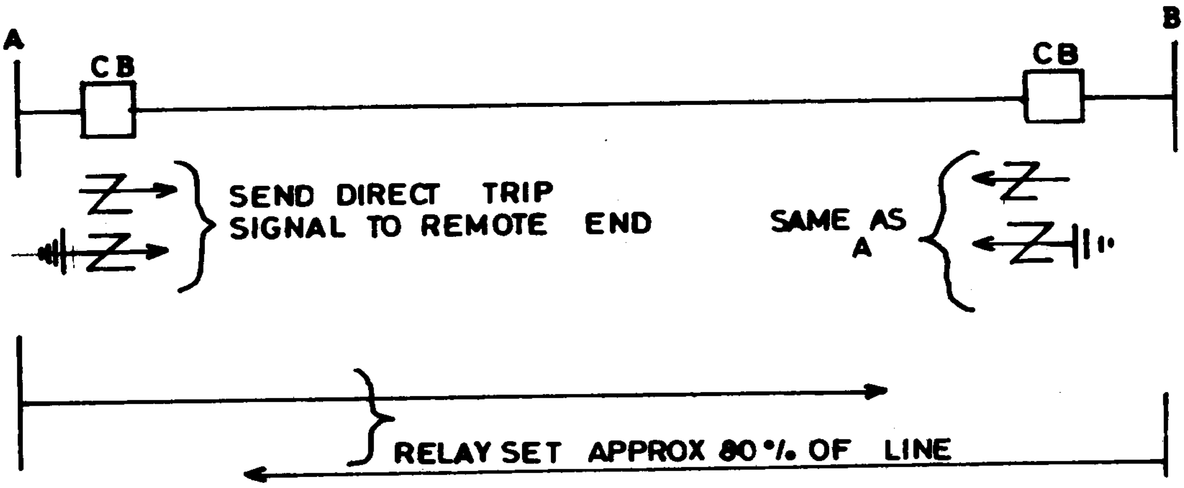


Figure 2. UNDER REACHING DIRECT TRANSFER TRIP SCHEME

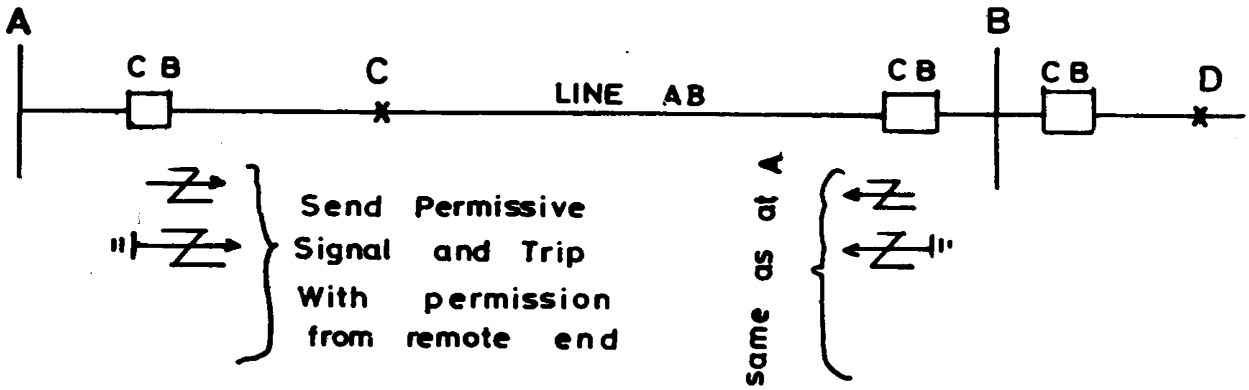


Figure 3 : PERMISSIVE OVERREACHING SCHEME

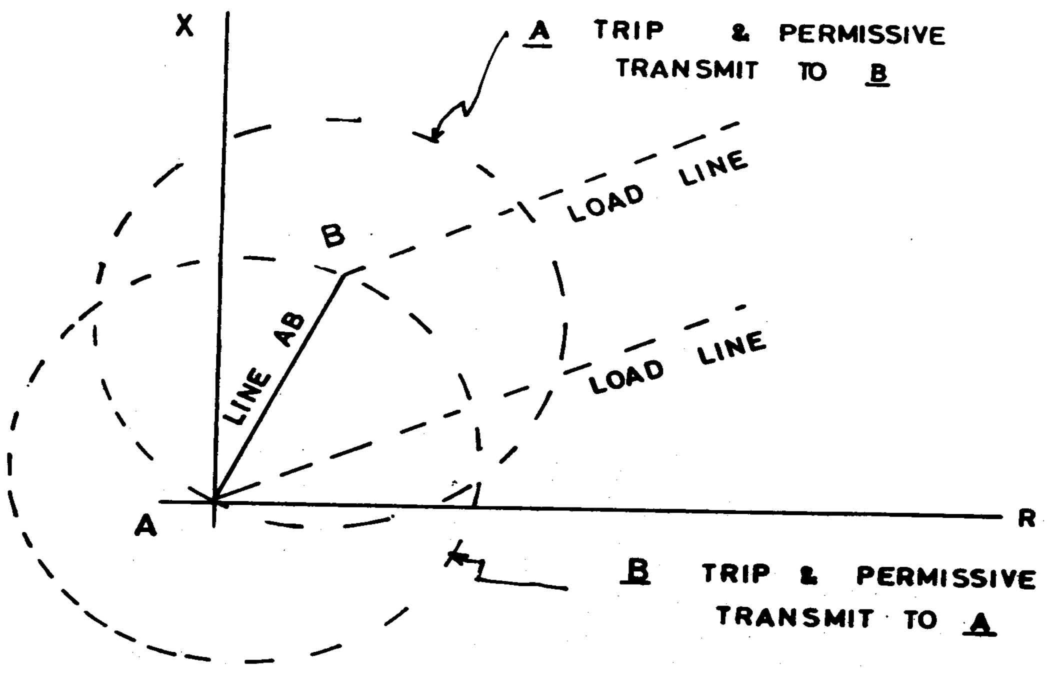


Figure 4 : TYPICAL PHASE RELAY SETTINGS FOR THE PERMISSIVE SCHEME.

at the completion of the time delay or start transmission of permissive trip signals during normal system load conditions.

3 BASIC SETTING PHILOSOPHY AND CHOICE OF DISTANCE RELAY ANGLE

A setting philosophy evolves in a company as a result of historical operating experiences and system special characteristics, and changes with time. In this study, the following were taken as general guidelines:

Distance Relays

Zone 1: These relay elements are set to cover 80% of the protected line and trip instantaneously.

Zone 2: These elements are set to cover 100% of line plus 50% of the next line section with a time delay of 0.4 seconds.

Zone 3: These are set to cover 100% of line, plus 100% of second line section, plus 25% of the third line section. The time delay is set for 1.0 second or 0.7 seconds when there is coordination problem with preceding adjacent line section.

When either the second or third zone reaches into a 330/132 KV transformer at the remote terminal, it is the usual practice to have the relays buried in the transformer. A reach of 50% into the transformer is considered adequate.

In setting both the second and third zone elements, the effect of intermediate current infeeds is taken into account in calculating the apparent impedance seen by the relay. Minimum system fault condition is employed in calculating the apparent impedance seen by the second zone element while maximum system conditions apply in computing apparent impedance seen by the third zone element in the presence of intermediate infeeds. Appropriate system contingencies are also taken into account to avoid relay over-reaches and incorrect tripping.

For medium length and long lines, the effect of arc resistance can be neglected. The relay maximum torque angle is set at 75^0, that is, as near as possible to the line impedance angle. However, for short lines, the maximum torque angle is set for 45^0 to take into account the effect of arc resistance. The transmission line ratings are broadly divided into two nominal classes:-

300 MVA and 400 MVA corresponding to current transformer ratios of 1600/1 and 800/1 respectively.

Employing a torque angle of 75^0, the maximum relay setting possible without pickup during load for lines rated at 800 MVA is determined by considering fig.5. It is usual practice to assume a pessimistic load angle of about 30^0. This gives a load power factor of 0.87 lagging. From figure 5, maximum load impedance at an angle of 30^0 lagging is given by

$$\mathbf{OA} = \frac{\mathbf{330^2}}{\mathbf{800}} = \mathbf{136\ ohms}$$

Load impedance at maximum torque angle is given by:

$$OB = \frac{136}{COS45^2} = 192\ ohms$$

Load impedance at line angle is given by

$$OC = 192\ Cos7.5^0 = 190\ ohms$$

Assuming a system voltage drop of five percent and ten percent safety margin, the maximum line reach without tripping onload is given by

$$Z_{800MVA} = 154\ ohms$$

The corresponding maximum reach for lines at 400 MVA is given by

$$Z_{400}\ MVA = 308\ ohms$$

If the calculations are repeated using a maximum relay torque angle of 45^0 the permissible maximum relay reaches will be 90 ohms and 180 ohms corresponding to lines rated at 800 MVA and 400 MVA respectively. It is clear from the computed values that the line reaches is very much improved by utilizing a relay torque angle of 75^0. (1)

Overcurrent and Directional Earth Fault Backup Relays

These relays should not pickup during system normal Load conditions. For coordination a time margin of 0.3 seconds is considered adequate

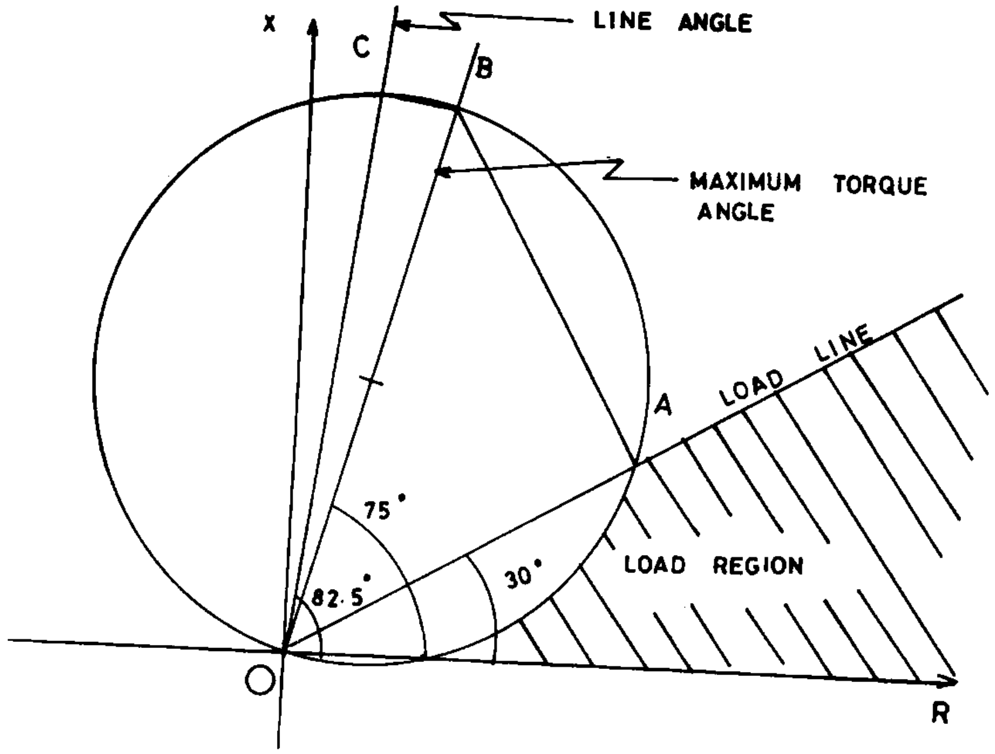


FIGURE 5: MAXIMUM RELAY REACH DUE TO LINE LOAD FOR A TORQUE ANGLE OF 75⁰

4. TYPICAL SETTING CALCUATIONS

To illustrate the application of principles enumerated in the setting philosophy, relay calculations for two typical lines at Ikeja West transmission station will be considered in detail. These calculations will demonstrate the mode of reasoning involved in arriving at the final settings shown in figures 6,7 and 8. [2].

4.1 Setting the Impedance Relays

The setting calculations are all in primary ohms and at line angle. Secondary settings will depend on the available current and voltage transformers and the final relay settings will correspond to the type of relay being applied.

4.1.1 Ikeja West - Ibadan Line

Zone 1: Z_1 PR = 0.8 x 44.5 = 35.6 ohms

Zone 2: Set to reach 50% into the Ibadan – Osshogbo line Z_2 PR = 44.5 + 37.4 x 0.5 = 63.2 ohms

Zone 2: Consider a fault at the Ibadan 132 KV bus and set to 50% into the Ibadan transformers

$$Z_3\text{PR} = 44.5 + \frac{87}{2}\,\frac{(1099 + 981)}{981} \times 0.5$$
$$= 90.6 \text{ ohms}$$

However, this will over-reach into the 132 KV circuit for a fault occuring when Ibadan-Oshogbo line is open. Hence set to just

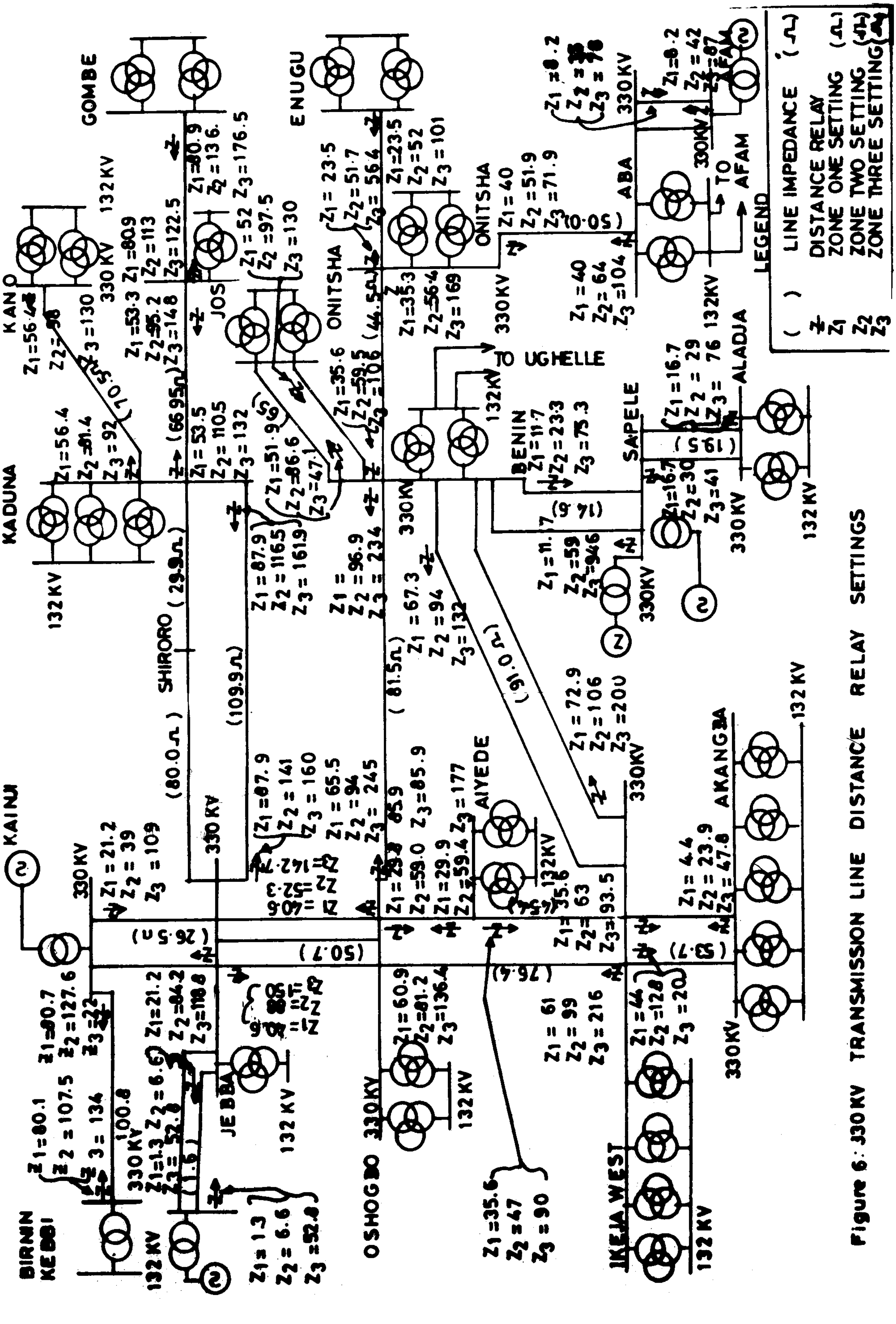


Figure 6: 330KV TRANSMISSION LINE DISTANCE RELAY SETTINGS

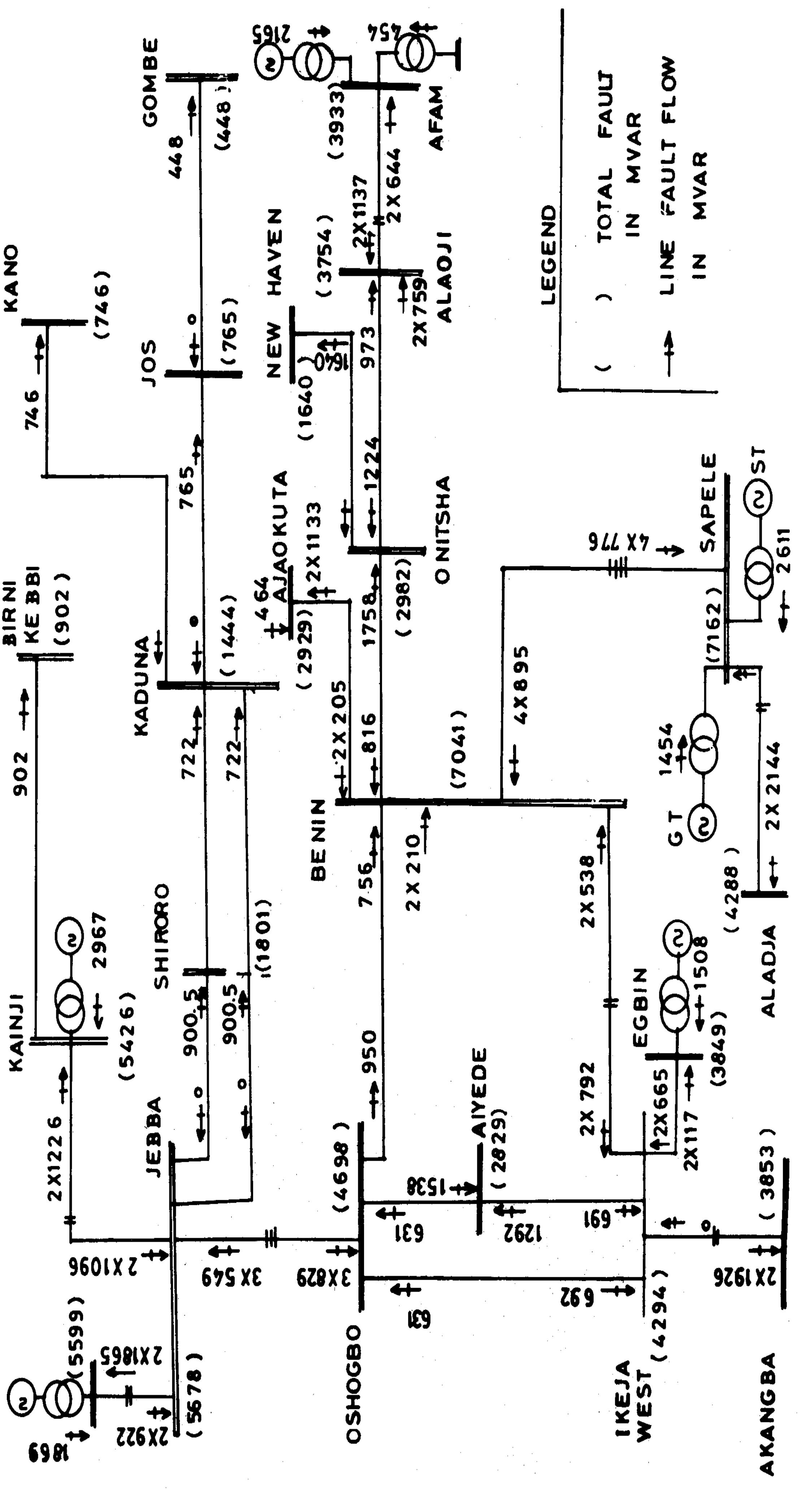


Figure 7: THREE PHASE FAULT. MAXIMUM SYSTEM CONDITION (1985)

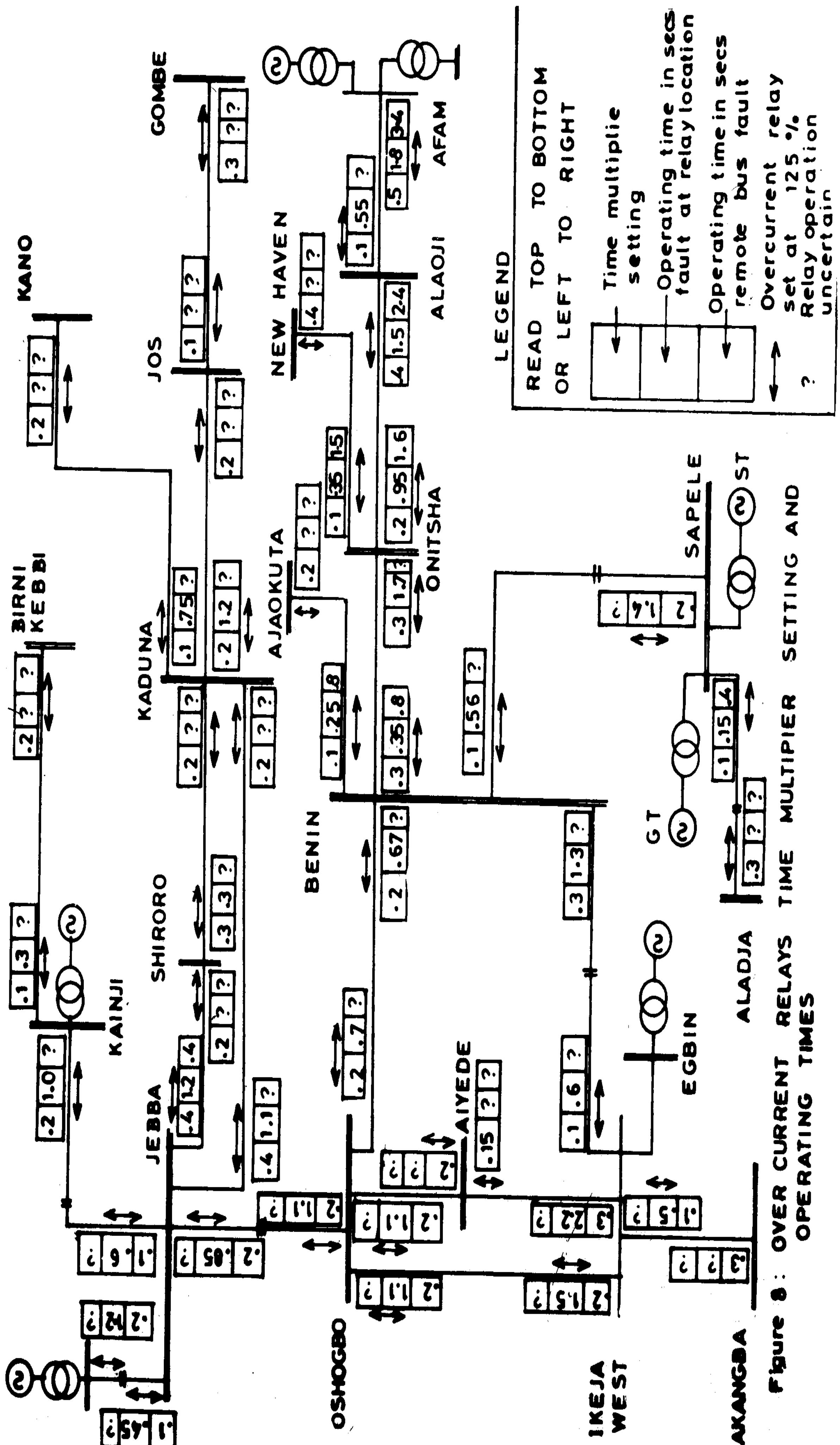


Figure 8: OVER CURRENT RELAYS TIME MULTIPIER SETTING AND OPERATING TIMES

cover the next line section by 10% and just underreach the transformer secondaries.

$Z_3PR = 44.5 + 37.4 \times 1.1 = 85.6$ ohm

Timers: T_2 0.4 seconds T_3 = 1.0secs.

4.1.2 Ikeja west - Benin Lines

Zone 1: $Z_1PR = 0.8 \times 91 = 72.8$ ohms

Zone 2: Assume one of the parallel lines our service and set relay to reach 50% into the Benin-Sapele lines during fault at system minimum condition

$$Z_2PR = 91 + \frac{14.6}{2}\frac{(502+294+621+242+710)}{355} \times 0.5 = 115.40 \text{ ohm}$$

Zone 3: None of the longer lines can be provided with complete backup because of the heavy infeed from Sapele station. The ·relays are set to have long reaches but still be able to provide a reverse power to Benin of 400 MVA and also avoid a reach into the 132 KV circuit at Benin. Considering a system voltage drop of 5% and a safety margin of 10%, the setting is given as:

Z_3PR = 200 ohms

Timers: T_2 = 0.4 seconds

T_3 = 1.0 seconds

It should be noted that all the zone two timers are set at 0.4 seconds. The third zone timers are set at 1.0 seconds unless where there is a coordination problem with backup third zone relay setting in which case the time is advanced to 0.7 seconds [1]. The complete system distance relay setting is given in figure 6.

4.2 Setting the Overcurrent Backup and Directional Earth Fault Relays

Both the overcurrent backup relays and the directional earth fault relays are connected to the second set of current transformers. This, in effect, increases the reliability of the protection scheme since any maloperation or failure to operate due to the first set of current transformers will not necessarily be transfered to these relays on the second set of CT's.

The pickup setting of the over-current backups relays is determined by the minimum load current the line is required to carry during emergency system conditions. After carefully considering these two factors it was decided to set the pickup values of all over current relays at 125% Even at these low settings most of the relays will not pickup for end of line faults. The single line to ground fault level are very adequate and the directional earth fault relay pickups are set between 20% and 80% of tap value. At places where 800?1 CT’s are in use, the 600/1 tap is utilized for both overcurrent and directional earth fault relays to improve sensitivity [2].

Time grading calculations are made using maximum values of system fault currents (figure 7) and the time margin of 0.3 seconds is considered adequate for both types of relays. To demonstrate the procedure, the settings of one of the directional earth fault relays at Ikeja West is presented.

4.2.1 Ikeja West - Ibadan Line

Set pickup = 20% (300A with a CT of 1500/1)

Multiple of pickup for remote end fault = 4.3

Time of operation required for coordinating with remote bus relays is 0.74 secs

From the relay curve, the time multiplier is set at 0.2

Time of operation for remote end fault - 0.95 seconds

Time of operation for fault at relay location = 0.44 seconds

The complete settings of the over-current backup relay time multipliers is given in figure 8. It contains also the operating times for faults at relay location and remote buses. Similar diagram was also developed for the directional earth fault relays. The boxes for remote bus fault operating times for most lines show question signs which means that these relays may not see end of line faults.

5 RELAY PERFORMANCES ANALYSIS

The study and analysis performed for 330 KV transmission system have revealed the following inadequacies [2]:

1. On the distance protection schemes, most of the lines do not have remote station backup for faults which are not cleared by their own protection schemes. This is because most of the adjacent lines are either very short lines whose third zone settings are limited by the short reach requirement of the zone one relay element, or are long lines and hence the third zone reach limited by line maximum load requirement or reach into remote bus 330/132 KV transformers. The following lines shown in table 1 do not have adequate backup protection.
2. The overcurrent backup protection scheme fails to provide full coverage either for the protected line or the adjacent lines and hence fails in the major objectives required for such a scheme.
3. For the direction earth fault backup relays, there is adequate reach on most lines except at few locations. This protection scheme can, therefore, be considered adequate and maintained as it exists.

These inadequacies together with possible correction schemes are discussed in the remaining part of this paper.

Table 1: Stations and Corresponding Lines on which remedy is needed to clear remote end fault not covered by adjacent line backup

Station		Line
Ikeja West	1	Ikeja West – Ibaadan
	2	Ikeja West – Oshogbo
	3	Ikeja West – Benin
Oshogbo	1	Oshogbo – Ikeja West
	2	Oshogbo – Benin
Senin	1	Benin – Ikeja West
	2	Benin – Oshogbo
	3	Benin – Onitsha
	4	Benin –Ajaokuta
Jebba	1	Jebba - Kaduna
Kainji	2	Kainji - Jebba
	2	Kainji – Birnin Kebbi
Kaduna	1	Kaduna – Kano
	2	Kaduna – Jos
Jos	1	Jos - Gombe

6. ADJACENT LINE BACKUP COVERAGE

The major objective in the desirability of remote station backup is provide alternative protection for the following protective scheme component failures:

1. Failure of the circuit breaker to operate to interrupt fault. In this case, an alternative relay at the breaker location will not help the station. The breaker trip coil may be defective or the control wiring to the trip coil may be open-

circuited. Remote station tripping comes in handy to interrupt the fault in delayed time.

2. Failure of the station battery in which the d.c. circuit cannot operate to trip the breaker even though the relays may have operated and the breaker is in good condition to operate if activated.

3. Failure of the current of voltage supply to the relays.

4. Failure of the protective relays. This is not a very important objective in modern EHV protection practice since redundancy can be increased by installing a second relay for the same objective. The clearing of fault by remote station backup assumes that the remote station relays can see the fault. Based on the relays presently in use on the NEPA network, the study has revealed that this remote backup cannot be provided for most lines.

Even when it is possible to provide remote station backup, triping in zone two or zone three times can easily lead to system instability. This has led to a few system shut down on the NEPA network [3]. Modern HV and EHV protection practice has recommended a protection scheme known as Local Breaker Backup Scheme (LBB) or breaker failure protection scheme which performs the same function as remote station backup but in faster time.

The basic principle involved in the Local Breaker Backup Scheme is to install current fault detectors relays on each of the circuit breakers, and these relays operate in association with the line relays. Figure 9 shows the connection arrangement and trip logic for a single-bus single breaker installation. When fault occurs beyond CB No.1, the associated protective relays attempt to trip that breaker. At the same time, operation of these protective relays and the current detectors energize the breaker failure timeer, which if it times out, will trip all backup circuit breakers However, if the protective relays succeed in tripping the primary breaker and hence clear the fault, the current fault detectors associated with CB No.1 will crop out. Timing will then cease short of a backup trip output. The setting of the breaker failure timer must be longer than the time required for the protective relays and the current fault detectors to drop out after circuit breaker No.1 has cleared the fault. Generally, it is desirable that the fault detector relays employed have fast drop out values. Figure 10 is the LBB arrangement for a breaker and a half bus installation.

7. OVER CURRENT BACKUP RELAY

In EHV networks, the transmission lines deliver large blocks of power and failure to trip during system faults could result in equipment damage or system shut down as a result of instability. Hence in EHV protection, a second main protection scheme is required. This second relay scheme will perform the same function as the first set of relays. The functions which include the following:

1. Interruption of faults on the protected line
2. Providing backup protection to remote bus adjacent lines.

These two schemes are then be designated as main I protection and main II protection schemes respectively.

Ideally, since it is the failure of the relay that is involved, the second protective scheme relays should be activated by another mode of fault detection than that for main I protection scheme. That is to say, if the main I scheme relays are activated by impedance measurement, main II relays should be activated by current measurement to increase the protection scheme reliability.

The overcurrent backup relays are installed to perform the functions requires

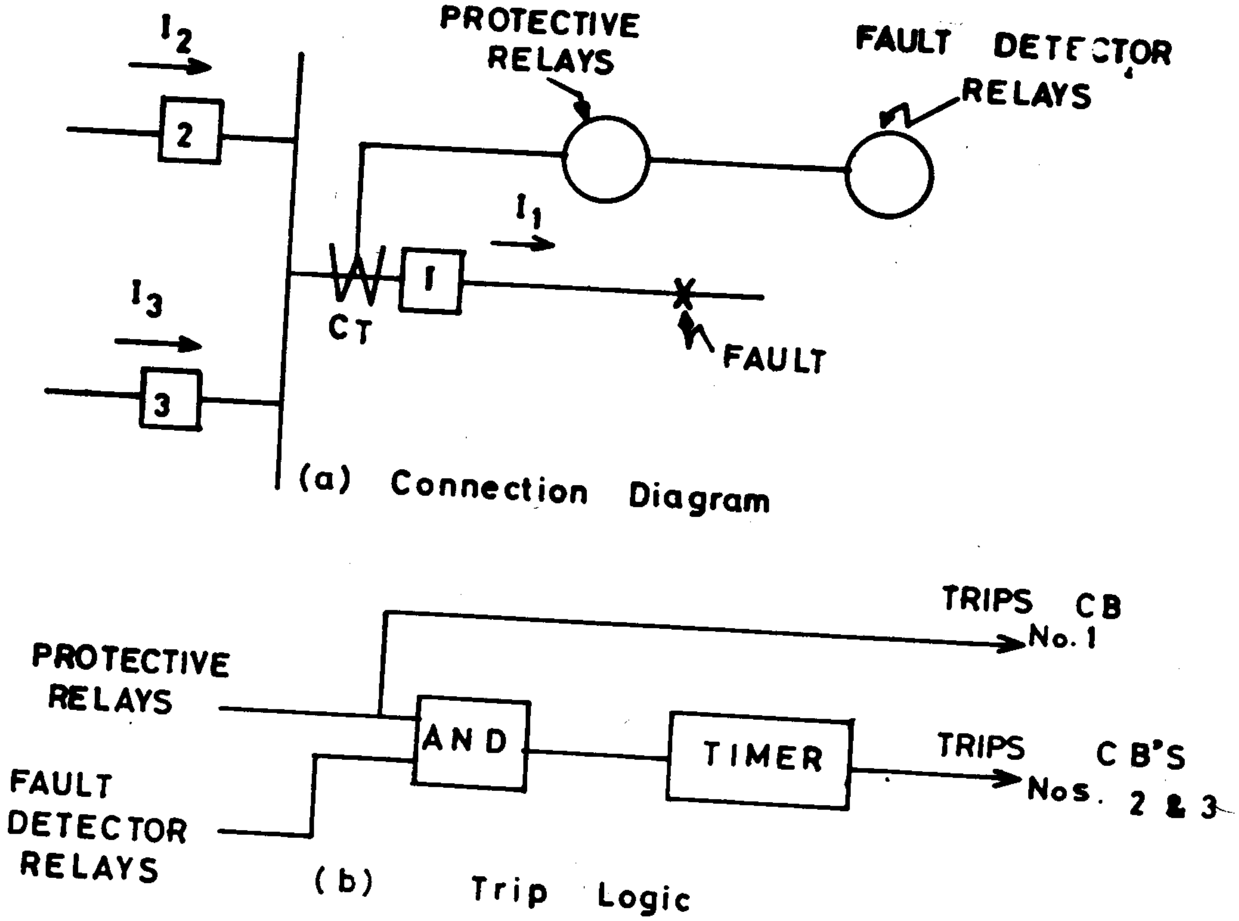


Figure 9: LBB Connection and Trip Logic For Single Bus Single Breaker Arrangement

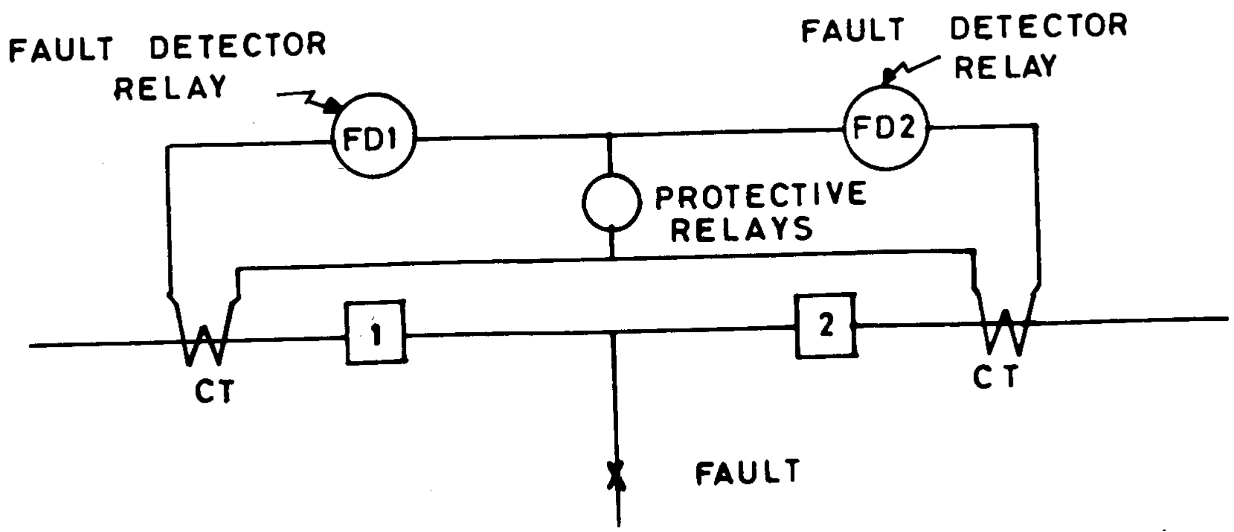


Figure 10: LBB Arrangement For The Breaker and A Half Bus Arrangement

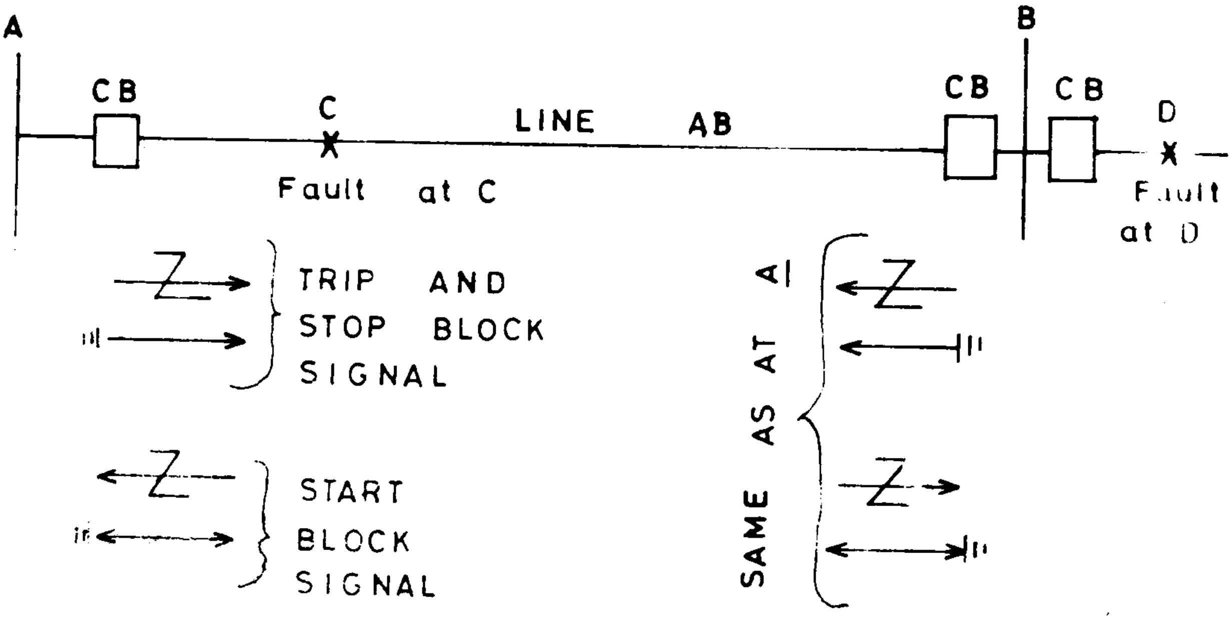


Figure 11: Directional Comparison Relaying

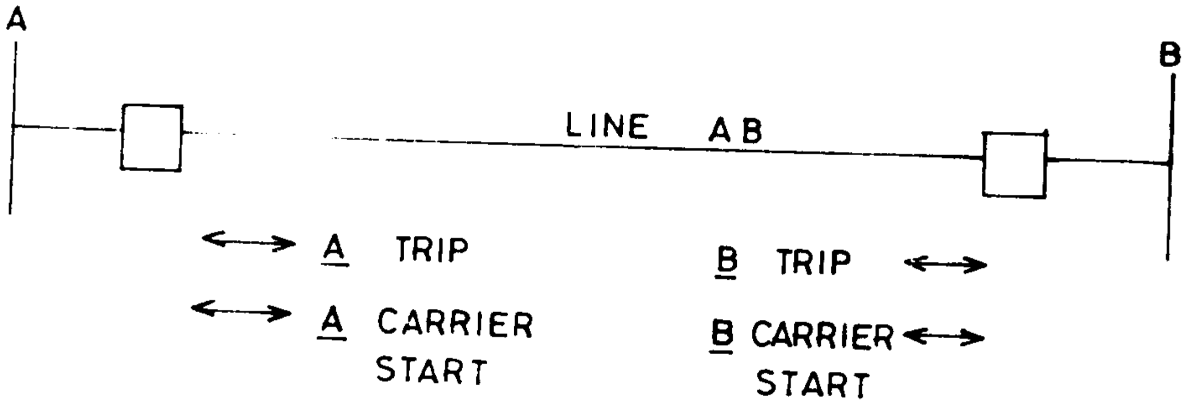


Figure 12: Phase - Comparison Overreaching Scheme

of the main II protection scheme. However, from this study, it *is* evident that this scheme does not provide full line protection coverage for most of the protected lines and certainly does not satisfy the second objective. Other protection schemes that can be employed to replace the overcurrent backup scheme are the directional comparison blocking scheme and the phase comparison relaying scheme. These schemes are discussed briefly as follows:

Directional Comparison Blocking Scheme

For a fault beyond *B* (fault at D) Fig. 11 the relay at A set to over-reach Bus B will pickup and will normally trip unless an intelligence at B is transmitted to *A* to indicate that the fault is external to the protected line AB. Similarly the relays at *B* are set to "see" disturbances external to line AB and to transmit a blocking signal to inhibit A from tripping. Naturally, a time race occur s in this scheme and A relays must be delayed in time sufficiently to ensure that the inhibiting block will appear at A before A trips falsely. [3]

For a fault on the line (fault at C) the relays A and B will "see" this disturbance-as being in the line. Operation of a tripping element overrides the blocking signal "start" elements ans tops local transmission of a block signal. Neither terminal will transmit a block signal and the fault will be cleared by opening the lines.

Phase Comparison Relaying:

A phase comparison scheme (figure 12) 1) operates on the principle that a fault can be considered to be either internal or external to a protected line by com- paring the relative phase positions of the fault currents at both ends of the line. To make the comparison using a single carrier or tone channel, the three phase currents are combined to give a Single phase 50 cycle output quantity. The output is used to provide the following functions:

1. Control the transmission of carrier in half cycle pulses.
2. Compare the phase positions of the pulses received from the remote terminal with the local single phase output of the sequence network.
3. Initiate local tripping if the comparison indicates the presence of internal faults.

8. RECOMMENDATION

From the analysis of the existing protective relay inadequacies and considering the special local constraints in our society the following recommendations are advanced:

1. Local Breaker Backup Schemes should be installed on the 330 KV circuit breakers as a matter of urgency. The programme should begin with all generating stations and major 330 KV transmission stations such as Benin, Ikeja West, Oshogbo, and Jebba stations. Where these schemes are already available their logic should be reviewed and the schemes made operations.
2. It is recommended that a second set of fast protection scheme (Main II) be installed on all the 330KV transmission lines to replace the existing overcurrent backup schemes. This is in line with modern EHV protection practices. The second main protection scheme should be the phase comparison scheme whose mode of fault detection is current level (mixture of positive, negative and zero sequence currents). The sensitivity to system fault of scheme chosen must be carefully examine.
3. The choice of distance relays must take into account that relatively long heavily loaded lines frequently occurs in the system. The load requirement of these lines limite the maximum zone three reaches. Relay planning engineers must consider the utilization of distance relays with adjustable characteristics, such as the THR Reyrolle relay, to overcome this limitation.
4. All modern fast protection schemes require the sending of intelligence between the terminals involved. The communication system performance as at present make this requirement difficult to fulfill most of the time. The reactivation and reinforcement of the communication system should be undertaken as a priority project.
5. No modern power system can operate satisfactorily without a well integrated under-frequency tripping policy. Faults cannot be avoided in the system and when they result in large imbalance between generation and load demand, the system can be saved from total collapse by a well planned under-frequency tripping scheme. A study should be initiated for the optimum application of under-frequency relays in the system.

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