INVESTIGATION OF SERIES COMPENSATION EFFECTS DURING FAULT CONDITIONS IN LONG TRANSMISSION LINES

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ÖZET

Gerilim düşümünün küçültülmesi ve keza enerji iletim kapasitesinin arttırılması için uzun enerji iletim hatlarında seri kapasiteler kullanılır.

Bu tezde, arıza düzeyi ve korunma bakış açısından Keban hidro-elektrik üretim merkezi ile Gölbaşı (Ankara) merkezi arasında şebekeye elektrik enerjisi ileten iki benzer hattan oluşan örnek sistem üzerinde seri kompansasyon etkileri incelenmiş ve arıza analizleri yapılmıştır. Yapılan hesapların sonuçlarına göre, seri kapasitelerin iletim hattı üzerinde optimal bir yerleşimi için öneriler verilmiştir.

ABSTRACT

To reduce the voltage drop and also to increase power transfer capacity of the long power transmission lines series capacitors are used.

In this thesis the effects of series compensation, from fault level and protection points of view, are investigated and fault analysis is done on the example system of two identical long transmission lines transferring electrical energy from Keban Hydro-electric Generating Station to the res of the grid at Gölbaşı Station (Ankara).

Based on the results of calculations, suggestions are made for the optimal placement of series capacitors along the transmission lines.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

A	Line constant
a	Operator :$1\,\underline{|120^{\circ}}$
B	Line constant
E_R	Receiving end Voltage
E_S	Sending Voltage
P	Power transfer in the line
P_N	Natural Power transfer of the line
R	Resitance of the line
X	Reactance of the line
Z	Impedance of the line
Z_o	Characteristic impedance of the line
α	Phase angle of A
β	Phase angle of B
δ	Power transfer phase angle
θ	Power factor angle
η	Propagation constant of the line

INTRODUCTION

In order to improve the power transmission capability of the transmission lines.There are three different main methods: increacing the line voltage, reducing the line reactance by using series capacitors or increacing the number at the lines. The easiest and and economical one is the reduction of series reactance of the line by inserting series capacitors to the line. This also improves the voltage condition.

Series capacitors were used in subtransmission lines for the purpose of reducing voltage drops. Because of rapid development in production of high voltage capacitors during the last two decades, their application to high voltage transmission lines have become very common.

Reducing of the series reactance in parallel of course means increasing the fault level which is important from circuit breakers rating and operation of the protection systems view point. This thesis is the investigation of these effects.

In chapter one a brief information is given about the long transmission lines and its important parameter, inductive reactance.

In chapter two the power transfer ability of transmission lines and reasons of reducing the line reactance are described.

In chapter three series capacitors as the main source of negative reactance and their effects to the system are explained.

In chapter four some necessary information about the principle short circuit and open circuit fault and the procedure and methods of their calculation is given.

In chapter five brief information is given about distance relays and circuit breakers as the main components to limit fault damages.

In chapter six the sepecifications of the system under investigation,necessary assumptions, approximations and methods used in fault calculations are described.

The result of the whole investigation is given in Conclusion part.

CHAPTER ONE

LONG TRANSMISSION LINES

Transmission lines are the arteries of the electric power systems. The availibilty of a well-developed high capacity system of transmission line makes it technically an economically feasible to move large blocks of electric energy over large distances.

Generally long high voltage transmission lines are used for the transport of electric energy from remote hydroelectric stations.

Power transmission lines may be classified as a short or long. A short line is defined as one for which shunting effects can be ignored. A short line has a simple series equivalent circuit (or model). This approximation is usually justified for lines up to about 80 km. route length. An approximate solution of long line (or sometimes refered to as a medium) assumes that all shunting effects can be lumped at a few selected points along the line, for example all at the middle giving the nomiral (T) or half at each end (Π) as shown in Fig.1.1

(a) (b)

FIG.1.1 (a) Nominal-Π. (b) Nominal-T.

The primary parameters (so called constents) of a transmission line are its series inductance (self and mutual), its shunt capacitance and its series and shunt resistance.

1.1. The Inductive Reactance of Transmission Lines

For fault analysis the main parameter is the line inductance, the effect of others are negligible in calcutions.

The inductance of a power line is by far the most important line parameter from engineering point of view. For normal line desgins the reactance is the dominating impedance element and it directly effects the transmission capacity of the line.

The effective self inductance of each phase conductor of a 3- Phase line is given by

$$L = \frac{\mu_0}{2\pi} \ln \frac{D_{eq}}{D_s} \quad H/m$$

Where Deq and D_s are geometric mean spacing distance (G. M.S or G.M.D) and geometric mean radius (G.M.R).

Positive and negative-sequences currents flowing in a transmission line require no return path because their algebric sum equals zero.

When zero sequence currents flow a transmission line they may choose any available return path. Some of the current may return through ground, some via the overhead ground wires. These latter wires are usually grounded at each transmission tower and therefore the return current in them may not be uniform through out the line.

The zero sequence impedence will have different values, depending upon the actual return path since the ground impedence depends greatly upon soil, humidity and other empiric factors it is customary to make certain simplifying assumptions regarding the actual current distributions.

Thus the zero-sequence inductive reactance of each phase conductor is

$$X_0 = 3 \cdot \frac{\mu_0}{2\pi} \cdot \ln \frac{D_e}{\sqrt{r_m \cdot D_m^2}} \ \Omega/m$$

where $D_e = K\sqrt{\rho/f}$

ρ is the earth resistivity which is very variable refered to nature of ground. The Zero Sequence reactance of a transmission line is usually between 2 and 3.5 times the positive-suquence series reactance X_1.

1.2. Improving Voltage Conditions in the Line

Since the voltage drop on a transmission line is approximately proportional to the inductive reactance the reduction of this reactance is an obviously powerful tool in improving voltage conditions. Unfortunately however, it is not easy to accomplish such a reduction.

Change of dimensions does not effect too much. Paralleling two or more similar lines is very effective but is not economical way of improving the voltage drop.

There remains the compensation of the line renctance by a capacitor connected in series with the line; so-called Series Capacitors.

They generate vars proportional to the square of the current in them and cancel of permissible 50% of line's series inductance moreover giving raise to the power limit and to improve the system stability (will be discussed latter).

CHAPTER TWO

POWER TRANSFER IN LONG LINES

The length of the line increases amounts of reactive power and results in the increase of current and losses. Also the longer the line, the more the stability enters as limiting factor. All this indicates that the maximum amount of power which can be transmitted on transmission lines is a complicated function of many engineering and economic varaiables.

The transmission of 25 M.W over a distance of more than 300 km.s would hardly be economical. The only power values close to the natural power* can be transmitted over large distances, a limit soon is reached where either the natural power has to be raised or the load has to be distributed on parallel lines (or both must be done).

The latter solution, while expensive, also increases the reliability and flexibility of the system. Further more, less capacity is lost in case of a fault if the load is derived between two lines.

The former solution can be obtained according to Eq.n (2.1) either by increasing the voltage or by reducing

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(*) If the line is terminated at its characterstic impedance the line losses will be minimum. The power transmitted in this condition,

$$P_N = E_R^2/Z_O \qquad (2.1)$$

Is called the natural power, where E_R is the receieving end voltage and $Z_O = \sqrt{L/C}$.

the characteristic impedance of the line. The most obvious way of increasing the natural power is by increasing the voltage since the natural power increases with its square.Forther more, according to Eq'n (2.2) and (2.3) the increase of voltage is

Sending End

$$P_{s.max}=\frac{E_s^2}{B}\left[A\cdot\cos(\beta-\alpha)+\frac{E_r}{E_s}\right] \qquad 2.2$$

Receieving End

$$P_{r.max}=\frac{E_r^2}{B}\left[\frac{E_s}{E_r}-A\cdot\cos(\beta-\alpha)\right] \qquad 2.3$$

equally as effective (square of the voltage) in increasing the power limit of moderately long but heavily loaded lines as it is increasing the natural power on long lines. The increase of transmission voltage, however, is accompanied by considerable difficults and it becames cumulatively more expensive as voltage rises,consequently, there is a need for investigating the possibilities of reducing the characteristic impedance.

The characteristic impedance derives from the line constants and the ultimately from the line dimensions cannot be changed widely since conductor distances are limited by consideration of insulation levels and corona. Furthermore, the line constants are proportional to the logarithm of the line dimension, consequently any change in the line dimensions is reflected only in a smaller proportion in the line constants. This then leaves the actual addition of capacitors as the only possible way of changing the characteristic impedance. Fig 2.1 shows the application of series capacitors.

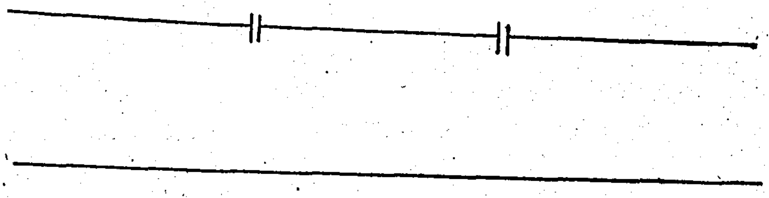


Fig 2.1 Single phase line with series capacitors

This results in a reduction of L and consequently in reduction of Z_o and η^*; this is completely desirable.

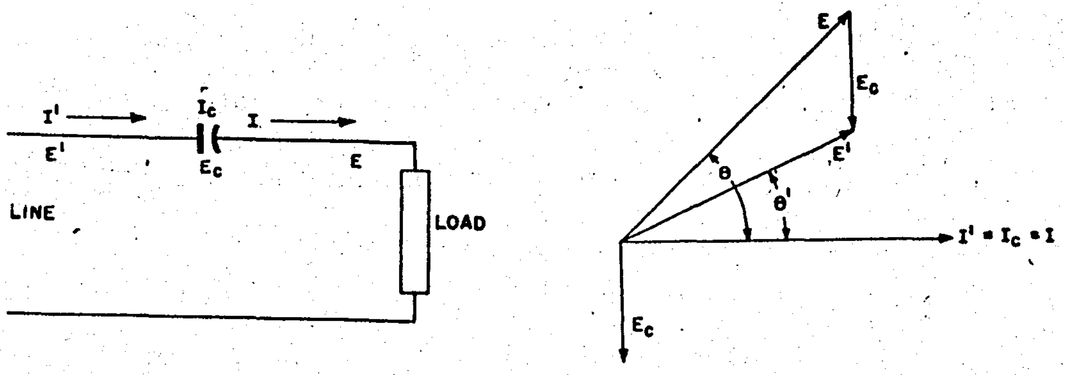
(*) η the propagation constant

CHAPTER THREE

3- SERIES CAPACITORS

A series capacitor may be considered as a negative (Capacitive) reactance in series with the line. The voltage rise across the capacitor, as a function of the circuit current, is automatic and practically instantanous, Fig. 3.1.

Series capacitors are applied to tie feeders to increase power-transfer ability and to improve system stability ,it has the effect of improving voltage condition too. They generate vars proportional to the square of the current in them and cancel of permissible up to 50 percent of line's series inductance.



ORIGINAL POWER FACTOR ANGLE

POWER FACTOR ANGLE WITH CAPACITORS

Fig 3.1

The voltage rise of the series capacitor is concentrated across the capacitor itself (Fig 3.2). This results in a step like voltage distribution along the line. The series capacitors have not considerable effect on power-factor improvement.

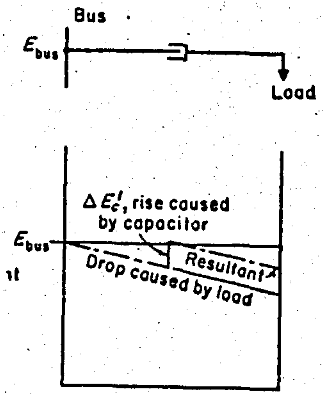


Fig 3.2

3.1- Effect of series capacitors on stability limits

Assuming that on a transmission line the resistance of line is much smaller than its reactance the transfered power can be obtained from :

where δ is the angle between the sending E_r and receiving E_s voltages. With a series capacitor the expression for power transfer is

Therefore for a given phase-angle difference between the voltages, the transfer is greater with a series capacitor.

Thus making possible a greater interchange of power, the normal load transfer and the synchronizing power flowing during transient conditions are increased, there_by helping stability. This is illustrated in Fig 3.3 which shows that for the same power angle, a series capacitor effects a 40 percent increase in power transfer ability and also the maximum power that can be transfered.

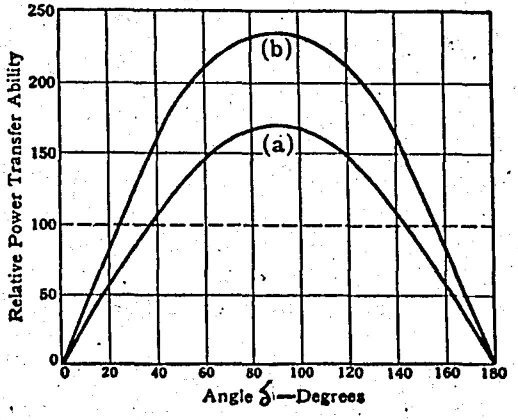


Fig.3.3-The power-transfer ability of a tie feeder may be increased from curve (a) without series capacitors,to curve (b) with series capacitors.

Furthermore to transfer the same amount of power through the transmission line angle δ is smaller, which aids stability of the system.

Complete compensation is generally not desirable for stability reasons. During line faults, the fault current produces an excessive voltage across the capacitor which makes it essential that to be taken out of service very quickly. But taking the capacitor out of service is equivalent to adding reactance to circuit, which is the worst thing that can be done at a time of fault view point of maintaining stability.

The manner in which this scheme effects stability of a system illustrated in Fig 3.4 for the case of two parallel lines with an intermediate sectionalizing station with series capacitor. The Fig. shows the power angle diagram for the system operating normally, for the system with an assumed fault to ground, for the system with the faulty line section removed but the capacitor still short-circuited, and for the system with the faulty line out and the capacitor reinserted. The initial operating condition is unit power and angle of 30 degrees.

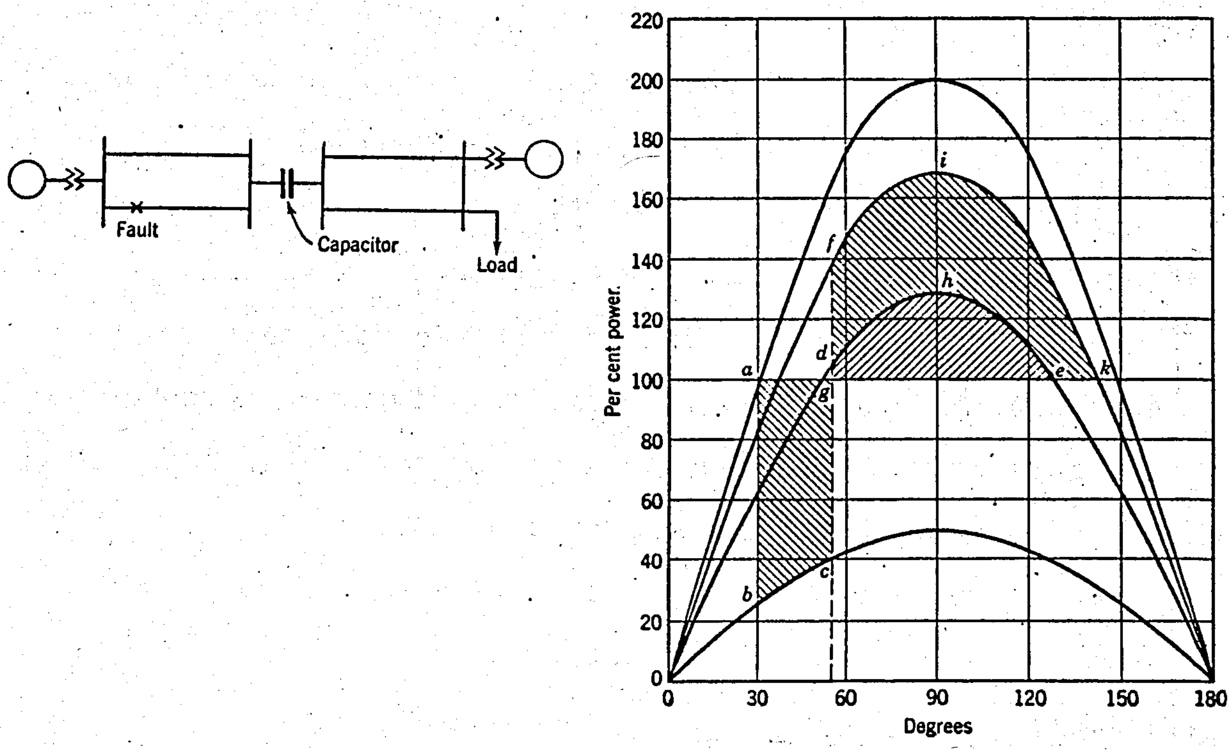


Figure 3.4 Power-angle diagram of trasmission system with intermediate series capacitor.

The fault reduces the power flow from a to b at the first instant of time , and angular shift moves the operating point to C. At this point the faulted section is removed and the operating point moves up to f with the capacitor reinserted in the circuit. The restoring forces are shown by the area dfikg without the capacitor the restoring forces would be as indicated by the area dheg. Thus the series capacitor, if properly applied greatly increase the restoring forces and the system stability during faults, provided that it does not have to be taken out of circuit to protect it against destruction.

3.2- Series-Capacitors Protection During Line Fault

An important problem is the protection of the series capacitors when they are called upon to carry heavy currents during fault conditions on the power system. The voltage drop across the capacitor is equal to IX_c and the value of I is large. This voltage which is of course applied across the capacitor plates, may reach a sufficiently high value to cause break down of the dielectric and the consequent destruction of the capacitor. One method of protection is to connect a spark-gap across the unit arranging it to breakdown at some voltage low enough to aviod risk of damage to the capacitor (Fig 3.5) when the IX_c drop across the unit reaches appropriate value the gap breaks down, effectively short circuiting the capacitor, reducing the voltage across it to zero.

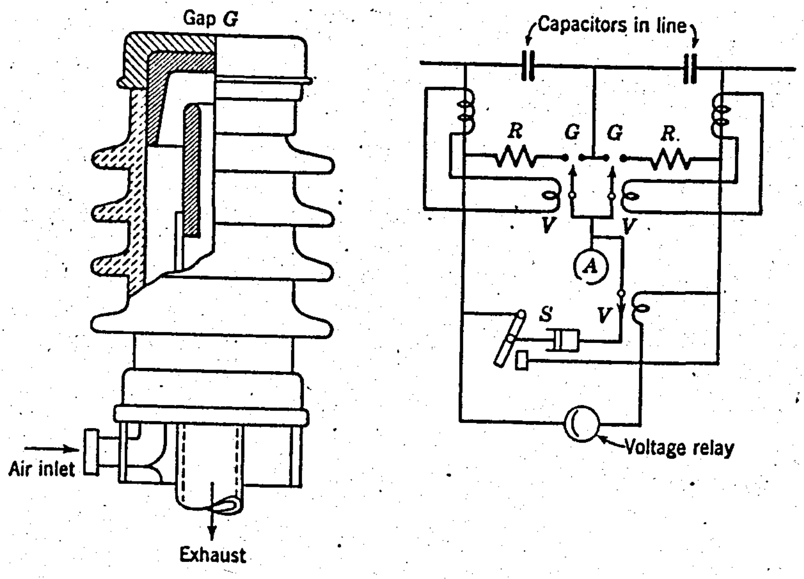


Figure 3.5 Typical protective scheme and gap for series capacitor.R.Resistor. G.Gap. V.Valve. A.Air reservoir. S. Short-circuiting switch.

As standard capacitor units can with-stand about 200 percant of their rated working voltage for brief periods without damage to the dielectric, it is necessary to use capacitors with continuous current ratings equal to 50 percent of the maximum current that may flow during a fault, or to use a voltage limiting device. For a given reactance, the cost of capacitors increase approximately as the square of the rated currents so that it is more economical to use capacitors whose ratings are based on the working current and to limit the voltage that can appear across their terminals by means of auxiliary apparatus.

On large series capacitors in transmission lines special high-speed circuit breakers or both may be required to protect the capacitor and re-insert them into the circuit within a half cycle or a cycle after the fault, it is necessary to enable the series capacitors to provide system stability. If the capacitors are not reinserted within a cycle or less, their fault benefit cannot be realized and their usefulness on tie lines would be reduced materially both electrically and economically.

3. 3. Location of Capacitors

In general a series capacitor can be lo uted at any convenient place on a line provided that certain requirements are met. The voltage level at the out-put terminals of the bank must not be too high for the line insulation and lighteing arresters.

It can be located in the middle of the line in one bank through the whole of line, or two banks may be preferable as more uniform voltage is obtained through, the circuit. Also for the same percent of reactance reduction of the line the short circuit current and voltage levels across the capacitor banks of the latter type will be less than the former one, but the cost and economical considerations is important factor in the desgin.

CHAPTER FOUR

4- FAULTS

Power systems are subject to many kinds of faults. The principle types are :

Three phase with and without earth connection, phas-to-phase (two phase), phase to earth (single-phase) and double phase-to-earth (phase-phase-earth). Faults sometimes occur simultaneously at separated points on the system and different phases (cross-country faults). Sometimes they are accompanied by a broken conductor or may even take the form of a broken conductor without earth-connection.

With the exception of the three-phase short circuit all of the faults listed represent unbalanced conditions.

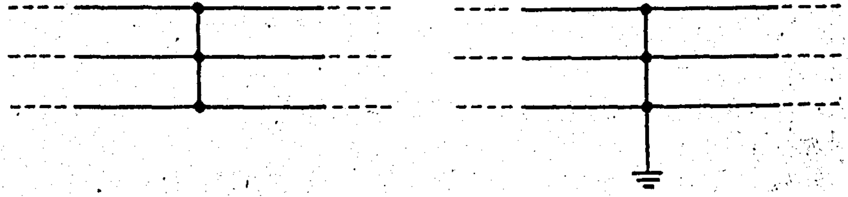
Faults are the result of the reduction in the basic insulation strength between phase conductors and earth for any natural, mechanical or electrical reason.

4.1- Types of Faults

The principle type of faults may be classified in four major following groups.

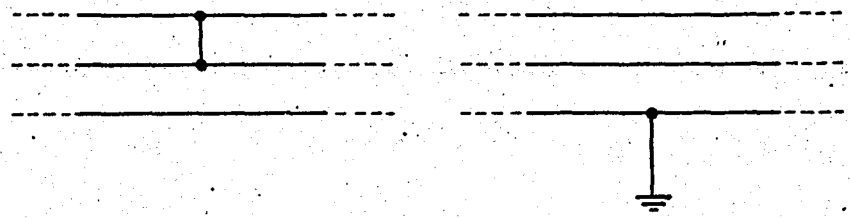
4.1.1- Short Circuited Phases

Faults of this type are caused by insulation failure between phase conductors or between phase conductors and earth (Fig 4.1 a)



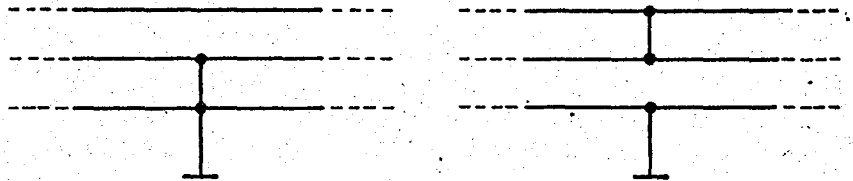
Three-phase clear of earth

Three-phase-to-earth



Phase-to-phase

Single-phase-to-earth



Two-phase-to-earth

Phase-to-phase plus single-phase-to-earth

Fig. 4.1.a. Short-circuited-phase faults.

4.1.2- Open Circuited phases

This type of fault is illustrated in Fig 4.1.b is the failure of one or more phases to conduct. The single-phase and two-phase open circuit conditions are of particular interest because they both tend to produce unbalance of power system currents and voltages with consequent risk of rotating plant.

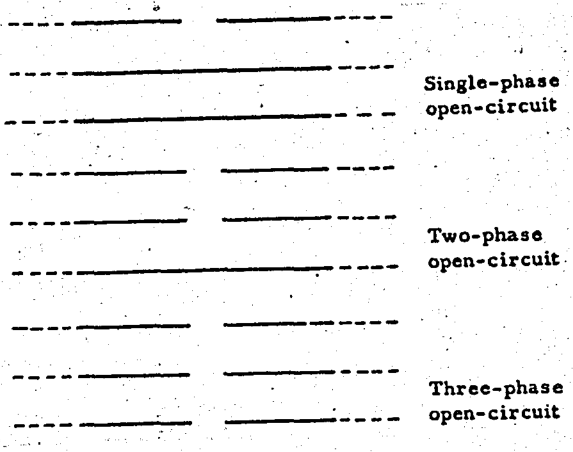


Fig.4.1.1.b. Open-circuited-phase faults

4.1.1,2- Simultaneous and Winding Faults

The rating of these faults do not exceed the rating of first type so they are not as important as the other two and are not included in our calculations.

4.2- Factors Effecting Fault Severity

The factors which are normally required to be considered are :

4.2.1- Source Conditions

These relate to the amount of power supplied to the system and wether the plant is in maximum or minumum load connected conditions.

4.2.2- Power System Configuration

This is determined by the items of plant namely generators transformers, overhead-lines and etc assumed to be in service for particular condition being investigated.

4.2.3- Neutral Earthing

Faults which involve the flow of earth current (e.g SLG) may be influenced by the system neutral-earthing arrangement, particulary by the number of neutral earthing points and the presence or absence of neutral earthing impedances. In most high voltage systems the neutrals are solidly grounded with the exception of generators. The advantages of such grounding are as follows :

- Intermittent ground faults and high voltages due to arcing faults are eliminated.

- Voltages to ground are limited to phase voltage.

- Sensitive protective relays operated by ground fault currents clear these faults at any early stage.

4.2.4- Nature and Type of Fault

The type of the fault and its position in the power system have a considerable effect on the magnitude and distribution of the system fault. The three-phase short circuit can normally be regarded as the most sever condition, therefore it is accordingly the maximum possible value of the three-phase fault level which normally determines the required short-circuit rating of the power-system switchgear.

Another important factor wich must be taken into account is the maximum value of single-phase-to-earth fault current, in a solidly earthed system may exceed the maximum three phase fault current.

4.3- Relative Number of different Kinds of Faults

Faults on overhead lines account for about one half of the total number of faults. For a power system the figures given below serve merely to indicate the order of prevalence and emphasize that there are usually a great many more line-to-ground faults than faults of other types.

Three-phase Faults		5 percent
Two-line-to-ground	Faults	10 percent
Line-to-line	Faults	15 percent
Line-to-ground	Faults	70 percent
Total		100 "

4.4- Methods of Fault Calculation

The information normally required from a fault calculation is that which gives the value of currents and voltages at the stated points in the power system. Fault calculation is therefore essentially a matter of network analysis and can be achieved by a number of alternative methods namely :

a- direct solution of the network equations obtained from the mesh-current or nodal-voltage methods,

b- solution by network reduction and back substitution,

c- solution by simulation using a fault calculator or network analyser,

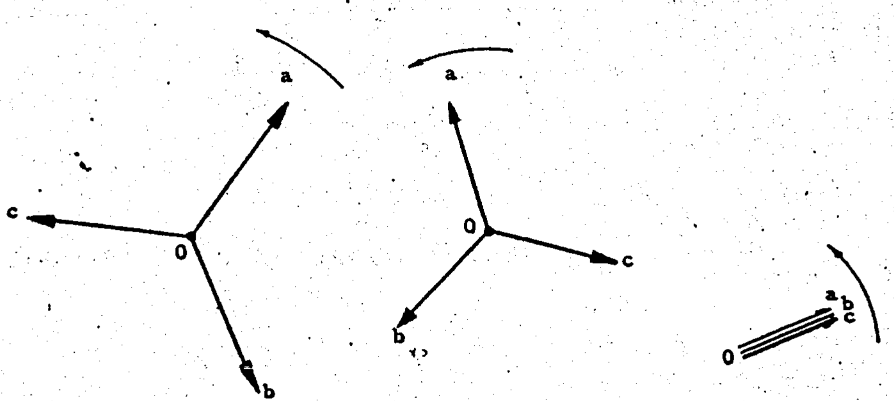
d- modern fault programs for digital computers, usually based on the bus impedance matrix, are widely used for large and complex systems now. However solution by network reduction, using manual hand calculators is done for the systems of limited size and complexity.

4.5- Unbalanced Fault Conditions

A full and proper analysis of unbalanced conditions in a three-phase network is made possible by the use of symmetrical components.

4.5.1- Symmetrical Components

These components are represented by the some of three set of balanced or symmetrical vectors, namely, the positive sequence set, the negative sequence set and the zero sequence set as shown in Fig 4.2



Positive sequence Negative sequence Zero sequence

Fig.4.2 Vector-diagram representation of phase-sequence components.

If I_a , I_b and I_c are any set of unbalanced three phase current. In terms of symmtric components of the reference phase (phase a) it can be easily shown that

$$\begin{aligned} I_a &= I_0 + I_1 + I_2 \\ I_b &= I_0 + a^2 I_1 + I_2 \\ I_c &= I_0 + aI_1 + a^2 I_2 \end{aligned} \Rightarrow \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} I & I & I \\ I & a^2 & a \\ I & a & a^2 \end{bmatrix} . \begin{bmatrix} I_0 \\ I_I \\ I_2 \end{bmatrix}$$

similar relationship between phase values and sequence component values are equally appliciable to voltage vectors in terms of reference-phase (phase a)

4.5.2- Phase-Sequence Networks and Impedances

The vector relation of the phase-sequence voltage drop to the phase sequence current producing it, is the same in all three phases and is termed the appropriate phase-sequence impedance of the circuit concerned. Where Z_1, Z_2 and Z_0 denote the positive, negative and zero sequence respectively.

4.5.2.a- The Positive Sequence Network

Each three-phase circuit is represented by its positive-sequence impedance or impedances and in case of a power source by driving voltage representing the generated e.m.f behind the source of positive sequence impedance.

4.5.2.b- The Negative Sequence Network

The three-phase circuit can be pepresented by its negative-sequence impedance or impedances, there will be no driving voltages since there are no generated negative-sequence e.m.fs in power systems. In static plant the positive and nagative impedances are always equal but differ so far as rotating machines are concerned.

4.5.2.c- The Zero-Sequence Network

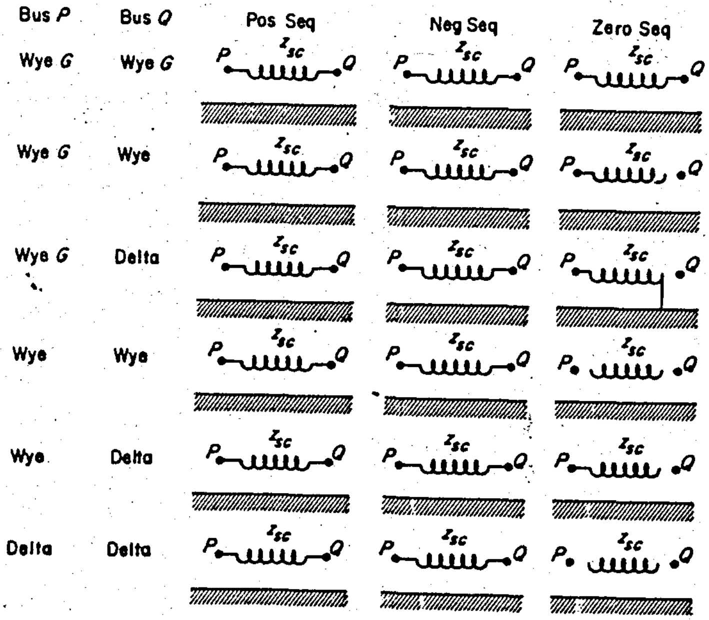
Similary the three phase circuit can be represented by its zero sequence impedance or impedances. There is no generated zero-sequence e.m.fs in power systems, so there will be no driving voltage in zero sequence network.

4.6- Sequence Impedances of Network Components

All sequence impedances for a synchronous machine are essentially purely reactive and since it is a dynamic element, its sequence values are different also the per-unit value of each sequence impedance varies for different machine types.

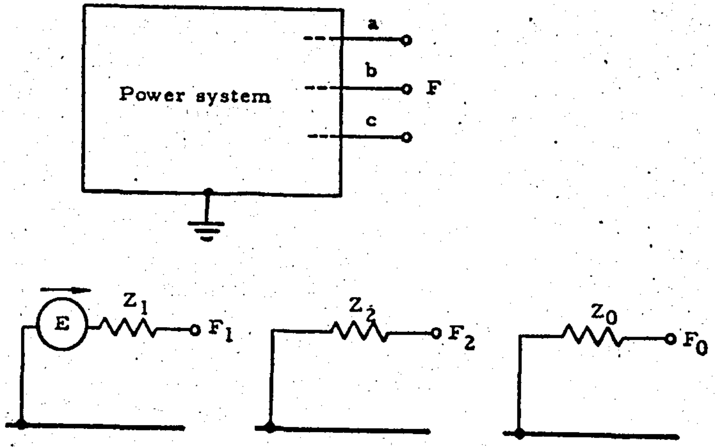
The positive and negative sequence impedances of transformers are identical as it is a static element but the zero-sequence greatly depends on the winding type (Delta or Star) also wether the neutrals are grounded.

Fig 4.3 Typical symmetrical-component models for the six most common connections of three-phase transformers.



4.7- Analysis of short circuit conditions

In general analysis of faulted conditions involve the three phase sequence networks of the given power system. It is convenient to represent each equence network in its simplest form asviewed from the point of short circuit, F.(Fig 4.5). It should be noted that the voltage E is the pre-fault reference voltage at the point of fault and Z_1 and Z_2 and Z_0 are the sequence measured from the point of fault.



Positive Negative Zero

Fig.4.5 Equivalent phase-sequence circuits of a power system as seen from the point of fault.

4.7.1- The Three-phase Fault

Considering the three-phase fault shown in Fig 4.6a, the required

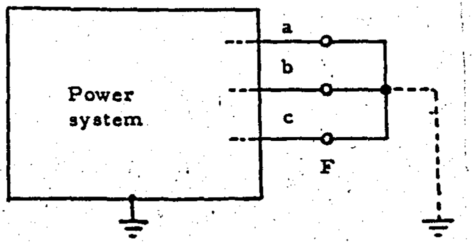


Fig.4.6.a The three-phase fault

symmetric-component equations

$$I_1 = E / Z_1$$

$$I_2 = 0$$

$$I_0 = 0$$

The phase currents flowing the fault are

$$I_a = I_1 = E / Z_1$$

$$I_b = a^2 . I_1 = a^2 . E / Z_1$$

$$I_c = a . I_1 = (a . E) / Z_1$$

$(a = 1 \underline{/120^\circ})$

4.7.2- The Phase-to-Phase Fault (L.L)

It is convenient to assume the phase-to-phase fault to be between phases b and c as shown in Fig 4.6.b

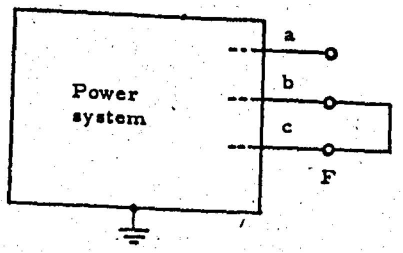


Fig.4.6. b The phase-to-phase fault

The required component equations

$$I_1 = E / (Z_1 + Z_2)$$

$$I_2 = - E / (Z_1 + Z_2)$$

$$I_0 = 0$$

The phase currents flowing into the fault are

$$I_a = I_1 + I_2 = 0$$

$$I_b = a^2 . I_1 + a . I = -(j\sqrt{3} E) / (Z_1 + Z_2)$$

$$Ic = a . I_1 + a^2 . I_2 = (j\sqrt{3} E) / (Z_1 + Z_2)$$

4.7.3- The Single-phase-to-Earth Fault (S.L.G)

For this fault condition it is convenient to assume the short circuit to be between phase a and earth as shown in Fig 4.6.c

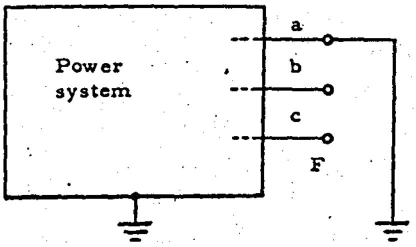


Fig.4.6.c The single-phase-to-earth fault.

The required phase-sequence currents in the faulted circuit are given by

$$I_1 = I_1 = I_0 = E / (Z_1 + Z_2 + Z_0)$$

The phase currents flowing into the fault

$$I_a = I_1 + I_2 + I_0 = 3E / (Z_1 + Z_2 + Z_0)$$

$$I_b = a^2 I_1 + a I_2 + I_0 = 0$$

$$I_c = a I_1 + a^2 I_2 + I_0 = 0$$

4.7.4- The Two-phase-to-Earth Fault (L.L.G)

It is convenient to assume the two-phase-to-earth fault to be between phases b and c and earth as shown in Fig. 4.6.d

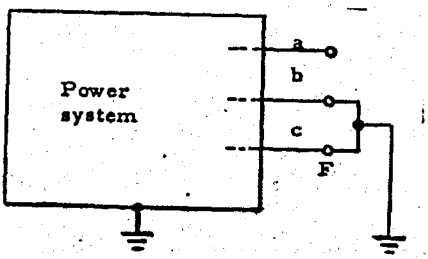


Fig.4.6.d The two-phase-to-earth fault.

The component equations

$$I_1 = (Z_2 + Z_0)E / (Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1)$$

$$I_2 = -Z_2 E / (Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1)$$

$$I_0 = -Z_2 E / (Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1)$$

The phase current flowing into the fault

$$I_a = I_1 + I_2 + I_o = 0$$

$$I_b = a^2 I_1 + a I_2 + I_o = \frac{-E(Z_o + aZ_2)}{(Z_1 Z_o + Z_2 Z_o + Z_2 Z_1)}$$

$$I_c = a I_1 + a^2 I_2 + I_o = \frac{E(Z_o + a^2 Z)}{(Z_1 Z_o + Z_2 Z_o + Z_2 Z_1)}$$

4.8- Analysis of Open Circuit Conditions

Two phase-open-circuit and single-phase-open circuit arc the important types. The remaining are of little practical significance. These faults are analysed by symmetrical components too.

4.8.1- The Two-Phase Open Circuit

For this case it is convenient to assume the open - circuit to be in phases b and c of the given circuit as shown in Fig 4.7.a the positions P and Q denoting the points in the circuit between which the open circuit is assumed to have occurred.

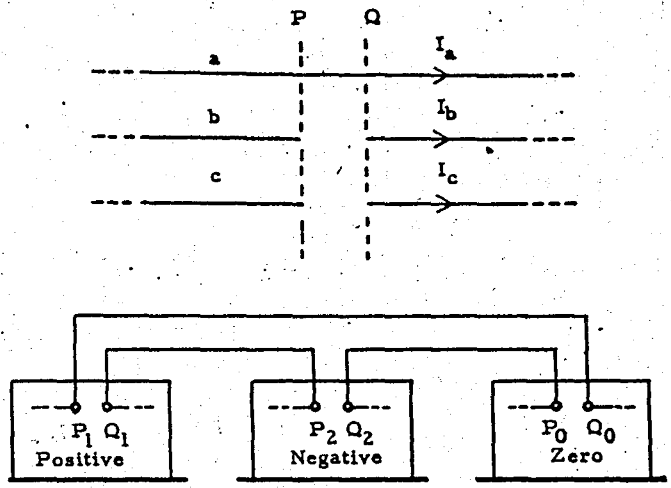


Fig. 4.7a The two-phase open-circuit condition

The required phase-sequence currents in the faulted circuit are given by :

$$I_1 = I_2 = I_0 = (Z_1 I_1 pf) / (Z_1 + Z_2 + Z_0)$$

and the phase currents in faulted circuit are :

$$I_a = (3Z_1 . I_1 pf) / (Z_1 + Z_2 + Z_0)$$

$$I_b = 0$$

$$I_c = 0$$

4.8.2- The Single-phase Open-Circuit

It is convenient to assume the single-phase open-circuit to be in phase a of the given circuit as shown in Fig. 4.7.b

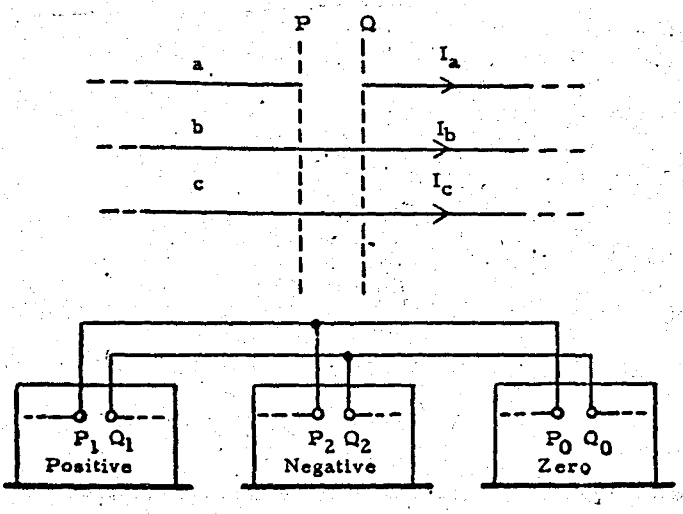


Fig. 4.7 b The single-phase open-circuit condition.

The phase-sequence currents are given by

$$I_1 = \frac{(Z_1 \cdot I_1 pf)}{Z_1 + \frac{Z_2 . Z_o}{Z_2 Z_o}}$$

$$I_2 = (Z_o \cdot I_1) / (Z_2 . Z_o)$$

$$I_o = (-Z_o \cdot I_1) / (Z_2 . Z_o)$$

The phase current

$$I_a = I_1 + I_2 + I_o = 0$$

$$I_b = a^2 . I_1 + a . I_2 + I_o$$

$$I_c = a I_1 + a^2 . I_2 + I_o$$

4.9- Fault Calculation Procedure

4.9.1- Over-Head Line and Cable Circuits

Overhead-lines and cable circuits are represented by their Π-circuits, it being usually sufficient to employ the nominal-Π circuit in which the series arm represents the total series impedance of the circuit concerned and each of the two shunt arms the impedance corresponding to one half of the total phase-to-neutral capacitance. The shunt arm impedances are always large in comparision with the series-arm impedance, and representation by the series arm alone is usually sufficiently exact for most practical purpose, particularly for over-head-line circuits.

4.9,2- Transformers and Synchronous Machines

Their impedances are predominantly reactive with X / R ratio typically between ten and twenty. It is therefore usually sufficient exact to ignore the resistive component of the impedances and to assume all the impedances to be purely reactive.

4.9.3- Load

Load impedances are always large in value in comparision with series impedances of power systems plant and they therefore have only small effect on the value of the total fault current conditions. Load can therefore be ignored in the majority of short-circuit calculations.

4.9.4- Transformer Tap-position

For the great majority of fault calculations it is usually sufficient to ignore actual tap position and to assume all the transformers to be operating on the nominal-ratio tap-position.

4.9.5- Equivalent Sources

The representation of a complex power-system network can often be simplified considerably by the use of an equivalent generator to represent the whole or cetain parts of a given network. Thus a complete network, as seen from any given point may be represented using. Thevenin's Theorem , as a single driving voltage in series with a single impedance.

4.9.6- Treatment of complex impedance

In many cases the resistance components of the impedances are small compared with the reactance components. The use of such a pure reactance form of representation results in a short circuit current slightly greater than the true value.

4. 10- Comparision of Fault Levels

The relative magnitude of fault currents and fault volt-ampers will be compared in this section, taking the 3-phase fault as the standard for comparision (1.0 p.u). For simplicity it will be assumed that the system resistance is negligible and that $x_1 = x_2$ i.e for alternators the subtransient is taken for also it will be assumed that the fault impedance is negligible. Since the main point is to show that an earth fault near a solidly-earthed source neutral-point can exceed that of a 3-phase fault.

a) 3 phase fault

Fault current = E_{an} / x_1

Fault VA = $3V_r E_{an} / x_1$

b) Earth fault

$$\text{Fault current} = \frac{3\ E_{an}}{x_1 + x_2 + x_0}$$

and expressed in per-unit of the 3-phase fault valve

Fault current $= 3x_1 / (2x_1 + x_0)$ p.u

If $x_0 = x_1$ then earth fault current 1.0 p.u

If $x_0 < x_1$ then earth fault currend 1.o p.u

Fault $VA = 3.V_r.E_{an} / (x_1 + x_2 + x_0)$

and again in per unit of the 3-phase fault valve we have

Fault $VA = X_1 / (2X_1 + X_0)$ p.u

This fault will be cleared on one pole of 3-phase circuit breaker having three identical poles. Thus the 3-phase breaking VA rating of the circuit breaker will be

$$3X_0 / (2X_1 + X_0)$$

Thus if $X_0 < X_1$ an earth fault requires a circuit breaker of larger rating.

CHAPTER FIVE

5- RELAY AND CIRCUIT-BREAKER APPLICATION

The function of the relays and the circuit breakers in the operation of a power system is to prevent or limit during faults or overloads and to minimize their effect on the remainder of the system.

5.1- The Selection of Circuit Breakers

Breakers are identified by nominal voltage. Among other factors specified are rated continuous current, rated maximum voltage, voltage range factor K and rated short circuit at rated maximum kilovolts. K determines the range of the voltage over which rated short-circuit times operating voltage is constant. Breakers of the 115 KV class and higher have a K of 1.0.

The data for selecting the breakers are available from fault studies.

5.2- Distance Relay and Distance Protection

In order to protect high voltage and mediume volage transmission lines against fault generally distance ralays are used. The distance relay is basically an impedance relay since the impedance of the line is directly proportional to its lenght. The driving point impedance of any network is $Z = V / I$. During a fault on a line I increases and as a result V decreases, consequently Z decreases too. So it can be deduced that in a faulted line the shorter the fault point distance from station the smaller the impedance . One of the main specifications of the distance relay , the duration of its response to command the circuit breaker to open the feeding point of the fault, is a function of the distance from fault point. The longer the distance, the longer the time of operation which is also acceptable from physical point since the short circuit current of a fault with longer distance (greater the impedance) will have smaller magnitude. The measure of the distance is based on the line impedance or its components, reactance or resistance.

Modern relays have stepped time characteristic. They are usually built with three protective zones as indicated in Fig 5.1. The stage (Zone) 1 of the relay provides instantaneous tripping for any fault within the predetermined distance from the relay (frequently 80 percent of the distance between substations A and B). Stage 2 operates with a time lag for any faults between the end of the first stage and well into the feeder between B and C (between 20 percent and 50 percent of B to C is usually included in this stage). Stage 3, in which a further time delay is provided for tripping, acts as a back up to the relay at B and also to the first two stages of A . The fault point is appointed by the impedance comparision between the fault impedance and a constant adjusted impedance of the relay. In case of short circuit on the line all operating elements of the distance protection are stimulated and compare the impedance. The only relay nearest to the fault point measures the smallest impedance in the other words the smallest distance and gives the shortest time command of its stepped time characteristic.

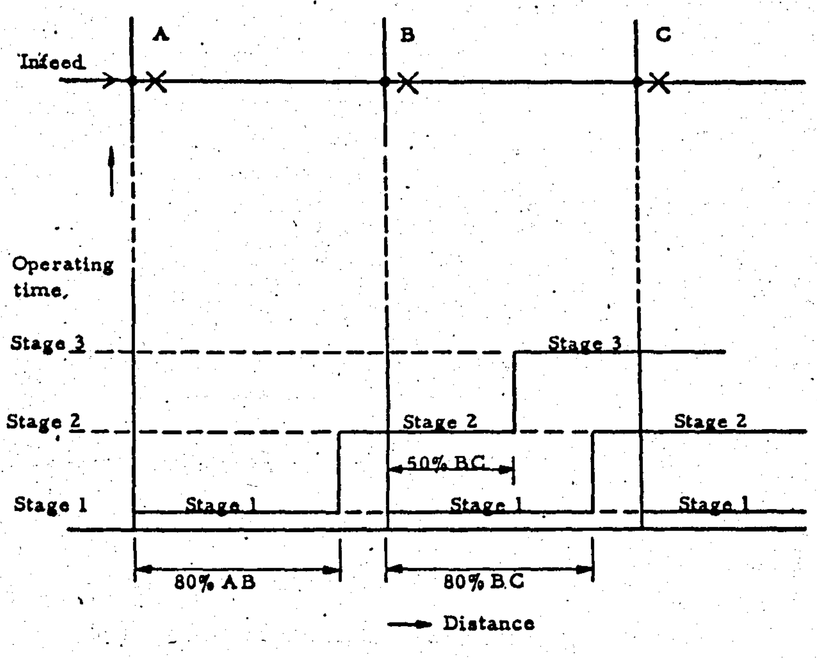


Fig.5.1 Characteristic of three stage distance relays.

5.3- Fault Impedance As Function of the Fault Type

By symmetrical component analysis it can be shown that the primary impedance is a function of the type fault and then devise methods whereby the relay need only be set in terms of three-phase fault condition i.e term of positive sequence impedance Z_1 .

In order to have the same primary impedance Z_1 for phase-to-phase and phase-to-phase-to-ground faults, phase-fault compensation method is employed which is delta combination of C.T.s and use of Line-to-line voltages.

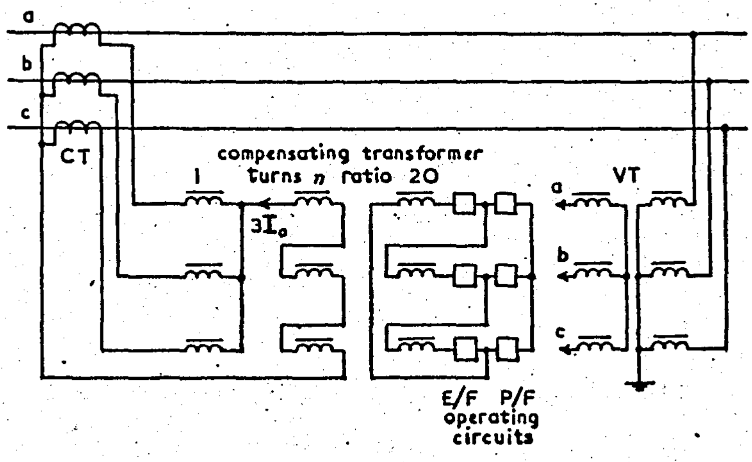


Fig 5.2 Residual compensation. Eart-fault (E/F) relays take phase voltage. Phase-fault (P/F) ralays take line voltage.

Also to have Z as primary impedance for single-phase-to-earth two different methods of residual and sound-phase compensation can be used which are special combination of C.T.s and V.T.s too. (Fig 5.3)

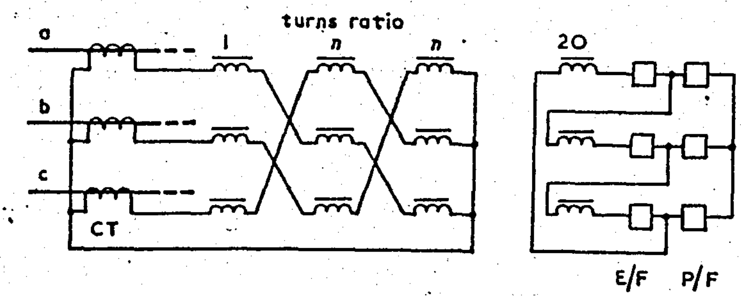


Fig 5.3 Sound-phase compensation

CHAPTER SIX

THE SYSTEM UNDER INVESTIGATION AND FAULT CALCULATIONS

The system consists of two parallel northern and southern transmission lines. These lines transfer electrical energy from Keban hydro-electric Generating station to Gölbaşı Station. The length of the lines is 546 kms and the values of line parameters are given in Table.2. The rated voltage of the lines is 380 KV.

The Keban Hydro-electric Generating station consists of two groups of generating units where each group has four identical generators with the rating of 175 MVA and 201.5 MVA respectively and the rated voltage is 14.4 KV. These generators are connected through corresponding delta/star step-up transformers to the common busbar of the sending end of the lines.

With reference to the information obtained from T.E.K (Türkiye Elektrik Kurumu), the rest of the grid connected to Gölbaşı-Station is represented by an assumed equivalent network consisting of two identical parallel lines with the length of one third and the same parameter/km. values as of the above mentioned lines connected through five identical step-up transformers to a group of five identical generators with the rating of 14.4 KV and 201.5 MVA. The necessary data about both plants are in Table 1 .

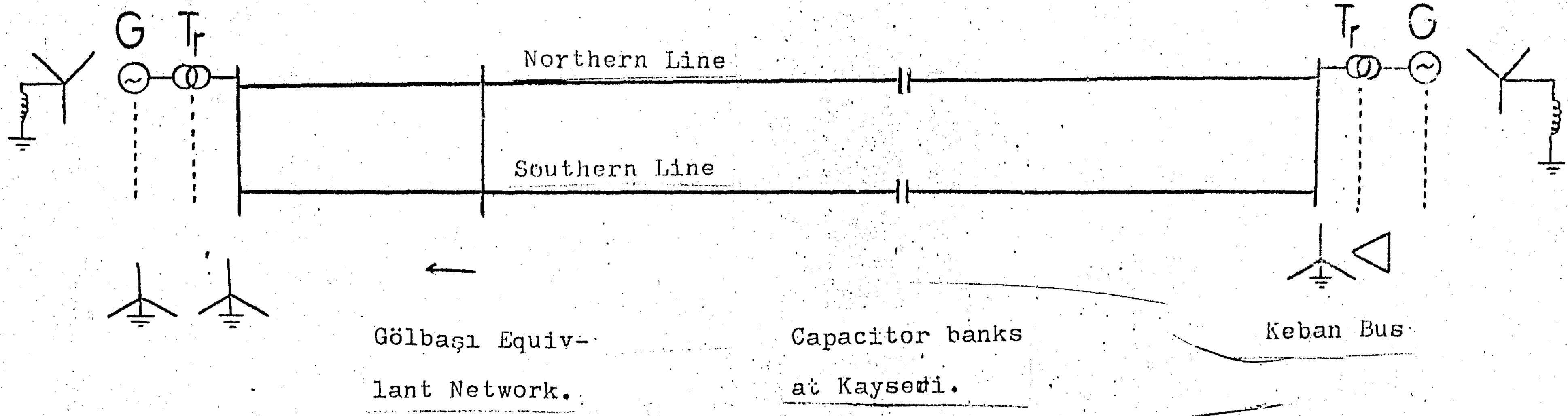

G
Tr
Northern Line
Southern Line
Tr
G
Gölbaşı Equivalant Network.
Capacitor banks at Kayseri.
Keban Bus

FIG 6.1

The length of the line from Gölbaşı to Kayseri (the location of capacitor banks) differes slightly from the Kayseri to Keban but in ' fault calculations ' it can be assumed that capacitors are inserted in the middle of the lines (Fig.6.1)

The base chosen in the calculations is 100 MVA and 380 KV and all other data are given in per unit with respect to this base.

6.1. The Thevenin Equivalent of Stations

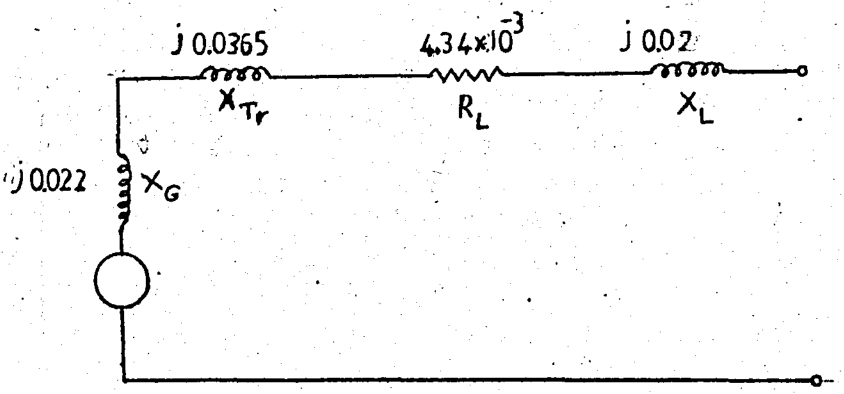


Fig.6.2.a. The Thevenin Equivalent of the Rest of the Turkey, Grid from Gölbaşı bus.

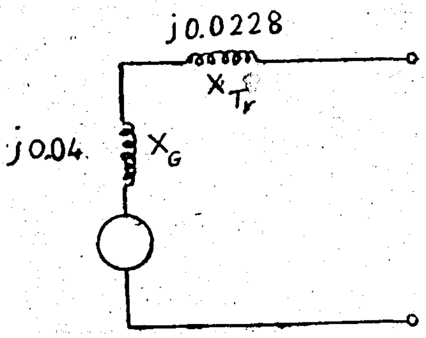


Fig 6.2.b The Thevenin Equivalent of Keban plant from Keban bus.

6.2. The Equivalent Sequence Networks of the System

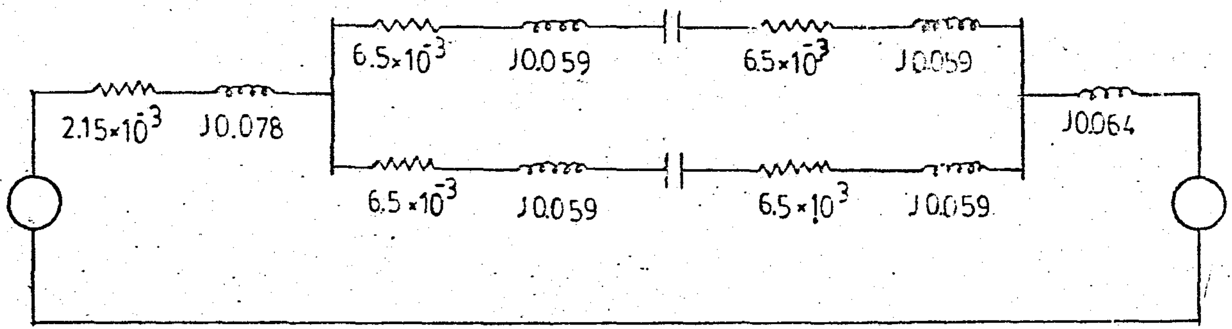


Fig 6.3.a. The Positive Sequence

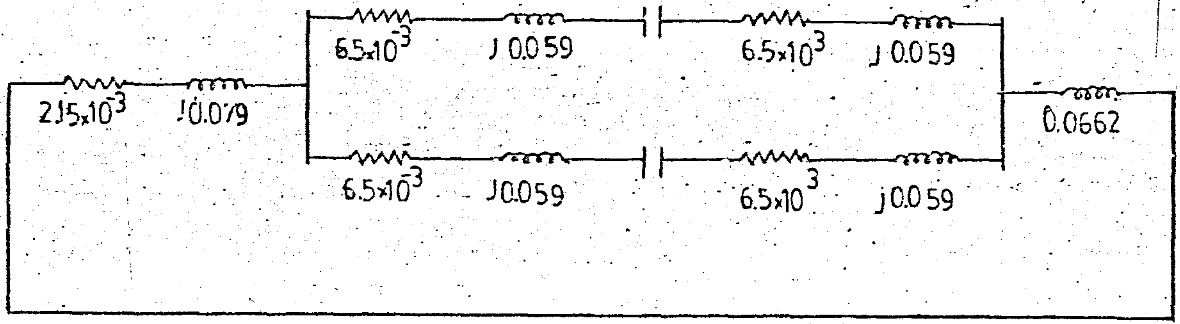


Fig 6.3.b. The Negative Sequence

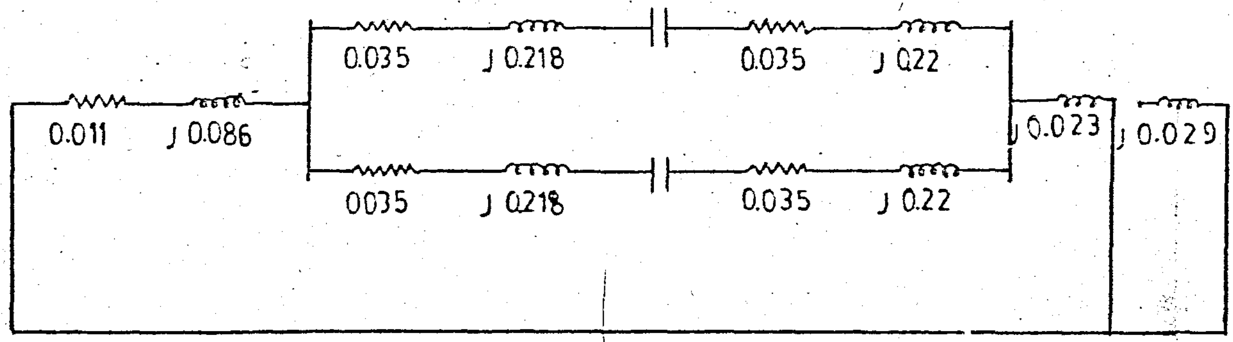
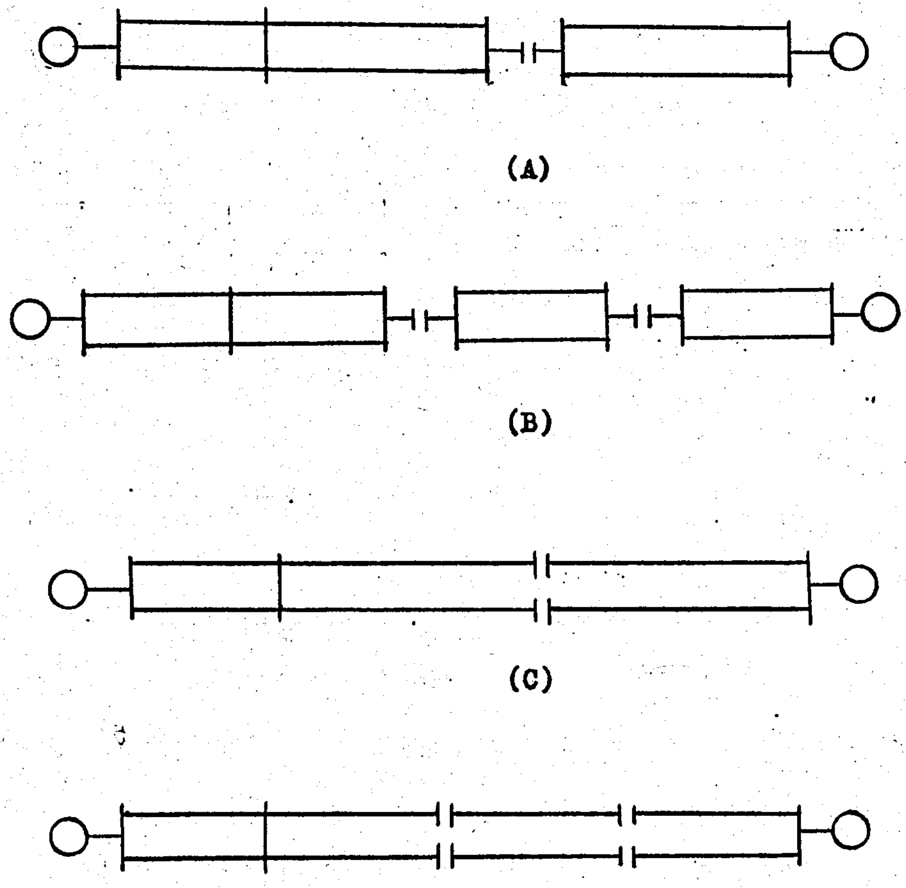


Fig 6.3.c. The Zero Sequence

6.3. Combination of Series Capacitors with the Lines

In order to reduce the reactance of the line, series capacitors can be inserted at different locations and in different combination . Some possible and practical types are given below:



(A)

(B)

(C)

(D)

FIG.6.4

The reactance of the capacitor banks is chosen to have the same compensation effect for any type of combination.

The above types of combination can be classified in two groups .

-the lines have common points where the capacitors are inserted, A and B types .

-the lines without any common points except at keban and Gölbaşı station , C and D types .

The first group has the advantage as viewed from stability point where as the second group is more reliable .

Also the type of combination affects on the rating of fault levels which is studied in the next section .

6.4. Fault Calculations

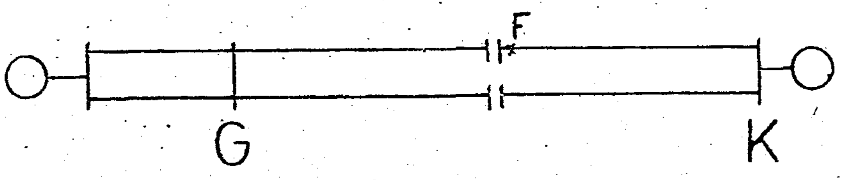
The main object of fault analysis is the calculation of fault levels for the determination of circuit breakers' capacity and performance of protective relays .

The principle short circuit faults (three phase , S.L.G, L.L.G and L.L) and open circuit faults at main buses and at the capacitor terminals are calculated for all abovecombination types . In the calculations the following permissible assumptions and approximations are made :

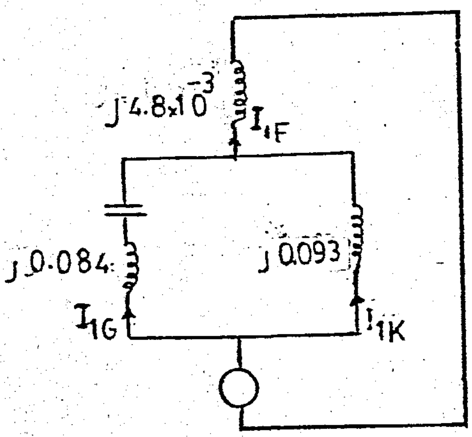
- the system is assumed to be under no - load conditions so the voltage behind the fault is taken one per unit ,
- the resistance of the system even under compensation is less than one fifth of its reactance , so is negligible ,
- shunt arm impedances are ignored and
- all generators are under operation .

The method used in the calculations is discussed by the following example . It is assumed that a fault developes at point F as shown below . Refered to the type of the fault the necessary combination of the sequence networks is given and - all figures are drawn after deltal star transformation process ,

- the currents with indicies of G and K (I_G and I_K) denote the currents feeding the fault location from Gölbaşı and Keban stations and I_T denotes the total fault current .



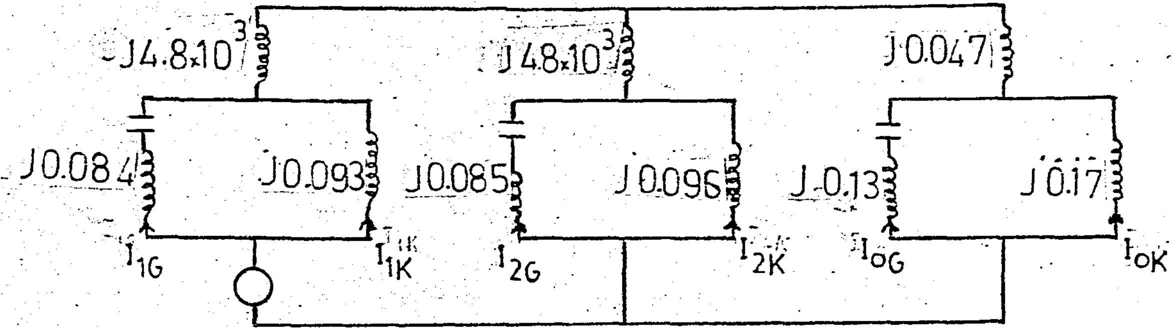
i) three phase fault



$I_{1K} = -J10.78$ $I_{1G} = -J9.67$

$I_F = -J\,20.45$

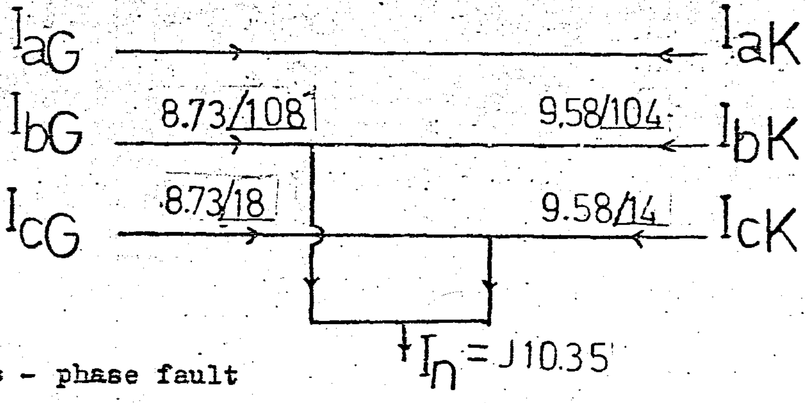
ii) Phase - to - Phase - to - ground fault



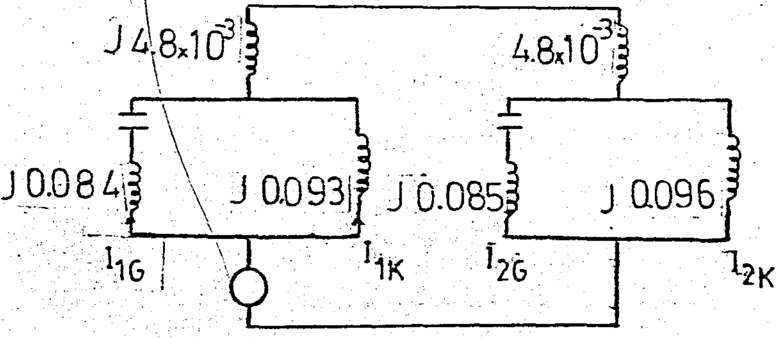
$I_{1K} = -j\ 5.61$ $\qquad$ $I_{1G} = -j6.25$

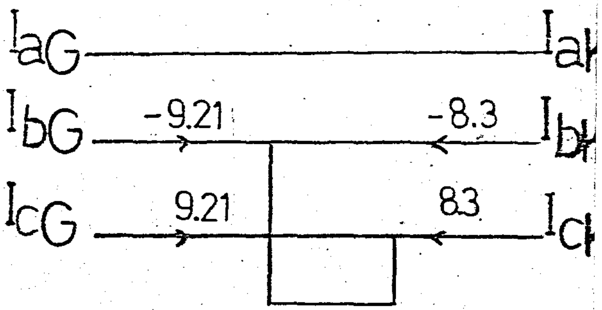
$I_{2K} = j\ 3.95$ $\qquad$ $I_{2G} = j\ 4.46$

$I_{0K} = j\ 1.95$ $\qquad$ $I_{0G} = j\ 1.50$



iii) Phase - to - phase fault

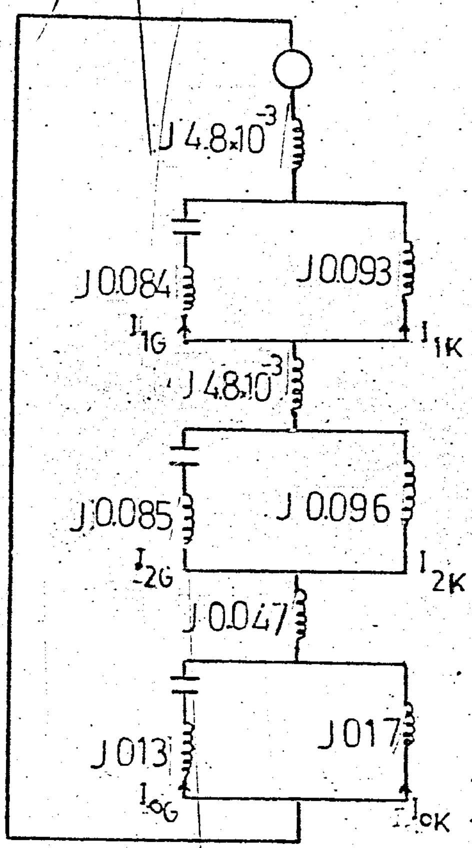




$I_{a1K} = -j\ 4.8$ $\qquad$ $I_{a1G} = -j\ 5.27$

$I_{a2K} = j\ 4.75$ $\qquad$ $I_{a2G} = j\ 5.36$

iv) Single - phase - ground fault



$I_{alf} = -j4.538$

$I_{af} = -j\ 13.6$

$I_{a1G} = -j\ 2.4$

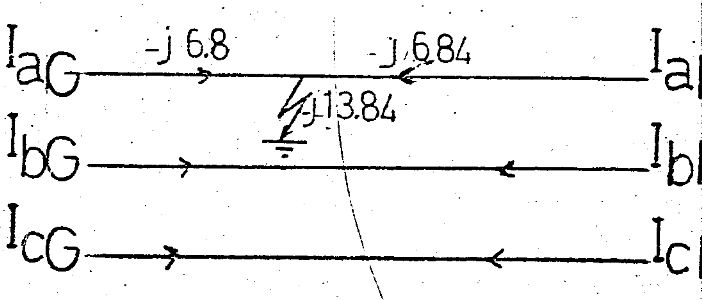
$I_{a2G} = -j\ 2.4$

$I_{a0G} = -j\ 1.97$

$I_{a1K} = -j\ 2.15$

$I_{a2K} = -j\ 2.13$

$I_{a0K} = -j\ 2.56$



The effect of different fault types on the southern line are little so negligible .

6.6 . Fault Calculation - Open Circuit

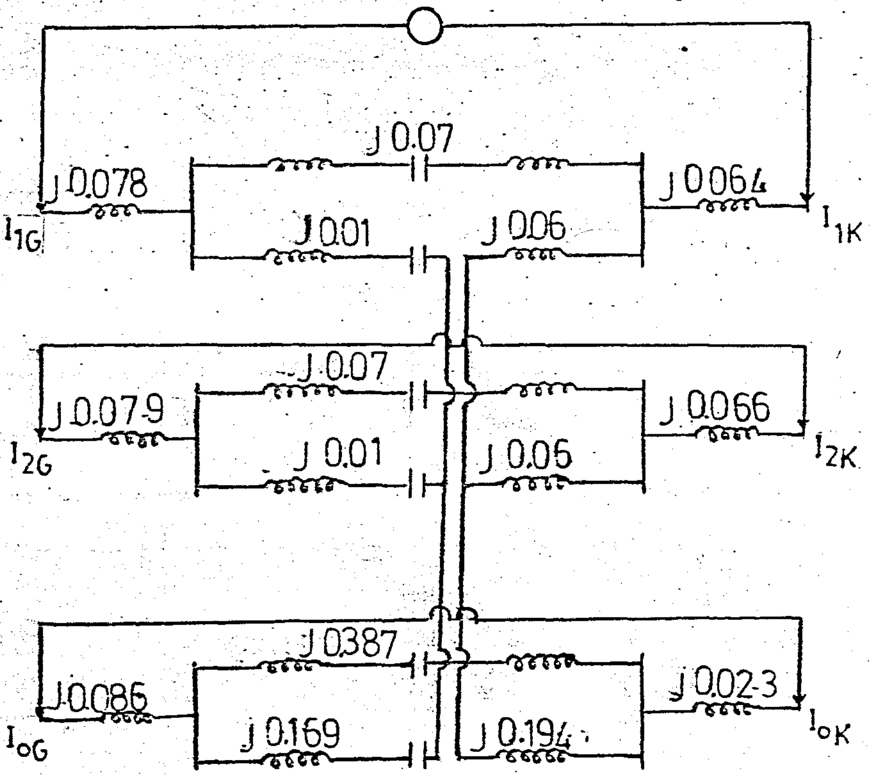
In order to obtain open circuit fault currents , the pre - fault should be known . In these calculations it is assumed that the system is operating at its rating current and p.f of 0.9 . So:

$$I_{1pf} = \frac{1025}{152} \; (0.9 - j \; 0.436)$$

$$= 6.7 \quad 25.8$$

The most important type of combination is tested as an example :

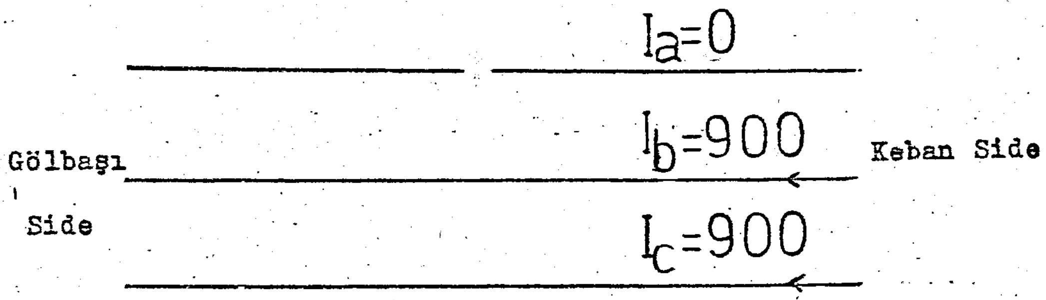
i) Single - phase open



$$I_{a1} = 3.45 - j\,1.67$$

$$I_{a2} = -2.76 + j\,1.334$$

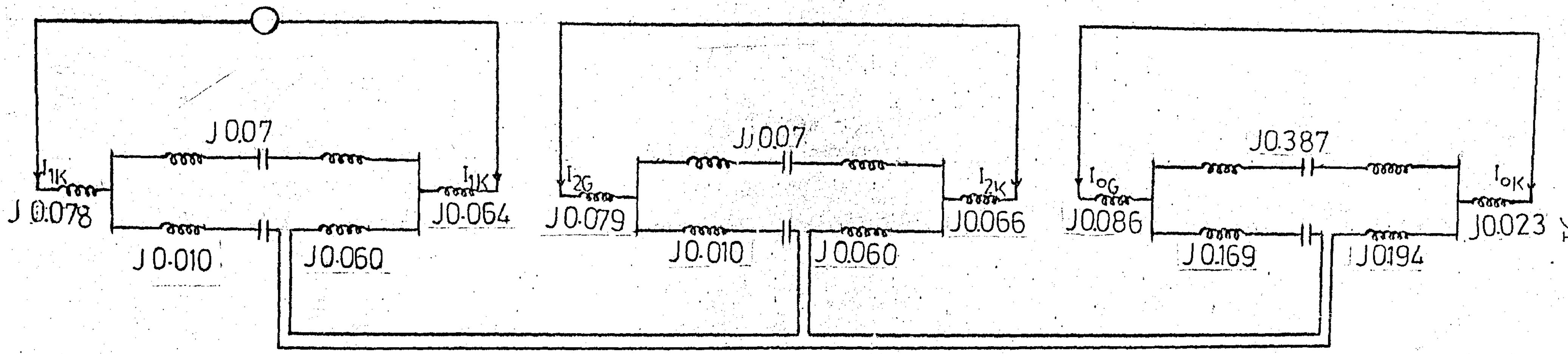
$$I_{a0} = -0.69 + j\,0.34$$



$I_{rated} = 1025$ A

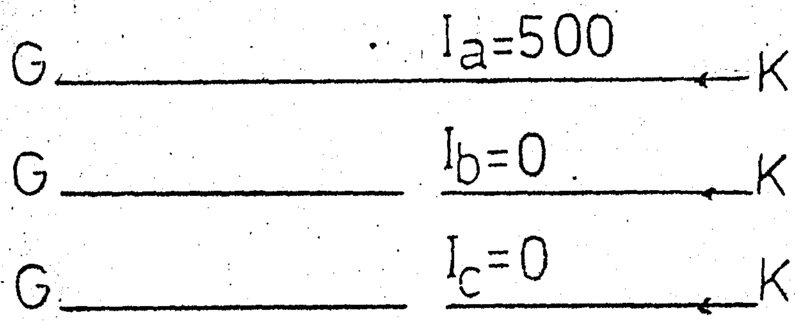
$I_{base} = 152$ A

ii) Two Phase Open



$I_1 = 1.15 \angle 205^\circ$

$I_a = 3.44 \angle 205^\circ$ p.u



Comparing the data obtained from the fault calculations, given in Tables 3.1-4, the following results are obtained:

-Since the neutrals of high voltage side of the transformers at Keban-Station are solidly grounded the rating of the single phase fault at this bus is higher than three-phase fault (Ref [4], Page 308) and

- fault levels at both sides of the capacitor terminals differ considerably which is important in setting the distance relays. Also for the case where capacitors are spread along the line (B and D types) the difference between fault levels at the same section produces important difficulties in setting the zones.

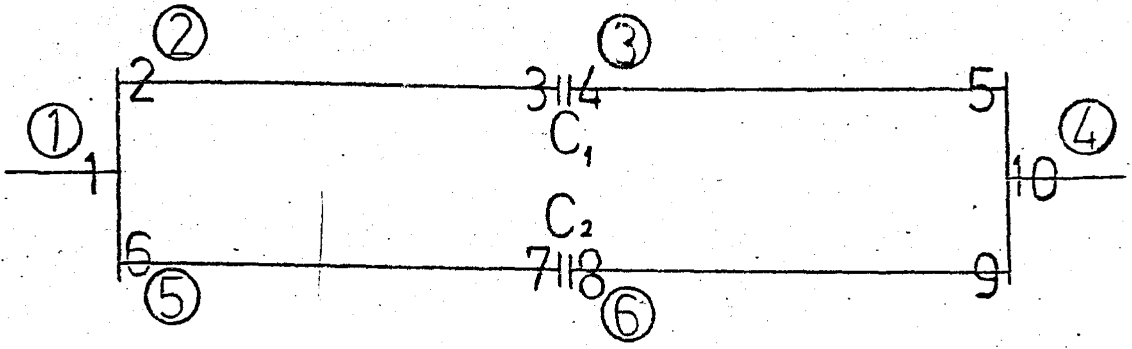
CHAPTER SEVEN

DISCUSSION

To be able to decide on the best choice from relay setting point of view , for different combination types , it is necessary to determine the extremum data.

With reference to the analysis of the results obtained from calculations (Table 3 and 4 given at the end) these necessary data , the per cent increase of voltage across capacitor terminals and the per cent increase of current in each line section with respect to their nominal values, are given in Tables 7.1 and 7.2 . in the following pages . Also for different fault types the maximum percentage of voltage - drop across capacitor terminals and maximum percentage of current passing through the line sections for any type of combination are shown in decreasing order in Tables 7.1.a and 7.2.a .

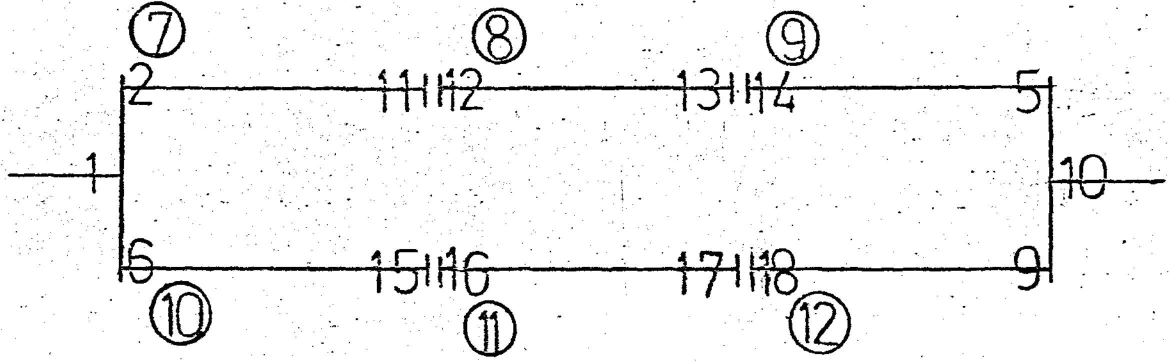
In the analysis of the different combinations the nominal values shown in the following figures are used .



$X_{C1} = X_{C2} = 35\Omega$ ($C_1 = C_2$)

I (C_1, C_2) = 1025 A

Vn (C_1, C_2)=35.87 Kv



$X_{C3} = X_{C4} = X_{C5} = X_{C6} = X_{C6} = \frac{1}{2} X_{C1} = 17.5\Omega$

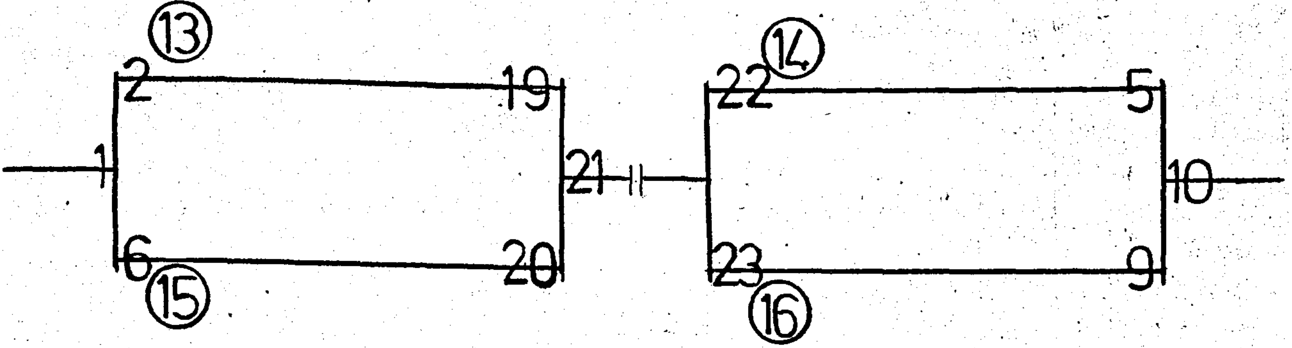
($C_3 = C_4 = C_5 = C_6 = 2C_1$)

In (C_3, C_4, C_5, C_6) = In (C_1, C_2) = 1025 A

Vn (C_3, C_4, C_5, C_6) $= \frac{1}{2}$ Vn (V_1, C_2)

- Numbers on the lines denote the fault locations.

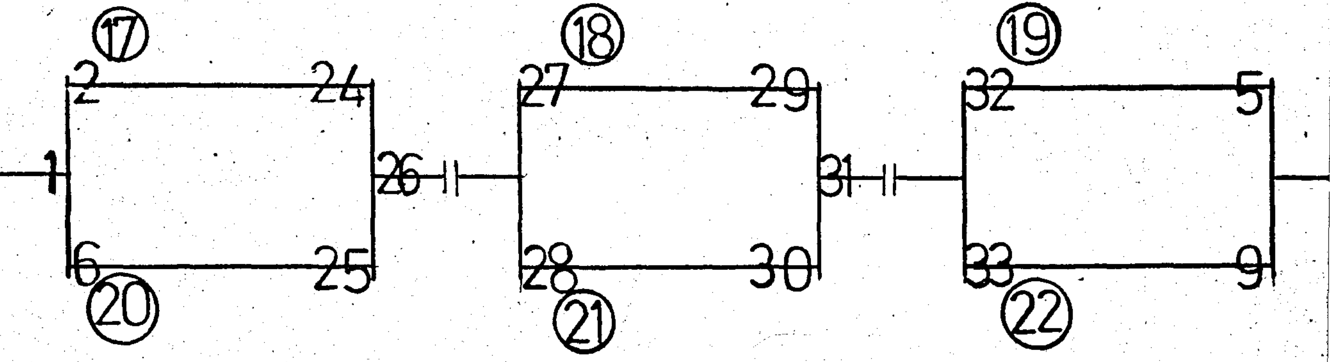
- Numbers inside the circules denote the line sections.



$X_{c7} = \frac{1}{2} XC_1 = 17.5$ $\quad$ ($C_7 = 2C_1$)

In (C_7) = 2 In (C_1,C_2) = 2050 A

Vn (C_7) = Vn (C_1,C_2) = 35.87 Kv



$X_{C8} = X_{C9} = \frac{1}{2} X_{C7} = 17.5$ $\quad$ ($C_8 = C_9 = 2C_7$)

In (C_8,C_9) = In (C_7) = 2050 A

Vn (C_8,C_9) = $\frac{1}{2}$ Vn (C_7) = 17.94 Kv

TABLES 7.1-9

Pecent Increase of the Voltage across Capacitors for Various Faults and Fault Locations

Capacitor C_1		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	74.45	74.45	210.5	143	65.0	74.45	-1.78	23	65	65.0
	S.L.G	57.5	57.5	129.6	100	57.15	57.5	0.7	0.7	57.15	57.15
	L.L.	63.8	63.8	163.9	123	56.0	63.8	1.1	1.1	56.0	64.45
	L.L.G	70.5	70.5	172.1	142.5	64.45	70.5	1.5	1.5	64.45	64.45

Capacitor C_2		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	74.45	74.45	-1.78	23	65	74.45	210.5	143	65.0	65.0
	S.L.G	57.5	57.5	0.7	0.7	57.15	57.5	129.6	100	57.15	57.15
	L.L	63.8	63.8	1.1	1.1	56.0	63.8	163.9	123	56.0	56
	L.L.G	70.5	70.5	1.5	1.5	64.45	70.5	172.1	142.5	64.45	64.45

Capacitor C_3		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3 - Phase	74.15	74.15	65.0	74.15	65.0	65.0	148.3	143.3	122.7	132.7
	S.L.G	57.15	57.15	57.15	57.15	57.15	57.15	114.8	105.4	80.3	85.9
	L.L	63.58	63.58	56.0	63.58	56	56	126.0	121.9	106.5	121.1
	L.L.G	70.8	70.8	64.45	70.8	64.45	64.45	141.6	136.6	109.3	114.3

Capacitor C_3		Fault Location									
		15	16	17	18						
Fault Type	3 - Phase	5.8	5.8	5.8	5.8						
	S.L.G	1.4	1.4	1.4	1.4						
	L.L	2.2	2.2	2.2	2.2						
	L.L.G	3.0	3.0	3.0	3.0						

Capacitor C_6		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3 - Phase	74.15	74.15	65.0	74.15	65.0	65.0	5.8	5.8	5.8	5.8
	S.L.G	57.15	57.15	57.15	57.15	57.15	57.15	1.4	1.4	1.4	1.4
	L.L	63.58	63.58	56.0	63.58	56	56	2.2	2.2	2.2	2.2
	L.L.G	70.8	70.8	64.45	70.8	64.45	64.45	3.0	3.0	3.0	3.0

Capacitor C_6		Fault Location									
		15	16	17	18						
Fault Type	3 - Phase	148.3	151.1	184	132.7						
	S.L.G	114.8	97.6	142.2	85.9						
	L.L	126	129.4	156.0	121.1						
	L.L.G	141.6	128.8	166.2	114.3						

Capacitor C_4		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3 - Phase	74.15	74.15	65.0	74.15	65.0	65.0	148.3	151.1	184	132.7
	S.L.G	57.15	57.15	57.15	57.15	57.15	57.15	114.8	97.6	142.2	85.9
	L.L	63.58	63.58	56.0	63.58	56.0	56.0	126	129.4	156.0	121.1
	L.L.G	70.8	70.8	64.45	70.8	64.45	64.45	141.6	128.8	166.2	114.3

Capacitor C_4		Fault Location									
		15	16	17	18						
Fault Type	3 - Phase	5.8	5.8	5.8	5.8						
	S.L.G	1.4	1.4	1.4	1.4						
	L.L	2.2	2.2	2.2	2.2						
	L.L.G	3.0	3.0	3.0	3.0						

Capacitor C_5		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3 - Phase	74.15	74.15	65.0	74.15	65.0	65.0	5.8	5.8	5.8	5.8
	S.L.G	57.15	57.15	57.15	57.15	57.15	57.15	1.4	1.4	1.4	1.4
	L.L	63.58	63.58	56.0	63.58	56.0	56.0	2.2	2.2	2.2	2.2
	L.L.G	70.8	70.8	64.45	70.8	64.45	64.45	3.0	3.0	3.0	3.0

Capacitor C_5		Fault Location									
		15	16	17	18						
Fault Type	3 - Phase	148.3	143.3	122.7	132.7						
	S.L.G	114.8	105.4	80.3	85.9						
	L.L	126.0	121.9	106.5	121.1						
	L.L.G	141.6	136.6	105.3	114.3						

Capacitor C_7		Fault Location									
		1	2	5	6	9	10	19	20	21	22
Fault Type	3 - Phase	75	75	64.9	75	64.9	64.9	107	107	107	88.4
	S.L.G	57.4	57.4	57.1	57.4	57.1	57.1	87.8	87.8	87.8	67.2
	L.L	63.8	63.8	56.3	63.8	56.3	56.3	91.2	91.2	91.2	76.1
	L.L.G	70.8	70.8	64.4	70.8	64.4	64.4	97.5	97.5	97.5	80.6

Capacitor C_7		Fault Location									
		23	24								
Fault Type	3 - Phase	88.4	88.4								
	S.L.G	67.2	67.2								
	L.L	76.1	76.1								
	L.L.G	80.6	80.6								

Capacitor C_8		Fault Location									
		1	2	5	6	9	10	25	26	27	28
Fault Type	3 - Phase	74.1	74.1	66.4	74.1	66.4	66.4	93.0	93.0	93.0	80.1
	S.L.G	57.4	57.4	57.0	57.4	57.0	57.0	73.0	73.0	73.0	65.2
	L.L	64.1	64.1	55.6	64.1	55.6	55.6	65.2	65.2	65.2	74.1
	L.L.G	70.1	70.1	64.7	70.1	64.7	64.7	85.9	85.9	85.9	74.7

Capacitor C_8		Fault Location									
		29	30	31	32	33	34	35	36		
Fault Type	3 - Phase	80.1	80.1	70.2	70.2	70.2	78.6	78.6	78.6		
	S.L.G	65.2	65.2	54.6	54.6	54.6	60.8	60.8	60.8		
	L.L	74.1	74.1	59.6	59.6	59.6	68.0	68.0	68.0		
	L.L.G	74.7	74.7	64.7	64.7	64.7	77.5	77.5	77.5		

Capacitor C_9		Fault Location									
		1	2	5	6	9	10	25	26	27	28
Fault Type	3 - Phase	74.1	74.1	66.4	74.1	66.4	66.4	93.0	93.0	93.0	85.7
	S.L.G	57.4	57.4	57.0	57.4	57.0	57.0	73.0	73.0	73.0	69.7
	L.L	64.1	64.1	55.6	64.1	55.6	55.6	65.2	65.2	65.2	69.1
	L.L.G	70.1	70.1	64.7	70.1	64.7	64.7	85.9	85.9	85.9	81.4

Capacitor C_9		Fault Location									
		29	30	31	32	33	34	35	36		
Fault Type	3 - Phase	85.7	85.7	103.7	103.7	103.7	78.6	78.6	78.6		
	S.L.G	69.7	69.7	96.5	96.5	96.5	60.8	60.8	60.8		
	L.L	69.1	69.1	89.2	89.2	89.2	60.0	60.0	60.0		
	L.L.G	81.4	81.4	99.2	99.2	99.2	77.5	77.5	77.5		

TABLE 7.a

Severe Voltage Percent Increase across the Terminals of Capacitors given in Deacreasing Order.

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase
Fault Type	3-Phase	1,2	3,7	210.5	4,6	13,17	184	4,6	16,12	151.1
	S.L.G	"	"	129.6	"	"	142.2	"	"	97.6
	L.L	"	"	163.0	"	"	156.0	"	"	129.4
	L.L.G	"	"	172.1	"	"	166.0	"	"	130

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase
Fault Type	3-Phase	4,6	11,15	148.3	3,5	12,16	143.3	1,2	4,8	143.0
	S.L.G	"	"	114.8	"	"	105.4	"	"	100.0
	L.L	"	"	126	"	"	121.9	"	"	123.0
	L.L.G	"	"	129	"	"	136	"	"	142.5

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase
Fault Type	3-Phase	4,6	14,18	132.7	3,5	13,17	122.7	7	21	107.0
	S.L.G	"	"	85.9	"	"	80.3	"	"	87.8
	L.L	"	"	121.1	"	"	106.5	"	"	91.2
	L.L.G	"	"	114.3	"	"	109.3	"	"	97.5

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Caapacitor	Fault Location	Percent Increase
Fault Type	3-Phase	9	31	103.7	8,9	27,27	93.0	7	23	88.4
	S.L.G	"	"	96.5	"	"	73.0	"	"	67.2
	L.L	"	"	89.2	"	"	65.2	"	"	76.1
	L.L.G	"	"	99.2	"	"	85.9	"	"	80.6

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase
Fault Type	3-Phase	9	29	85.7	8	28	80.1	9	35	78.6
	S.L.G	"	"	69.7	"	"	65.2	"	"	60.8
	L.L	"	"	69.1	"	"	74.1	"	"	60.0
	L.L.G	"	"	81.4	"	"	74.7	"	"	77.5

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase
Fault Type	3-Phase	1-9	1,2,6	75	1-9	5,9,10	65	1,2	8,4	23
	S.L.G	"	"	57.4	"	"	57.15	"	"	0.7
	L.L	"	"	63.8	"	"	56.3	"	"	1.1
	L.L.G	"	"	70.8	"	"	64.4	"	"	1.5

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase
Fault Type	3-Phase	2-6	16,16,13,13	5.8	1,2	7,3	-1.78			
	S.L.G	"	"	1.4	"	"	0.7			
	L.L	"	"	2.2	"	"	1.1			
	L.L.G	"	"	3.0	"	"	1.5			

		Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase	Capacitor	Fault Location	Percent Increase
Fault Type	3-Phase									
	S.L.G									
	L.L									
	L.L.G									

TABLES 7.2-22

Percent Increase of Currents through the line sections for various Faults and Fault Locations.

Line Section (1)		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	95.0	95.0	61.57	71.9	65.25	95.0	61.57	71.9	65.3	65.3
	S.L.G	90.5	90.5	39.3	50.45	57.1	90.5	39.5	50.45	57.1	57.1
	L.L	81.55	81.55	53.4	61.5	56.35	81.55	53.4	61.5	56.35	56.35
	L.L.G	92.65	92.65	54.9	71.2	64.5	92.65	54.9	71.2	64.5	64.5

Line Section (2)		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	74.2	74.2	105.3	144.0	65.2	74.2	-17.8	23.7	65.3	65.3
	S.L.G	57.8	57.8	77.1	100.9	57.1	57.8	1.5	1.5	57.1	57.1
	L.L	63.8	63.8	103.0	123.4	56.4	63.8	2.2	2.2	56.4	56.4
	L.L.G	70.5	70.5	104.0	142.4	65.5	70.5	3.0	3.0	64.5	64.5

Line Section (3)		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	74.2	74.2	193.5	160	65.3	74.2	-17.8	23.7	65.3	65.3
	S.L.G	57.8	57.8	132.0	100.0	57.1	57.8	1.5	1.5	57.1	57.1
	L.L	63.8	63.8	165.4	136.6	56.4	63.8	2.2	2.2	56.4	56.4
	L.L.G	70.5	70.5	175.0	137.5	64.5	70.5	3.0	3.0	64.5	64.5

Line Section (4)		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	74.2	74.2	105.3	68.25	116.5	65.3	105.3	68.25	116.5	116.5
	S.L.G	57.8	57.8	66.0	53.7	157.3	57.1	66.0	57.3	157.3	157.3
	L.L	63.8	63.8	82.7	69.35	98.7	56.4	82.7	69.35	98.7	98.7
	L.L.G	70.5	70.5	87.5	61.55	149.1	64.5	87.5	61.55	149.1	149.1

Line Section (5)		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	74.2	74.2	-17.8	23.7	65.3	74.2	105.3	144.0	65.3	65.3
	S.L.G	57.8	57.8	1.5	1.5	57.1	57.8	77.1	100.9	57.1	57.1
	L.L	63.8	63.8	2.2	2.2	56.4	63.8	103.0	123.4	56.4	56.4
	L.L.G	70.5	70.5	3.0	3.0	64.5	70.5	104.0	142.4	64.5	64.5

Line Section (6)		Fault Location									
		1	2	3	4	5	6	7	8	9	10
Fault Type	3-Phase	74.2	74.2	-17.8	23.7	65.2	74.2	190.5	160.0	65.3	65.3
	S.L.G	57.8	57.8	1.5	1.5	57.1	57.8	132.0	100.0	57.1	57.1
	L.L	63.8	63.8	2.2	2.2	56.4	63.8	165.4	136.6	56.4	56.4
	L.L.G	70.5	70.5	3.0	3.0	64.5	70.5	175.0	137.5	64.5	65.5

Line Section (7)		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	65.3	126.1	143.0	122.7	132
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	89.0	105.3	80.1	86.0
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	108.3	121.7	105.3	121.6
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	120.2	129.1	109.8	114.2

Line Section (7)		Fault Location									
		15	16	17	18						
Fault Type	3-Phase	5.9	5.9	5.9	5.9						
	S.L.G	1.5	1.5	1.5	1.5						
	L.L	2.2	2.2	2.2	2.2						
	L.L.G	2.97	2.97	2.97	2.97						

Line Section (8)		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	65.3	155.8	151.5	122.7	132
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	106.4	97.9	80.1	86.0
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	133.5	130.5	105.3	121.6
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	120.1	136.5	109.8	114.2

Line Section (8)		Fault Location									
		15	16	17	18						
Fault Type	3-Phase	5.9	5.9	5.9	5.9						
	S.L.G	1.5	1.5	1.5	1.5						
	L.L	2.2	2.2	2.2	2.2						
	L.L.G	2.97	2.97	2.97	2.97						

Line Section (9)		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	65.3	155.8	151.5	183.2	148.4
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	106.4	97.9	142.4	118.7
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	133.5	130.5	155.8	128.6
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	120.1	135.5	166.1	139.4

Line Section (9)		Fault Location									
		15	16	17	18						
Fault Type	3-Phase	5.9	5.9	5.9	5.9						
	S.L.G	1.5	1.5	1.5	1.5						
	L.L	2.2	2.2	2.2	2.2						
	L.L.G	2.97	2.97	2.97	2.97						

Line Section (10)		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3 - Phase	74.2	74.2	65.3	74.2	65.3	65.3	5.9	5.9	5.9	5.9
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	1.5	1.5	1.5	1.5
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	2.2	2.2	2.2	2.2
	L.L.G	70,5	70.5	64.5	70.5	64.5	64.5	2.97	297	2.97	2.97

Line Section (10)		Fault Location									
		15	16	17	18						
Fault Type	3 - Phase	126.1	143.0	122.7	132.0						
	S.L.G	83.0	105.3	80.1	86.0						
	L.L	108.3	121.7	105.3	121.6						
	L.L.G	120.2	129.1	109.8	114.2						

Line Section (11)		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	65.3	5.9	5.9	5.9	5.9
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	1.5	1.5	1.5	1.5
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	2.2	2.2	2.2	2.2
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.4	2.97	2.97	2.97	2.97

Line Section (11)		Fault Location									
		15	16	17	18						
Fault Type	3-Phase	155.8	151.5	122.7	132						
	S.L.G	106.4	97.9	80.1	86.0						
	L.L	133.5	130.5	105.3	121.6						
	L.L.G	120.1	136.5	109.8	144.2						

Line Section (12)		Fault Location									
		1	2	5	6	9	10	11	12	13	14
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	65.3	5.9	5.9	5.9	5.9
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	1.5	1.5	1.5	1.5
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	2.2	2.2	2.2	2.2
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	2.97	2.97	2.97	2.97

Line Section (12)		Fault Location									
		15	16	17	18						
Fault Type	3-Phase	155.8	151.5	183.2	148.4						
	S.L.G	106.4	97.9	142.4	118.7						
	L.L	133.5	130.5	155.8	128.6						
	L.L.G	120.1	138.5	166.1	139.4						

Line Section (13)		Fault Location									
		1	2	5	6	9	19	20	21	22	23
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	68.6	68.6	68.6	88.3	88.3
	S.L.G	57.8	57.8	57.1	57.8	57.1	54.9	54.9	54.9	67.6	67.6
	L.L	63.8	63.8	56.4	63.8	56.4	59.3	59.3	59.3	76.4	76.4
	L.L.G	70.5	70.5	64.5	70.5	64.5	65.3	65.3	65.3	80.9	80.9

Line Section (14)		Fault Location									
		1	2	5	6	9	19	20	21	22	23
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	107.6	107.6	107.6	79.4	79.4
	S.L.G	57.8	57.8	57.1	57.8	57.1	89.0	89.0	89.0	68.3	68.3
	L.L	63.8	63.8	56.4	63.8	56.4	91.2	91.2	91.2	67.5	67.5
	L.L.G	70.5	70.5	64.5	70.5	64.5	97.9	97.9	97.9	74.9	74.9

Line Section (15)		Fault Location									
		1	2	5	6	9	19	20	21	22	23
Fault Type	3 - Phase	74.2	74.2	65.3	74.2	65.3	68.6	68.6	68.6	88.3	88.3
	S.L.G	57.8	57.8	57.1	57.8	57.1	54.9	54.9	54.9	67.6	67.6
	L.L	63.8	63.8	56.4	63.8	56.4	59.3	59.3	59.3	76.4	76.4
	L.L.G	70.5	70.5	64.5	70.5	64.5	65.3	65.3	65.3	80.9	80.9

Line Section (16)		Fault Location									
		1	2	5	6	9	19	20	21	22	23
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	107.6	107.6	107.6	79.4	79.4
	S.L.G	57.8	57.8	57.1	57.8	57.1	89.0	89.0	89.0	68.3	68.3
	L.L	63.8	63.8	56.4	63.8	56.4	91.2	91.2	91.2	67.5	67.5
	L.L.G	70.5	70.5	64.5	70.5	64.5	97.9	97.9	97.9	74.9	74.9

Line Section (17)		Fault Location									
		1	2	5	6	9	10	24	25	26	27
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	65.3	75.7	81.6	70.5	81.6
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	62.3	65.3	54.9	65.3
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	80.1	74.2	60.0	74.2
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	70.5	74.9	64.5	74.9

Line Section (17)		Fault Location									
		28	29	30	31	32	33				
Fault Type	3-Phase	81.6	70.5	70.5	70.5	78.6	78.6				
	S.L.G	65.3	54.9	56.9	56.9	60.8	60.8				
	L.L	74.2	60.0	60.0	60.0	75.7	75.7				
	L.L.G	74.9	64.5	64.5	64.5	71.9	71.9				

Line Section (18)		Fault Location									
		1	2	5	6	9	10	24	25	26	27
Fault Type	3-Phase	74.2	74.2	65.3	74.2	65.3	65.3	94.2	94.2	94.2	86.0
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	73.4	73.4	73.4	69.7
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	65.3	65.3	65.3	69.4
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	86.0	86.0	86.3	81.6

Line Section (18)		Fault Location									
		28	29	30	31	32	33				
Fault Type	3 - Phase	86.0	70.5	70.5	70.5	78.6	78.6				
	S.L.G	69.7	54.9	54.9	54.9	60.8	60.8				
	L.L	69.4	60.0	60.0	60.0	67.5	67.5				
	L.L.G	81.6	64.5	64.5	64.5	71.9	71.9				

Line Section (19)		Fault Location									
		1	2	5	6	9	10	24	25	26	27
Fault Type	3 - Phase	74.2	74.2	65.3	74.2	65.3	65.3	94.2	94.2	94.2	86.0
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	73.4	73.4	73.4	69.7
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	65.3	65.3	65.3	69.4
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	86.0	86.0	86.0	81.6

Line Section (19)		Fault Location									
		28	29	30	31	32	33				
Fault Type	3 - Phase	86.0	103.8	103.8	103.8	89.0	89.0				
	S.L.G	69.7	96.0	96.0	96.0	83.0	83.0				
	L.L	69.4	89.0	89.0	89.0	75.7	75.7				
	L.L.G	81.6	99.4	99.4	89.0	86.0	86.0				

Line Section (20)		Fault Location									
		1	2	5	6	9	10	24	25	26	27
Fault Type	3 - Phase	74.2	74.2	65.3	74.2	65.3	65.3	75.7	81.6	70.5	81.6
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	62.3	65.3	54.9	65.3
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	80.1	74.2	60.0	74.2
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	70.5	74.9	64.5	74.9

Line Section (20)		Fault Location									
		28	29	30	31	32	33				
Fault Type	3 - Phase	81.6	70.5	70.5	70.5	78.6	78.6				
	S.L.G	65.3	54.9	56.9	56.9	60.8	60.8				
	L.L	74.2	60.0	60.0	60.0	75.7	75.7				
	L.L.G	74.9	64.5	64.5	64.5	71.9	71.9				

Line Section (21)		Fault Location									
		1	2	5	6	9	10	24	25	26	27
Fault Type	3 - Phase	74.2	74.2	65.3	74.2	65.3	65.3	94.2	94.2	94.2	86
	S.L.G	57.8	57.8	57.1	57.8	57.1	57.1	73.4	73.4	73.4	69.7
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	65.3	65.3	65.3	69.4
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	86.0	86.0	86.3	81.6

Line Section (21)		Fault Location									
		28	29	30	31	32	34				
Fault Type	3 - Phase	86.0	70.5	70.5	70.5	78.6	78.6				
	S.L.G	69.7	56.9	54.9	54.9	60.8	60.8				
	L.L	69.4	60.0	60.0	60.0	67.5	67.5				
	L.L.G	81.6	64.5	64.5	64.5	71.9	71.9				

Line Section (22)		Fault Location									
		1	2	5	6	9	10	24	25	26	27
Fault Type	3 - Phase	74.2	74.2	65.3	74.2	65.3	65.3	94.2	94.2	94.2	86.0
	S.L.G	57.8	57.8	59.1	57.8	57.1	57.1	73.4	73.4	73.4	69.7
	L.L	63.8	63.8	56.4	63.8	56.4	56.4	64.3	65.3	65.3	69.4
	L.L.G	70.5	70.5	64.5	70.5	64.5	64.5	86.0	86.0	86.0	81.6

Line Section		Fault Location									
		28	29	30	31	32	33				
Fault Type	3 - Phase	86.0	103.8	103.8	103.8	89.0	89.0				
	S.L.G	69.7	96.0	96.0	96.0	83.0	83.0				
	L.L	69.7	89.0	89.0	89.0	75.7	75.7				
	L.L.G	81.6	99.4	99.4	99.4	86.0	86.0				

TABLE 7.b

Severe Current Percent Increase the line sections given in Decreasing Order.

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	3,6	9,7	193.5	9,12	13,17	183.2	3,6	4,8	160.0
	S.L.G	3,6	9,7	132.0	9,12	13,17	142.4	3,6	4,8	100.0
	L.L	3,6	9,7	165.4	9,12	13,17	155.8	3,6	4,8	136.6
	L.L.G	3,6	9,7	175.0	9,12	13,17	166.1	3,6	4,8	137.5

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	8,9,11	11,12,15	155.8	8,11	12,16	151.5	9,12	14,18	148.4
	S.L.G	8,9,11	11,12,15	106.4	8,11	12,16	97.9	9,12	14,18	118.7
	L.L	8,9,11	11,12,15	133.5	8,11	12,16	130.5	9,12	14,18	128.6
	L.L.G	8,11	11,12,15	136.5	8,11	12,16	136.5	9,12	14,18	139.4

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	2,5	4,8	144.0	7,10	12,16	143	7,8,11	14,14,18	132.0
	S.L.G	2,5	4,8	100.9	7,10	12.16	105.3	7,8,11	14,14,18	86.0
	L.L	2,5	4,8	123.4	7,10	12,16	121.7	7,8,11	14,14,18	121.6
	L.L.G	2,5	4,8	142.4	7,10	12,16	129.1	7,8,11	14,14,18	114.2

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	7,10	11,15	126.1	7,10	13,17	122.7	4,4	5,10	116.5
	S.L.G	7,10	11,15	89.0	7,10	13,17	80.1	4,4	5,10	157.3
	L.L	7,10	11,15	108.3	7,10	13,17	105.3	4,4	5,10	98.7
	L.L.G	7,10	11,15	120.2	7,10	13,17	109.8	4,4	5,10	149.1

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	14,16	21,21	107.6	2,5	3,7	105.3	19,22	31,30	103.8
	S.L.G	14,16	21,21	89.0	2,5	3,7	77.1	19,22	31,30	96
	L.L	14,16	21,21	91.2	2,5	3,7	103	19,22	31,30	89
	L.L.G	14,16	21,21	97.9	2,5	3,7	104	19,22	31,30	99.4

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	1,1	1,2	95	18,19	24,24	94.2	19,22	32,32	89.0
	S.L.G	1,1	1,2	90.5	18,19	24,24	73.4	19,22	32,32	83.0
	L.L	1,1	1,2	81.55	18,19	24,24	65.3	19,22	32,32	75.7
	L.L.G	1,1	1,2	92.65	18,19	24,24	86.3	19,22	32,32	86.0

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	15,13	22,22	88.3	18,19	27,27	86	20,17	27,27	81.6
	S.L.G	15,13	22,22	67.6	18,19	27,27	69.7	20,17	27,27	65.3
	L.L	15,13	22,22	76.4	18,19	27,27	69.4	20,17	27,27	74.2
	L.L.G	15,13	22,22	80.9	18,19	27,27	81.6	20,17	27,27	74.9

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	14,16	22,22	79.4	17,18,20	32,32,32	78.6	17,20	24,24	75.7
	S.L.G	14,16	22,22	68.3	17,18,20	32,32,32	60.8	17,20	24,24	62.3
	L.L	14,16	22,22	67.5	17,18,20	32,32,32	75.7	17,20	24,24	80.1
	L.L.G	14,16	22,22	74.9	17,18,20	32,32,32	71.9	17,20	24,24	70.5

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	2-22	1,2,6	74.2	1,11	4,7	71.9	17,21	30,31	70.5
	S.L.G	2-22	1,2,6	57.8	1,11	4,7	50.5	17,21	30,31	54.9
	L.L	2-22	1,2,6	63.8	1,11	4,7	61.5	17,21	30,31	60.0
	L.L.G	2-22	1,2,6	70.5	1,11	4,7	71.2	17,21	30,31	64.5

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	13,15	20,20	68.6	1-22	5,9,10	65.3	5,7	1,1	61.57
	S.L.G	13,15	20,20	54.9	1-22	5,9,10	57.1	5,7	1,1	39.3
	L.L	13,15	20,20	59.3	1-22	5,9,10	56.4	5,7	1,1	53.4
	L.L.G	13,15	20,20	65.3	1-22	5,9,10	64.5	5,7	1,1	54.9

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase	2,6	8,4	23.7	7,10	16,12	5.9	3,5	7,3	-17.8
	S.L.G	2,6	8,4	1.5	7,10	16,12	1.5	3,5	7,3	1.5
	L.L	2,6	8,4	2.2	7,10	16,12	2.2	3,5	7,3	2.2
	L.L.G	2,6	8,4	3.0	7,10	16,12	2.9	3,5	7,3	3.0

		Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase	Line Section	Fault Location	Percent Increase
Fault Type	3-Phase									
	S.L.G									
	L.L									
	L.L.G									

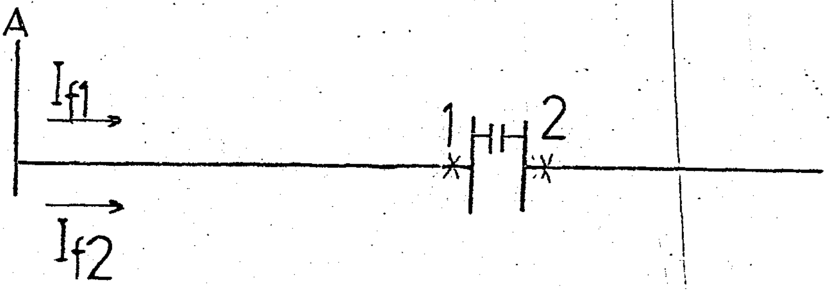
CONCLUSION

From the reliablity point of view , the C and D types of combination are prefered , since the system contists of two independent parallel lines , in case of a fault in one of them the other line will continue its normal operation .

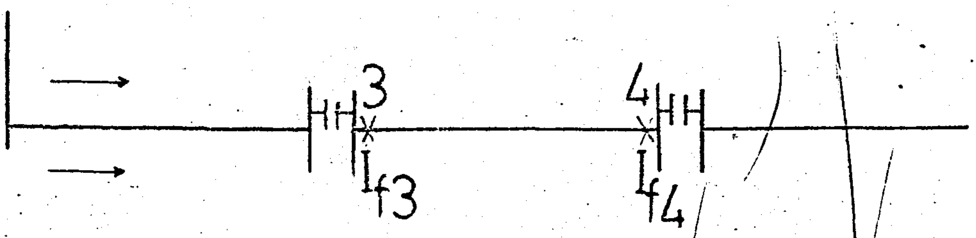
From stability point of view , B and A combination types are prefered respectively . When the faulted line section is removed , the increase in line reactance of these types will be less than the others .

From protection point of view the following problems will exist :

I_{f1} and I_{f2} are the currents feeding fault locations 1 and 2 close to the capacitor buses . With reference to the calculations the magnitude of I_{f2} is considerably greater than I_{f1} , meaning a fault standing in reach of second zone of distance relaying system located at A will have much greater magnitude . So care should be taken in setting the relays .



Spreading the capacitor banks along the line as shown below may have the following advantages :



- smaller step drops in line voltage and relatively uniform voltage along the line and

- Lower voltag - drop level across capacitor terminals during faults .

But there will be serious difficulties in setting the distance relays .

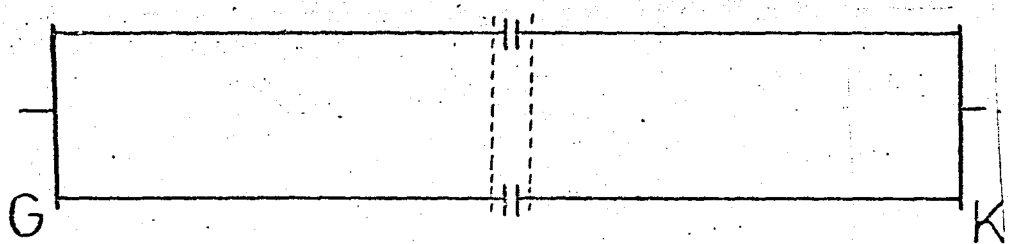
Refered to the results of calculations , if I_{f3} and I_{f4} are currents feeding a single - Phase - to - ground fault at point 3 and a three - phase fault at point 4 respectively , the magnitude of I_{f4} is considerably greater than I_{f3} . So setting the zone one for I_{f4} , the relay will see negative reactance resulting in its disability to operate for the fault at point 3 .

Considering the above factors , the following suggestion is given : since the system is the main interconnector of the main electrical energy source of Turkey to the rest of the grid , its reliable and permanent operation becomes the most important factor . There-fore the C type is the best combination since it is one of the most reliable ones .

The advantages of the C type to the D type are :

- the insallation cost is less and
- the relaying coordination is much simpler , easier and more accurate.

The increase of power transfer can be achieved using two spare busbars at both sides of capacitor banks . These buses which are shown by dashed lines enter operation when one of the lines from the left or right sides is removed from operation.



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NAME OF POWER PLANT	KEBAN		GÖLBAŞI Thevenin Equivalent
No. of GENERATORS	1 - 4	5 - 8	1 - 5
RATED POWER (MVA)	175	201.25	201.25
Cos ø	0.9	0.9	0.9
Speed (rgm)	166.7	166.67	166.67
Rated Voltage (kV)	14.4	14.4	14.4
Gb^2 (tm^2)	16014	18500	18500
H. (MW sec)/ MVA	3.5	3.52	3.52
X_d (%)	92/83[b]	87/81[b]	87/81
X_q "	70	61/57[b]	61/57
X_d^1 "	29	32/30[b]	32/30
X_q^1 "	70	61/57[b]	61/57
X_d'' "	19	22	221
X_q'' "	22	24	24
X_2 "	20.5	23	23
X_o "	11	8.5	8.5
X_p "	21	25	25
Tdo (sec)	6.01	72	72
T d'	2.1	2.65	2.65
T d"	0.032	0.04	0.04

Cont.

Table 1 - Necessary data of the Plants

T''_d	0.02	0.027	0.027
T''_{qo}	0.0827	0.1425	0.1425
T''_q	0.026	0.06	0.06
T_a	0.277	0.24	0.24
T_A	7.77	7.82	7.82

STEP - UP TRANSFORMER DATA			
No of Phases	1	1	1
Vector Group Symbols	Ynd1	Ynol 1	Ynol 1
Rated Out put (MVA)	60.3	60.3	60.3
No Load Rotio (kv)	14.4 /380	14.4/380	14.4 / 380
Tap Range (%)	+2 X 5 -2 X 2.5	+2 X 5 -2 X 2.5	+2 X 5 -2 X 2.5
Impedance (%)	11	11	11

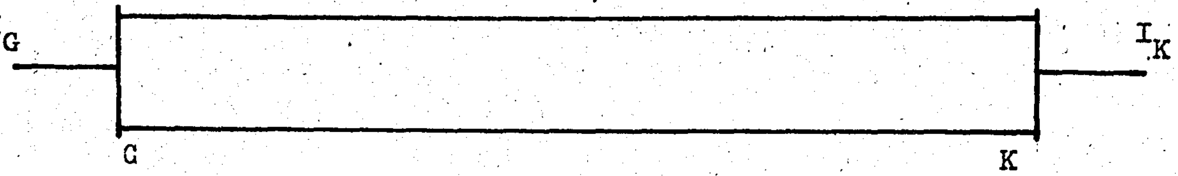
Table 1.

	Gölbaşı - Kayseri	Kayseri - Keban
Length (km)	271	275
Voltage (Kv)	380	380
R (Ohm)	9.4	9.5
Cross Section	R2X 945	R2X 945
X (Ohm)	85.3	86.5
y (Mmho)	937.0	950.0
R_o (Ohm)	49.6	50.3
X_o (Ohm)	312.1	316.7
Y_o (Mmho)	481.2	488.3

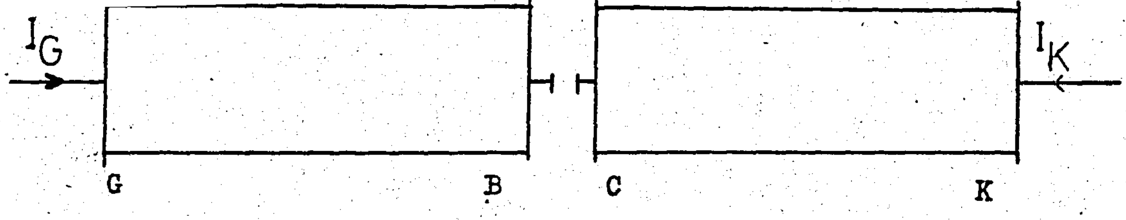
Table 2 - Data of the Lines.

TABLES 3.1-4

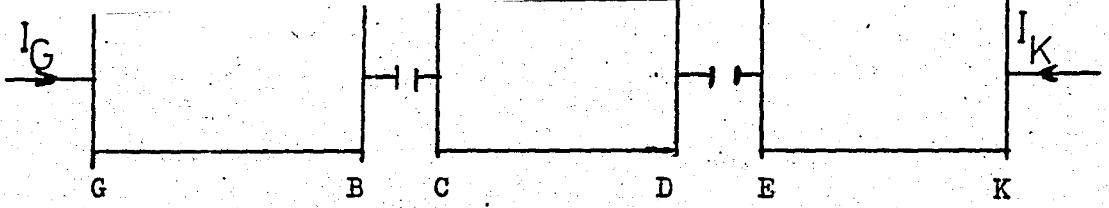
Rating of Fault Currents at Fault Locations (I_T), from Gölbaşı (I_G) and Keban (I_K) Buses



Type of The Fault		Fault Location					
		G			K		
		I_G	I_K	I_T	I_G	I_K	I_T
Three Phase	P.U.	12.75	8.1	20.85	7.2	15.7	22.9
	R(A)	1940	1230	3160	1100	2380	3480
S . L . G	P.U.	12.23	6.5	18.7	6.5	20.9	27.4
	R(A)	1860	990	2850	990	3170	4160
L . L	P.U.	11.0	6.9	17.9	6.3	13.3	19.6
	R(A)	1660	1060	2720	950	2030	2980
L . L . G	P.U.	12.5	7.6	20.1	7.0	20.1	27.1
	R(A)	1900	1160	3060	1060	3060	4120

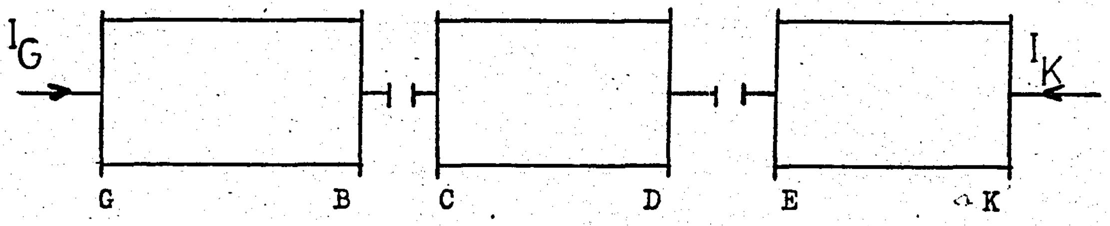


Type of The Fault		Fault Location											
		G			B			C			K		
		I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T
Three - Phase	P.U	12.75	10.0	22.8	9.25	14.5	23.7	11.9	10.7	22.6	8.8	15.7	24.5
	R(A)	1940	1530	3470	1400	2200	3600	1810	1630	3440	1330	2390	3720
S . L . G	P.U	12.2	7.8	20	7.4	12.0	19.4	9.11	9.21	18.33	7.7	21.2	28.9
	R(A)	1850	1180	3040	1120	1800	2950	1385	1400	2790	1170	3200	4370
L . L	P.U	11	8.6	19.6	8.0	12.3	20.3	10.3	9.1	19.4	7.6	13.3	20.9
	R(A)	1670	1310	2980	1210	1870	3080	1560	1380	2950	1150	2030	3180
L . L . G	P.U	12.5	9.5	21.3	8.8	13.2	22	10.9	10.1	21	8.7	20.1	28
	R(A)	1900	1450	3230	1340	2000	3340	1650	1530	3180	1320	3060	4260



Type of The Fault		Fault Location											
		G			B			C			D		
		I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T
Three - phase	P.U	12.8	10	22.8	10.2	12.7	22.8	11	11.6	22.6	9.5	14	23.5
	R(A)	1940	1525	3470	1550	1920	3470	1660	1760	3440	1440	2130	3560
S . L . G	P.U	12.2	7.8	20.0	8.4	9.9	18.3	8.8	9.4	18.2	7.4	13.0	20.4
	R(A)	1854	1180	3030	1280	1500	2780	1340	1430	2770	1120	1980	3100
L . L	P.U	11.0	8.6	19.6	10.8	8.8	19.6	10.0	9.35	19.35	8.1	12.0	20.1
	R(A)	1670	1310	2980	1640	1340	3000	1520	1420	2940	1230	1824	3060
L . L . G	P.U	12.5	9.5	21.3	9.5	11.6	21.1	10.0	11.0	21	8.7	13.4	22.1
	R(A)	1900	1450	1130	1440	1760	3200	1520	1670	3170	1320	2040	3340

Cont.



Type of the Fault		Fault Location											
		E			K								
		I_G	I_K	I_T	I_G	I_K	I_T						
Three - phase	P.U	10.6	12.0	22.6	8.8	15.7	24.5						
	R(A)	1610	1820	3440	1330	2390	3720						
S . L . G	P.U	8.2	11.2	19.4	7.7	21.2	28.9						
	R(A)	1250	1700	2950	1170	3200	4370						
L . L	P.U	9.1	10.2	19.4	7.6	13.3	20.9						
	R(A)	1380	1550	2940	1150	2030	3180						
L . L . G	P.U	9.7	11.6	21.3	8.7	20.1	28						
	R(A)	1480	1770	3230	1320	3060	4260						

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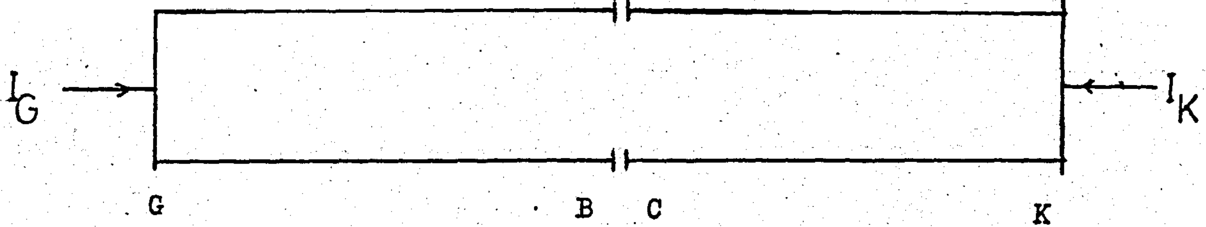
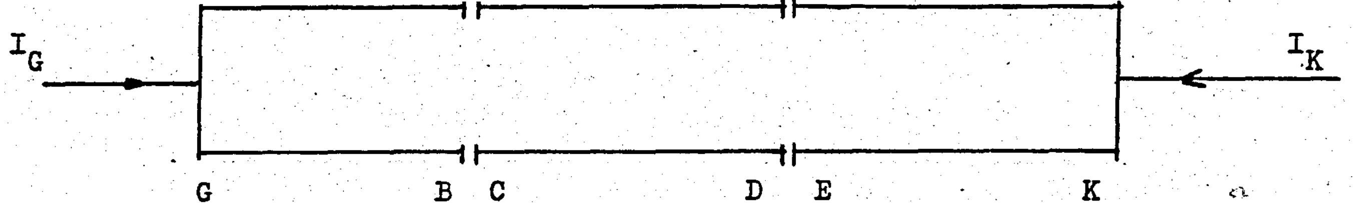
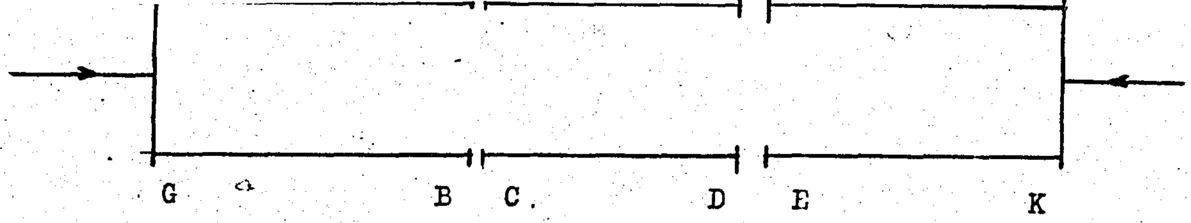


Type of The Fault		Fault Location											
		G			B			C			K		
		I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T
Three - phase	P.U	12.8	10.	22.8	8.3	13	21.3	9.7	10.8	20.4	8.8	15.7	24.5
	R(A)	1940	1525	3470	1260	1980	3240	1470	1640	3110	1330	2390	3720
S . L . G	P.U	12.2	7.8	20.0	5.3	8.8	14.2	6.8	6.8	13.6	7.7	21.2	28.9
	R(A)	1850	1180	3030	810	1330	2153	1030	1030	20.7	1170	3200	4370
L . L	P.U	11.0	8.6	19.6	7.2	11.0	18.2	8.3	9.2	17.5	7.6	13.3	20.9
	R(A)	1670	1310	2980	1090	1680	2770	1260	1400	2660	1150	2030	3180
L . L . G	P.U	12.5	9.5	21.3	7.40	11.6	19.0	8.3	9.3	18	8.7	20.1	28
	R(A)	1900	1450	3230	1130	1760	2890	1260	1410	2750	1320	3060	4260



Type of The Fault		Fault Location											
		G			B			C			D		
		I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T	I_G	I_K	I_T
Three - phase	P.	12.8	10.0	22.8	8.5	10.5	19	9.64	10.21	19.9	8.27	12.35	20.6
	R(A)	1940	1520	3470	1200	1600	2900	1470	1551	3020	1260	1880	3134
S - L.G	P.	12.2	7.8	20	6.0	7.17	13.2	7.1	6.6	13.7	5.4	9.6	15
	R(A)	1854	1180	3040	900	1100	2000	1080	1000	2080	823	1455	2280
L . L	P.	11.0	8.6	19.6	7.3	9.0	16.33	8.2	8.8	17.0	7.1	10.5	17.6
	R(A)	1070	1310	2980	1110	1370	2480	1250	1330	2580	1090	1600	2690
L . L . G	P.	12.5	9.5	21.3	8.1	9.2	17.3	8.7	9.2	17.9	7.4	11.2	18.6
	R(A)	1900	1450	3230	1230	1400	2630	1320	1400	2610	1120	1700	2830

Cont.



Type of The fault		Fault Location											
		E			K								
		I_G	I_K	I_T	I_G	I_K	I_T						
Three - phase	P.U	8.9	10	18.9	8.8	15.7	24.5						
	R(A)	1360	1520	2880	1330	2390	3720						
S . L . G	P.U	5.8	8	13.8	7.7	21.2	28.9						
	R(A)	881	1210	2100	1070	3200	4310						
L . L	P.U	9.56	8.67	16.23	7.6	13.3	20.9						
	R(A)	1150	1320	2470	1150	2030	3180						
L . L . G	P.U	7.7	9.4	17.1	8.7	20.1	28						
	R(A)	1170	1430	2600	1322	3060	4260						

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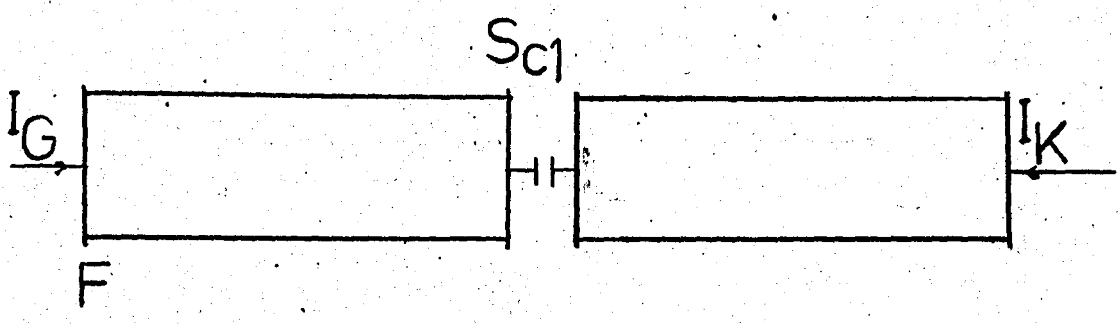
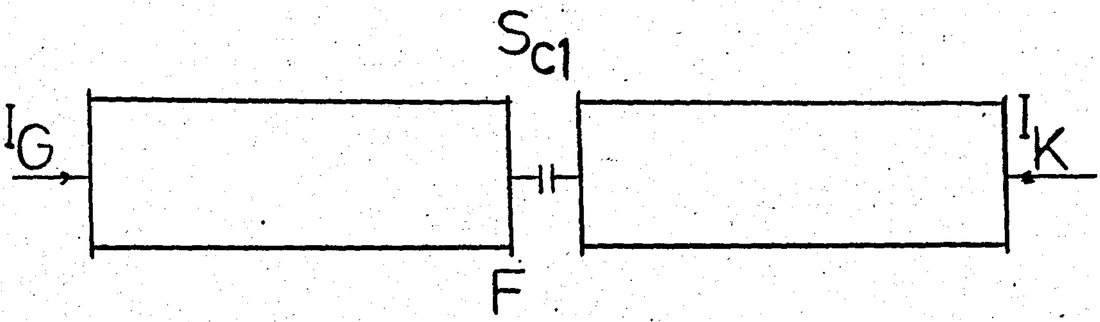
TABLE 4.1-4

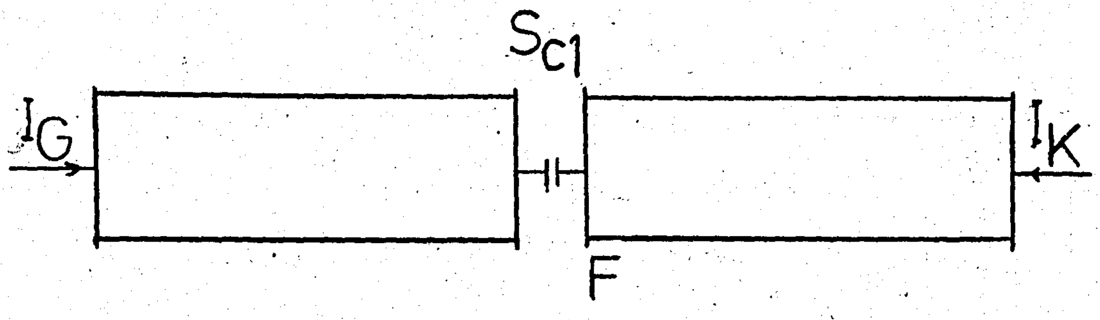
Fault Currents in Series Capacitors (Ifc) and Resultant Voltage Drops (Vfc) for the given Fault Location.



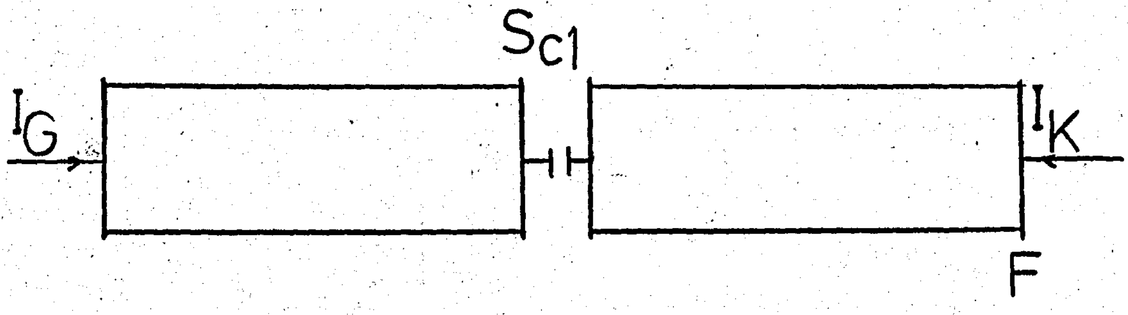
Fault Type		SC_1	
		I_{fc}	V_{fc}
Three - Phase	P.U	10.0	0.07
	$R_{A,KV}$	1530	26.6
S . L . G	P.U	7.8	0.054
	$R_{A,KV}$	1180	20.6
L . L	P.U	8.6	0.06
	$R_{A,KV}$	1310	22.9
L . L .G	P.U	9.5	0.07
	$R_{A,KV}$	1450	25.4



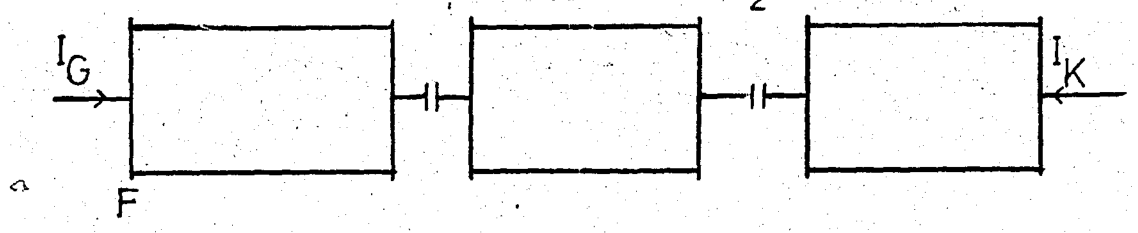
Fault Type		SC_1	
		I_{fc}	V_{fc}
Three - Phase	P.U	14.5	0.1
	$R_{A,Kv}$	2200	38.1
S . L . G	P.U	12.0	0.08
	$R_{A,KV}$	1800	31.5
L . L	P.U	12.3	0.086
	$R_{A,KV}$	1870	32.7
L . L . G	P.U	13.2	0.09
	$R_{A,KV}$	2000	35.0



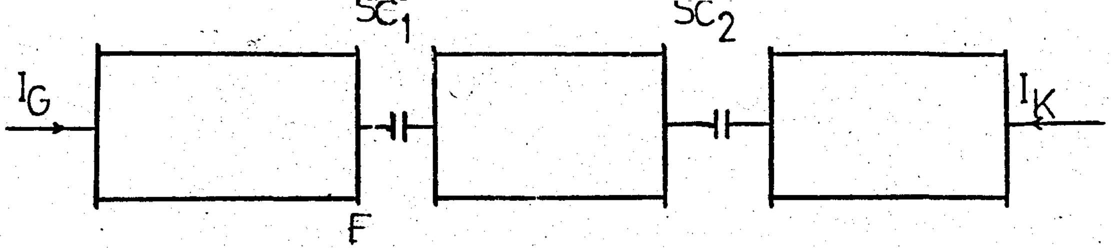
Fault Type		SC_1	
		I_{fc}	V_{fc}
Three - Phase	P.U	11.9	0.08
	$R_{A,KV}$	1810	31.7
S . L .G	P.U	9.11	0.063
	$R_{A,KV}$	1380	24.1
L . L	P.U	10.3	0.07
	$R_{A,KV}$	1560	27.3
L . L .G	P.U	10.9	0.08
	$R_{A,KV}$	1650	28.9



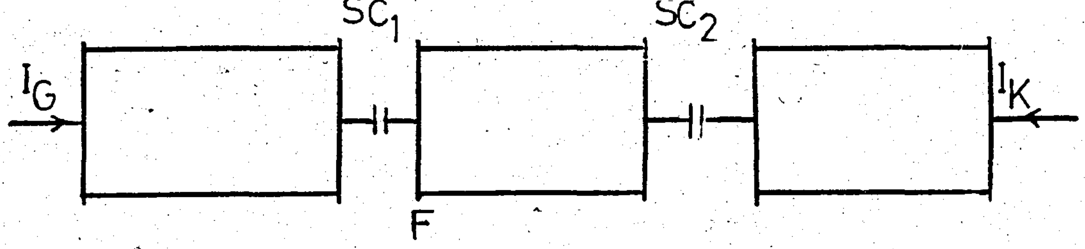
Fault Type		SC_1	
		I_{fc}	V_{fc}
Three - Phase	P.U	8.8	0.016
	$R_{A,KV}$	1330	23.3
S . L .G	P.U	7.7	0.053
	$R_{A,KV}$	1170	20.5
L . L	P.U	7.6	0.052
	$R_{A,KV}$	1150	20.2
L . L .G	P.U	8.7	0.06
	$R_{A,KV}$	1320	23.1



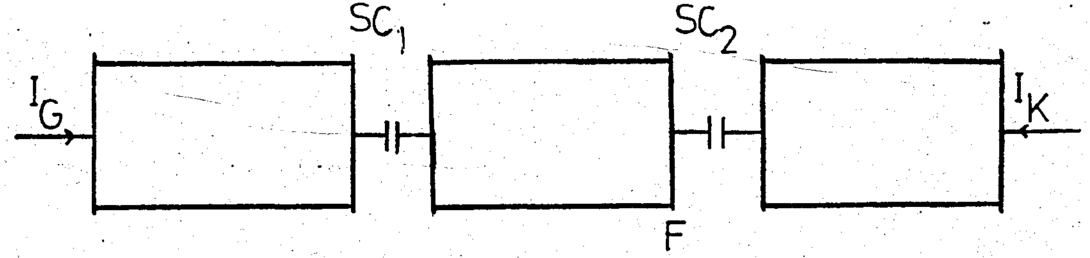
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
3 - phase	P.U	10	0.035	10	0.035
	$R_{A,KV}$	1525	13.3	1525	13.3
S . L . G	P.U	7.8	0.027	7.8	0.027
	$R_{A,KV}$	1180	10.3	1180	10.3
L . L	P.U	8.6	0.03	8.6	0.03
	$R_{A,KV}$	1310	11.5	1310	11.5
L . L . G	P.U	9.5	0.033	9.5	0.033
	$R_{A,KV}$	1450	12.7	1450	12.7



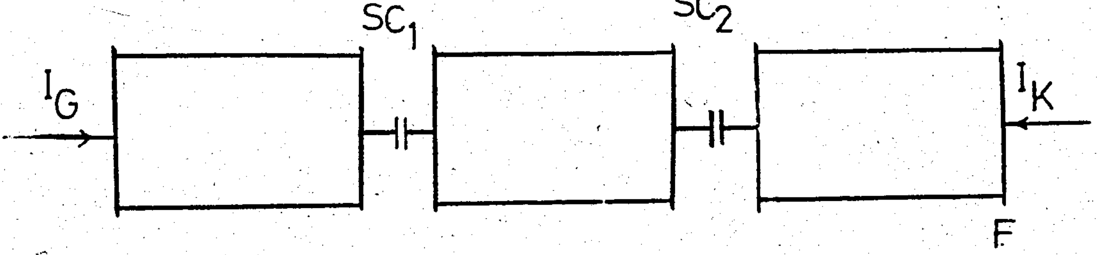
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
3 - phase	P.U	12.7	0.036	12.7	0.036
	$R_{A,KV}$	1920	13.6	1920	13.6
S . L . G	P.U	9.9	0.029	9.9	0.029
	$R_{A,KV}$	1500	11.2	1500	11.2
L . L	P.U	8.8	0.038	8.8	0.038
	$R_{A,KV}$	1340	14.4	1340	14.4
L . L . G	P.U	11.6	0.033	11.6	0.033
	$R_{A,KV}$	1760	12.6	1760	12.6



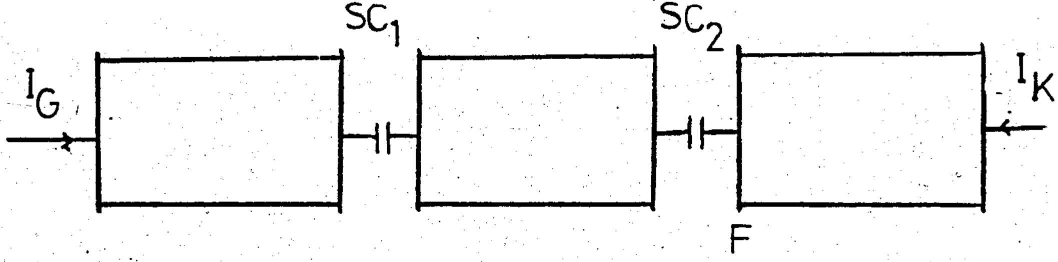
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
3 - phase	P.U	11.0	0.038	11.6	0.04
	$R_{A,KV}$	1660	14.5	1760	15.4
S . L . G	P.U	8.8	0.035	9.4	0.033
	$R_{A,KV}$	1340	11.7	1430	12.5
L . L	P.U	10.0	0.035	9.35	0.033
	$R_{A,KV}$	1520	13.3	1420	12.4
L . L .G	P.U	10.0	0.035	11.0	0.038
	$R_{A,KV}$	1520	13.3	1670	14.6



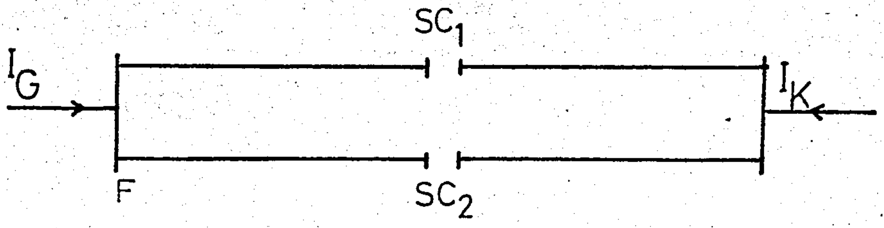
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
3 - phase	P.U	9.5	0.033	14.0	0.05
	$R_{A,KV}$	1440	12.6	2130	18.6
S . L . G	P.U	7.4	0.026	13.0	0.046
	$R_{A,KV}$	1120	9.8	1980	17.3
L . L	P.U	12.0	0.042	8.1	0.028
	$R_{A,KV}$	1824	16.0	1230	10.7
L . L . G	P.U	8.7	0.03	13.4	0.047
	$R_{A,KV}$	1320	11.6	2040	17.8



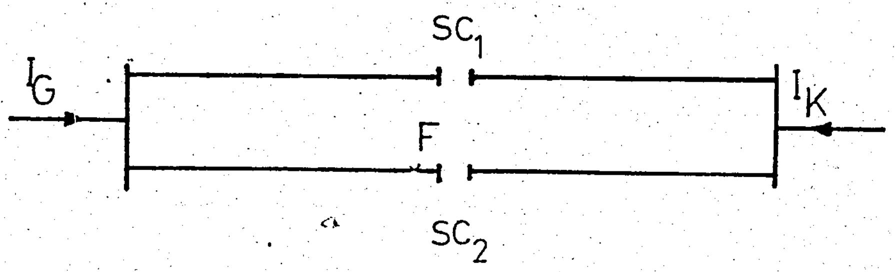
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - phase	P.U	8.8	0.031	8.8	0.031
	$R_{A,KV}$	1330	11.6	1330	11.6
S . L . G	P.U	7.7	0.027	7.7	0.027
	$R_{A,KV}$	1170	10.2	1170	10.2
L . L	P.U	7.6	0.026	7.6	0.026
	$R_{A,KV}$	1150	10.0	1150	10.0
L . L . G	P.U	8.7	0.03	8.7	0.03
	$R_{A,KV}$	1320	11.6	1320	11.6



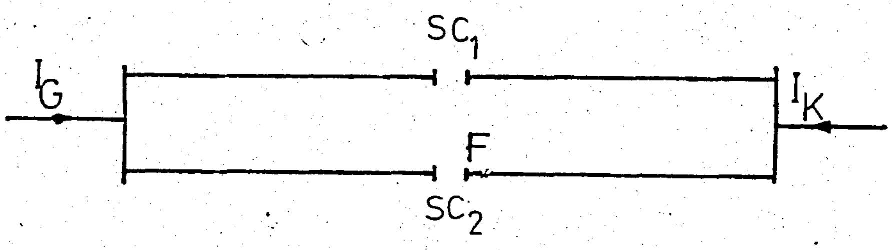
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - phase	P.U	10.6	0.037	10.6	0.037
	R.$_{A,KV}$	1610	14.1	1610	14.1
S . L . G	P.U	8.2	0.029	8.2	0.029
	$R_{A,KV}$	1250	10.9	1250	10.9
L . L	P.U	10.2	0.032	10.2	0.032
	$R_{A,KV}$	1550	12.2	1550	12.2
L . L . G	P.U	9.7	0.034	9.7	0.034
	$R_{A,KV}$	1480	13.9	1480	13.9



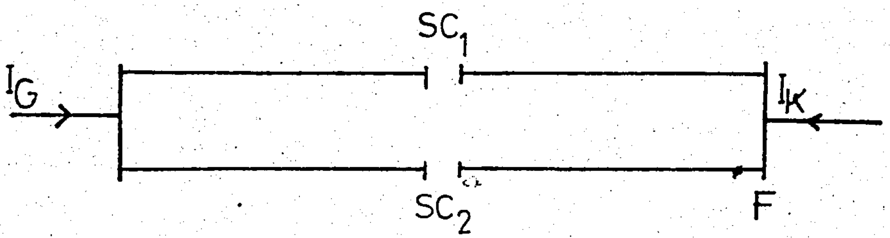
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	5.0	0.07	5.0	0.07
	$R_{A,KV}$	760	26.7	760	26.7
S . L . G	P.U	3.9	0.055	3.9	0.055
	$R_{A,KV}$	590	20.65	590	20.65
L . L	P.U	4.3	0.06	4.3	0.06
	$R_{A,KV}$	655	22.9	655	22.9
L . L . G	P.U	4.75	0.0665	4.75	0.665
	$R_{A,KV}$	725	25.35	725	25.35



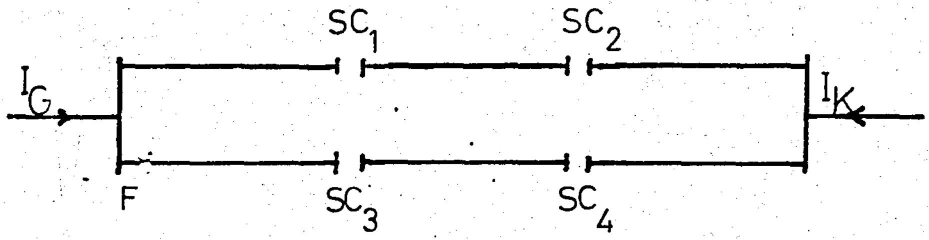
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	-1.2	0.017	14.2	0.20
	$R_{A,KV}$	-80	-6.4	2160	75.5
S . L . G	P.U	0.1	0.0007	8.8	0.122
	$R_{A,KV}$	15.2	0.26	1330	46.5
L . L	P.U	0.15	0.001	11.0	0.155
	$R_{A,KV}$	22.8	0.4	1680	58.8
L . L . G	P.U	0.2	0.0015	11.6	0.162
	$R_{A,KV}$	30.4	0.5	1760	61.6



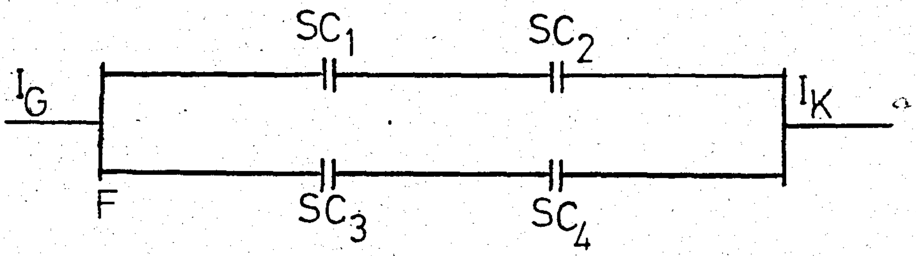
Fault Type		SC_1		SC_2	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	1.6	0.022	9.7	0.135
	^{R}A,KV	243	8.5	1470	51.5
S . L . G	P.U	0.1	0.0007	6.8	0.095
	^{R}A,KV	15.2	0.26	1030	36.05
L . L	P.U	0.15	0.001	8.3	0.116
	^{R}A,KV	22.8	0.4	1260	44.1
L . L . G	P.U	0.2	0.0015	9.6	0.134
	^{R}A,KV	30.4	0.53	1460	51.1



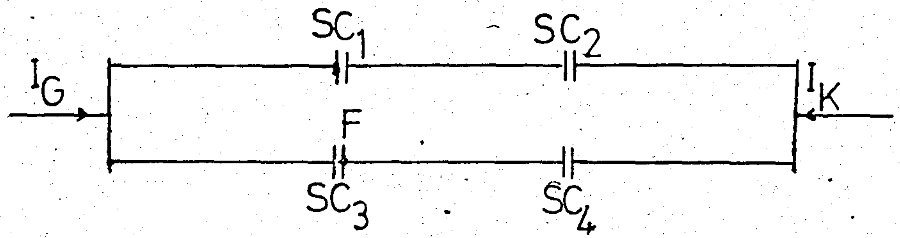
Fault Type		SC$_1$		SC$_2$	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	44	0.061	44	0.061
	$R_{A,KV}$	660	23.25	660	23.25
S. L . G	P.U	3.85	0.0535	3.85	0.0535
	$R_{A,KV}$	590	20.45	590	20.45
L . L	P.U	3.8	0.053	3.8	0.053
	$R_{A,KV}$	580	20.125	580	20.125
L . L . G	P.U	4.35	0.06	4.35	0.06
	$R_{A,KV}$	660	23.1	660	23.1



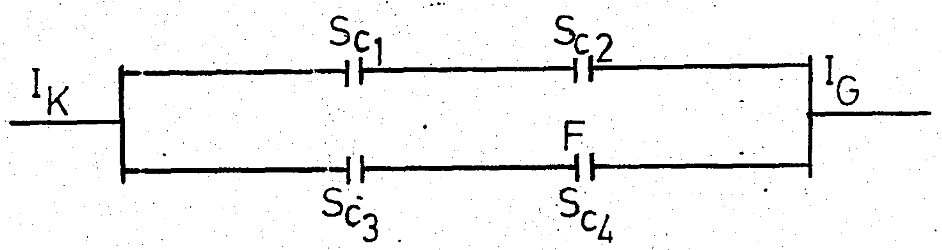
Fault Type		SC_1		SC_2		SC_3		SC_4	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	5.0	0.035	5.0	0.035	5.0	0.035	5.0	0.035
	$R_{A,KV}$	760	13.3	760	13.3	760	13.3	760	13.3
S . L .G	P.U	3.9	0.027	3.9	0.027	3.9	0.027	3.9	0.027
	$R_{A,KV}$	590	10.3	590	10.3	590	10.3	590	10.3
L . L	P.U	4.3	0.03	4.3	0.03	4.3	0.03	4.3	0.03
	$R_{A,KV}$	650	11.4	650	11.4	650	11.4	650	11.4
L . L . G	P.U	4.75	0.035	4.75	0.035	4.75	0.035	4.75	0.035
	$R_{A,KV}$	725	12.7	725	12.7	725	12.7	725	12.7



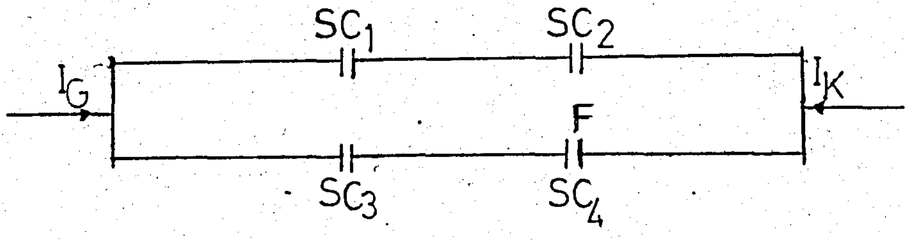
Fault Type		SC_1		SC_2		SC_3		SC_4	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	0.4	0.003	0.4	0.003	10.0	0.07	10.0	0.07
	$R_{A,KV}$	59.75	1.05	59.75	1.05	1520	26.6	1520	26.6
S . L . G	P.U	0.1	0.0007	0.1	0.0007	7.8	0.054	7.8	0.054
	$R_{A,KV}$	15.2	0.26	15.2	0.26	1180	20.6	1180	20.6
L . L	P.U	0.15	0.001	0.15	0.001	8.6	0.06	8.6	0.06
	$R_{A,KV}$	22.8	.40	22.8	.40	1310	22.9	1310	22.9
L . L . G	P.U	0.2	0.0015	0.2	0.0015	9.5	0.07	9.5	0.07
	$R_{A,KV}$	30.4	.53	30.4	.53	1450	25.4	1450	25.4



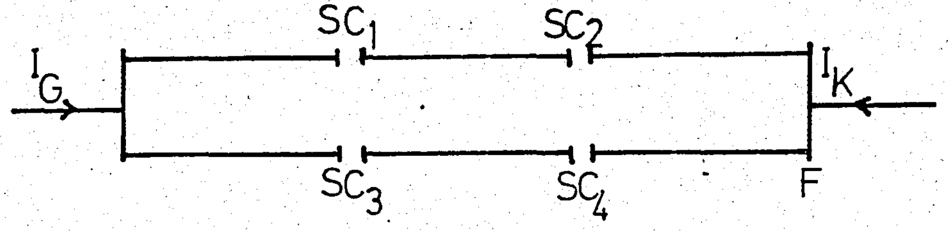
Fault Type		SC_1		SC_2		SC_3		SC_4	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	0.4	0.003	0.4	0.003	9.64	0.068	10.21	0.071
	$R_{A,KV}$	59.75	1.05	59.75	1.05	1470	25.7	1551	27.1
S . L . G	P.U	0.1	0.0007	0.1	0.0007	7.1	0.05	6.6	0.046
	$R_{A,KV}$	15.2	0.26	15.2	0.26	1080	18.9	1000	17.5
L . L	P.U	0.15	0.001	0.15	0.001	8.2	0.058	8.8	0.061
	$R_{A,KV}$	22.8	0.4	22.8	0.4	1250	21.8	1330	23.3
L . L . G	P.U	0.2	0.0015	0.2	0.0015	9.2	0.064	8.7	0.06
	$R_{A,KV}$	30.4	.53	30.4	0.53	1400	24.5	1320	23.1



Fault Type		SC_1		SC_2		SC_3		SC_4	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	0,4	0.003	0.4	0.003	8.27	0.06	12.35	0.09
	^{R}A,KV	59.7	1.05	59.75	1.05	1260	22.0	1880	33.0
S . L . G	P.U	0.1	0.0007	0.1	0.0007	5.4	26.4	9.6	0.07
	^{R}A,KV	15.2	0.26	15.2	0.26	823	14.4	1460	25.5
L . L	P.U	0.15	0.001	0.15	0.001	7.1	0.05	10.5	0.07
	^{R}A,KV	22.8	0.40	22.8	400	1090	19.1	1600	28.0
L . L . G	P.U	0.2	0.0015	0.2	0.0015	11.2	0.08	7.4	0.05
	^{R}A,KV	30.4	0.53	30.4	532	1700	29.8	1120	19.6



Fault Type		SC_1		SC_2		SC_3		SC_4	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}
Three - Phase	P.U	0.4	0.003	0.4	0.003	8.9	0.06	8.9	0.06
	$R_{A,KV}$	59,7	1.05	59.7	1.05	1360	23.8	1360	23.8
S . L . G	P.U	0.1	0.0007	0.1	0.0007	5.8	0.04	5.8	0.04
	$R_{A,KV}$	15.2	0.26	15.2	0.26	880	15.4	880	15.4
L . L	P.U	0.15	0.001	0.15	0.001	7.56	0.05	7.56	0.05
	$R_{A,KV}$	22.8	0.40	22.8	0.40	1150	20.1	1150	20.1
L . L . G	P.U	0.2	0.0015	0.2	0.0015	7.7	0.05	7.7	0.05
	$R_{A,KV}$	30.4	0.53	30.4	0.53	1170	20.5	1170	20.5



Fault Type		SC$_1$		SC$_2$		SC$_3$		SC$_4$	
		I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}	I_{fc}	V_{fc}
3 - Phase	P.U	4.4	0.03	4.4	0.03	4.4	0.03	4.4	0.03
	$R_{A,KV}$	660	11.65	660	11.65	660	11.65	660	11.65
S . L . G	P.U	3.85	0.025	3.85	0.025	3.85	0.025	3.85	0.025
	$R_{A,KV}$	590	10.3	590	10.3	590	10.3	590	10.3
L . L	P.U	3.8	0.025	3.8	0.025	3.8	0.025	3.8	0.025
	$R_{A,KV}$	580	10.05	580	10.05	580	10.05	580	10.05
L . L . G	P.U	4.35	0.03	4.35	0.03	4.35	0.03	4.35	0.03
	$R_{A,KV}$	660	11.55	660	11.55	660	11.55	660	11.55