מטודולגיה הגנות פחת ברשתות חלוקה שונות
טאוריה ושיטות ההגנה.

ABSTRACT

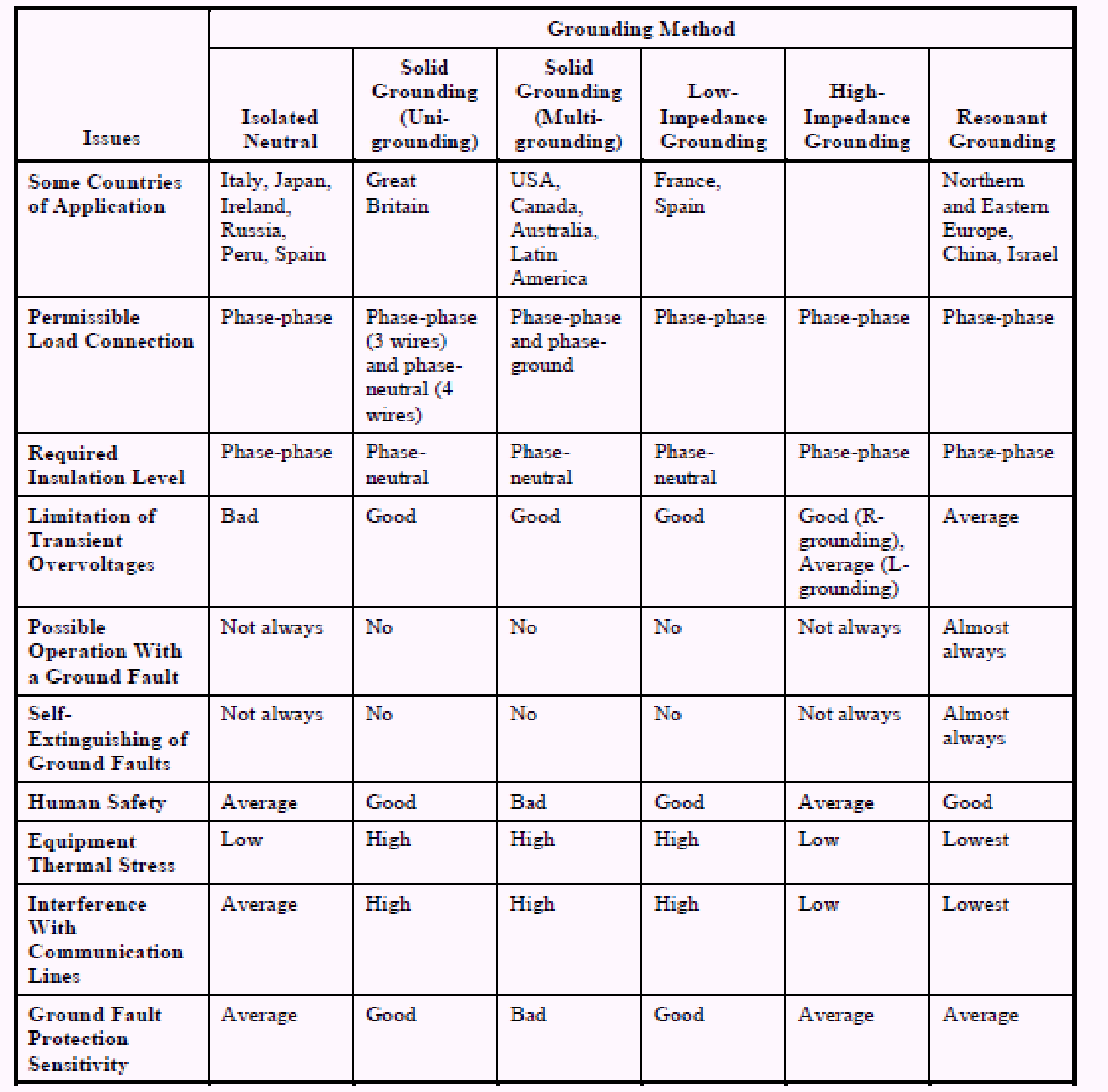
This presentation show ground fault protection and detection methods for distribution systems.
First:
Compare medium-voltage distribution-system grounding methods.
Next:
Describe directional/or non directional elements suitable to provide ground fault protection in solidly- and low impedance grounded distribution systems. Then analyze the behavior of ungrounded systems, fault conditions and introduce a ground directional element for these systems.
Then show the behavior of compensated systems during ground faults and describe traditional fault detection methods.

INTRODUCTION

Ground fault current magnitudes depend on the system grounding method. Solidly- and lowimpedance grounded systems may have high levels of ground fault currents. These high levels typically require line tripping to remove the fault from the system. Ground overcurrent and directional overcurrent relays are the typical ground fault protection solution for such systems. However, high-impedance ground fault detection is difficult in multigrounded four-wire systems, in which the relay measures the ground fault current combined with the unbalance current generated by line phasing and configuration and load unbalance.
Ungrounded systems have no intentional ground. For a single-line-to-ground fault on these systems, the only path for ground current to flow is through the distributed line-to-ground capacitance of the surrounding system and of the two remaining unfaulted phases of the faulted circuit.
In resonant-grounded or compensated distribution networks the system is grounded through a Variable impedance reactor connected to the power transformer secondary neutral or the neutral of a grounding bank. This reactor compensates the system phase-to-ground capacitance such that the zero-sequence network becomes a very high impedance path. The reactor, known as the Petersen coil, permits adjustment of the inductance value to preserve the tuning condition of the system for different network topologies.
Resonant grounding provides self-extinction of the fault arc in overhead lines for about 80 percent of temporary ground faults . Considering that about 80 percent of ground faults are temporary, conclude that more than 60 percent of overhead line ground faults clear without breaker tripping. High-impedance grounded systems are grounded through a high-impedance resistor or reactor with an impedance equal to or slightly less than the total system capacitive reactance to ground. The neutral resistor is of such a high value that ground faults on such systems have very similar characteristics to those of resonant-grounded systems.
Because ground faults in ungrounded, high-impedance grounded and compensated systems do not affect the phase-to-phase voltage triangle, it is possible to continue operating either system in the faulted condition. However, the system must have a phase-to-phase insulation level and all loads must be connected phase-to-phase.

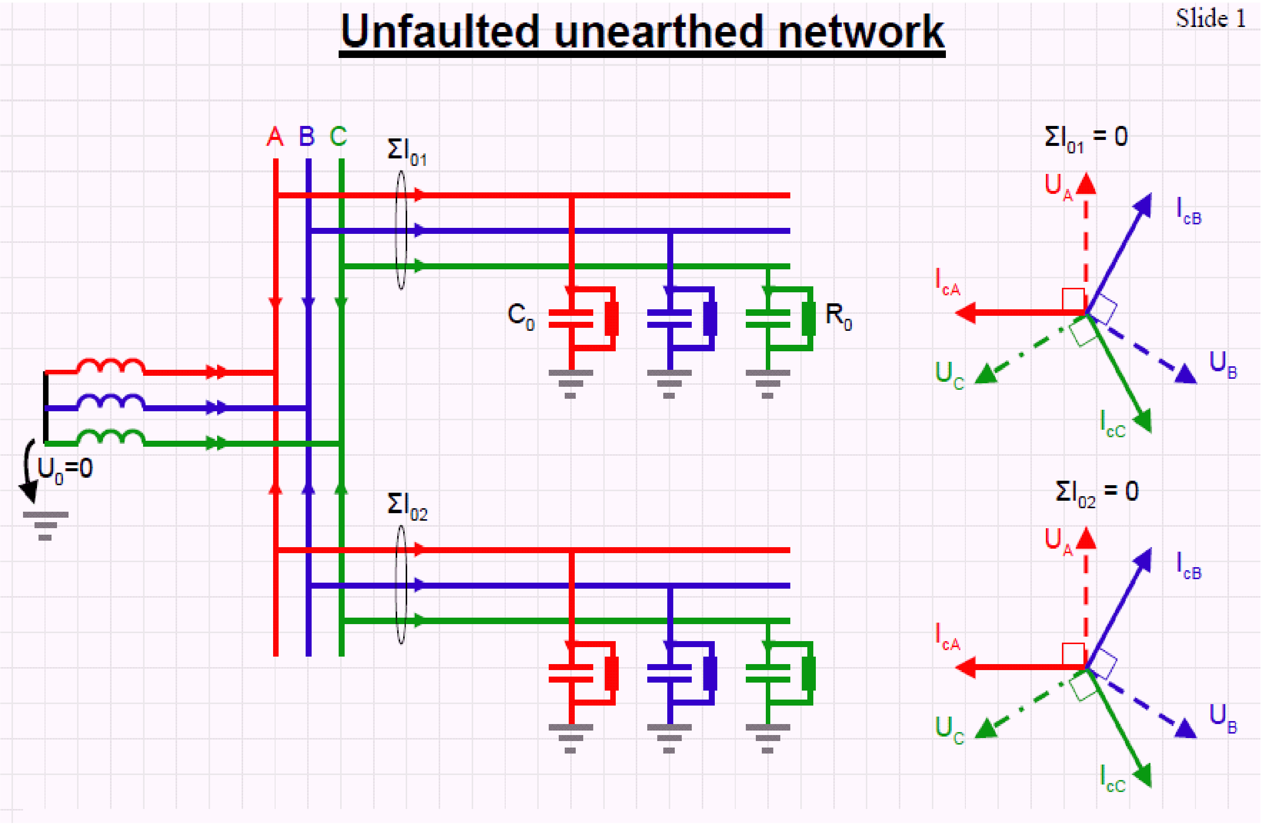
Ground relays for these systems require high relay sensitivity because the fault current is very low compared to solidly grounded systems. Most ground-fault detection methods use fundamental-frequency voltage and current components. The varmetric method is the traditional ground fault detection solution in ungrounded systems. Possible also use this method in high-impedance grounded systems. The wattmetric method is a common directional element solution for compensated systems, but its sensitivity is limited to fault resistances no higher than a few kilohms. Possible also use the wattmetric method in high-impedance grounded systems and isolated neutral systems

GROUNDING METHODS OF MEDIUM-VOLTAGE DISTRIBUTION NETWORKS



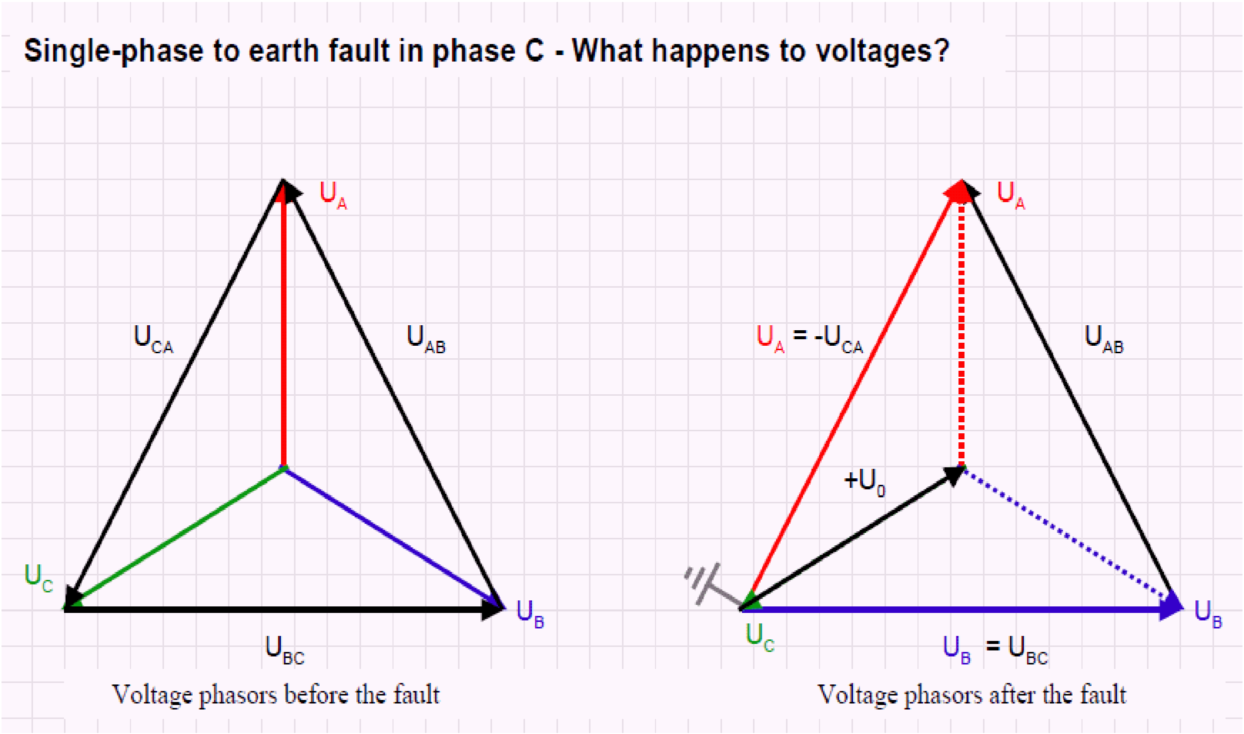
Issues	Grounding Method					
	Isolated Neutral	**Solid Grounding (Uni-grounding)**	**Solid Grounding (Multi-grounding)**	**Low-Impedance Grounding**	**High-Impedance Grounding**	**Resonant Grounding**
Some Countries of Application	Italy, Japan, Ireland, Russia, Peru, Spain	Great Britain	USA, Canada, Australia, Latin America	France, Spain		Northern and Eastern Europe, China, Israel
Permissible Load Connection	Phase-phase	Phase-phase (3 wires) and phase-neutral (4 wires)	Phase-phase and phase-ground	Phase-phase	Phase-phase	Phase-phase
Required Insulation Level	Phase-phase	Phase-neutral	Phase-neutral	Phase-neutral	Phase-phase	Phase-phase
Limitation of Transient Overvoltages	Bad	Good	Good	Good	Good (R-grounding), Average (L-grounding)	Average
Possible Operation With a Ground Fault	Not always	No	No	No	Not always	Almost always
Self-Extinguishing of Ground Faults	Not always	No	No	No	Not always	Almost always
Human Safety	Average	Good	Bad	Good	Average	Good
Equipment Thermal Stress	Low	High	High	High	Low	Lowest
Interference With Communication Lines	Average	High	High	High	Low	Lowest
Ground Fault Protection Sensitivity	Average	Good	Bad	Good	Average	Average

Current flow and vector diagrams



Slide 1

Unfaulted unearthed network



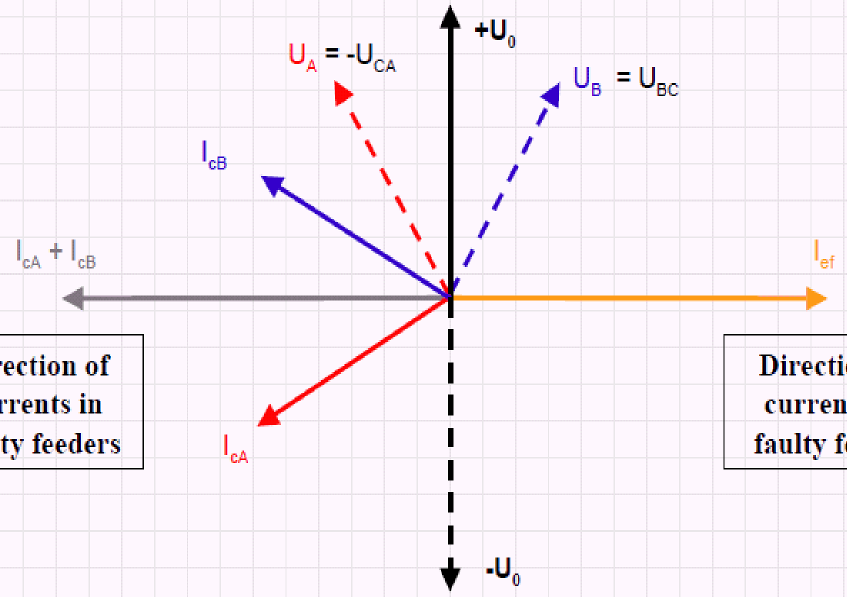
Single-phase to earth fault in phase C - What happens to voltages?

Voltage phasors before the fault

Voltage phasors after the fault

Single-phase to earth fault in phase C - What happens to currents ?

- By turning the **$+U_0$-phasor** in order to have it pointing upwards, the previous figure can be drawn as:

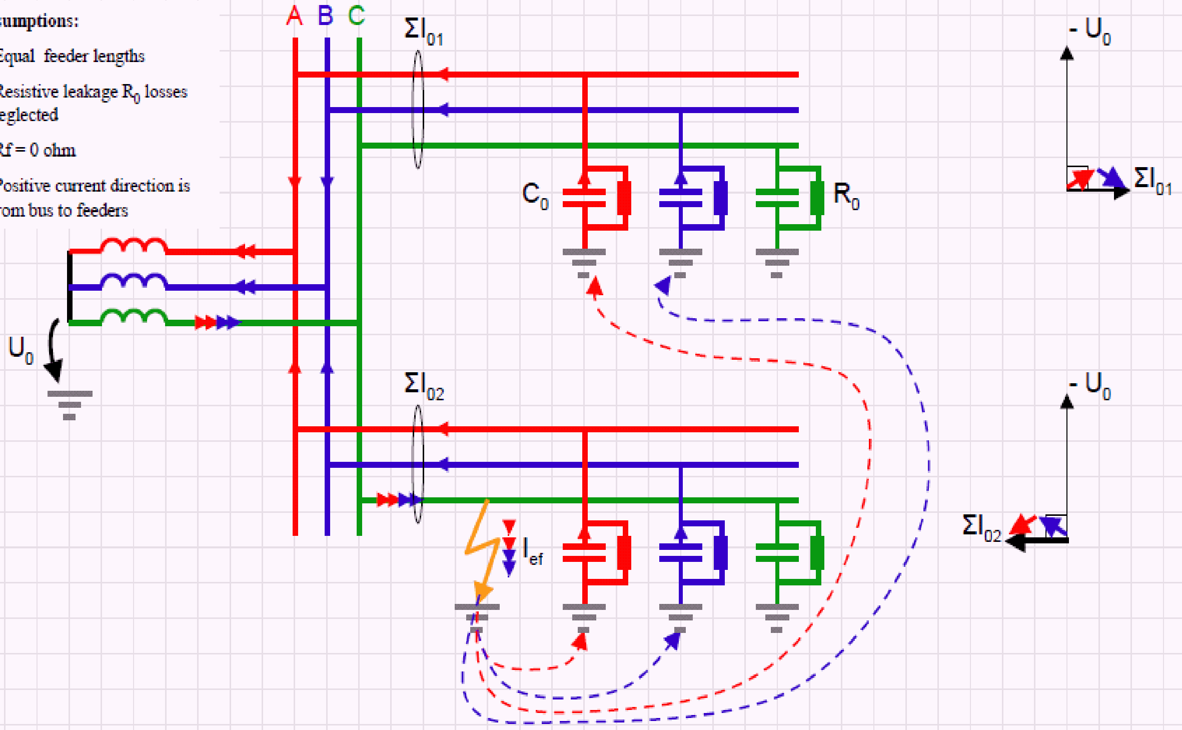


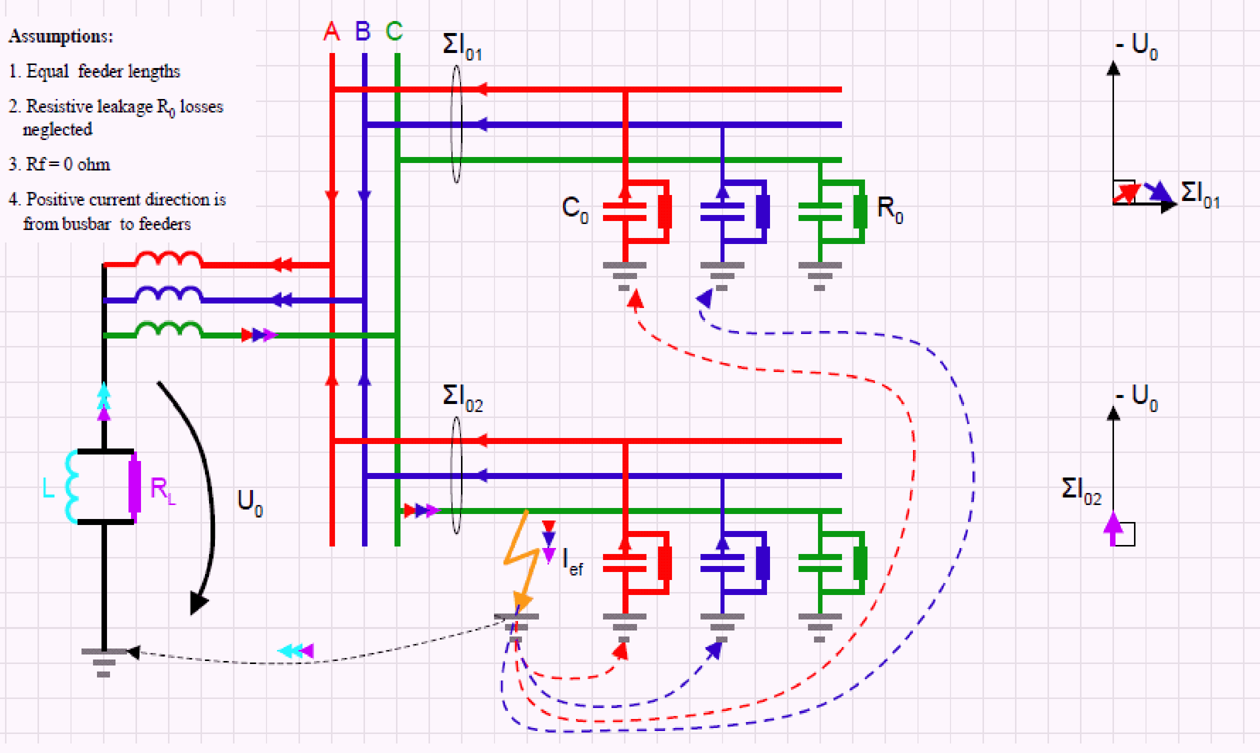
Direction of currents in healty feeders

Direction of currents in faulty feeder

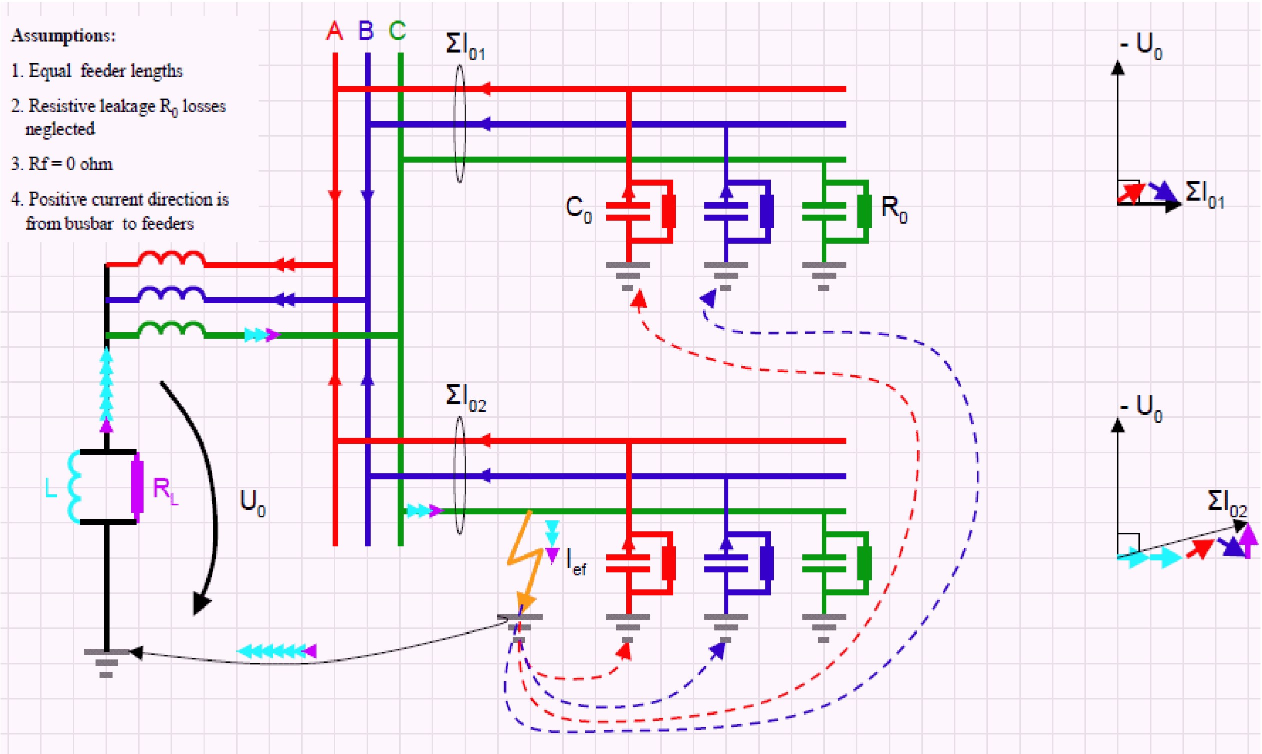
Assumptions:

1. Equal feeder lengths
2. Resistive leakage R_0 losses neglected
3. $Rf = 0$ ohm
4. Positive current direction is from bus to feeders

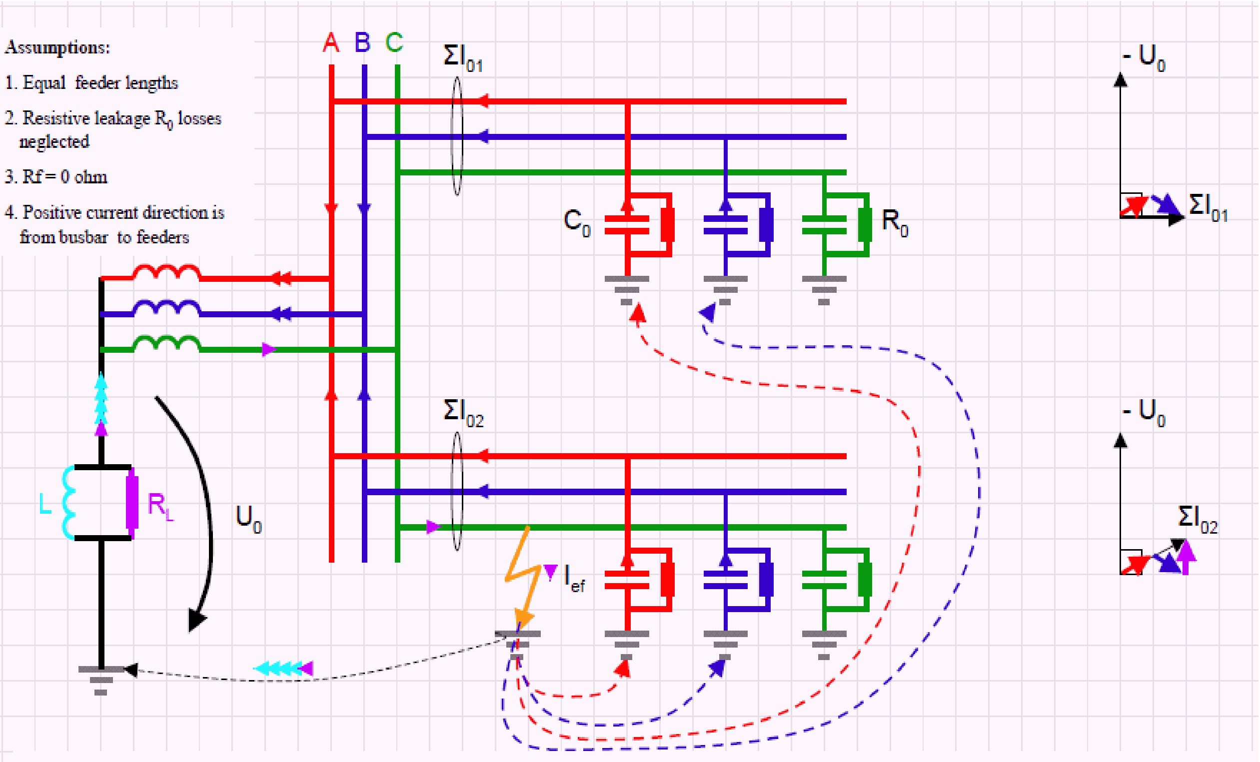




50% compensated network



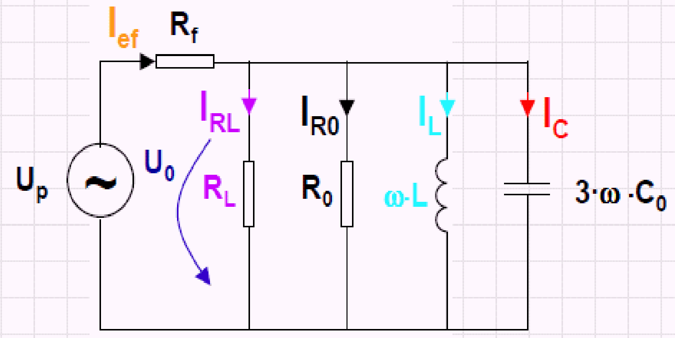
150% compensated network



Assumptions:

1. Equal feeder lengths
2. Resistive leakage R_0 losses neglected
3. Rf = 0 ohm
4. Positive current direction is from busbar to feeders

Equivalent circuit

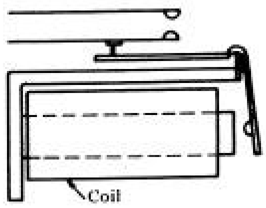


$$\boxed{U_0 = \frac{I_{ef}}{\sqrt{\left(\frac{1}{R_0}\right)^2 + \left(3\cdot\omega\cdot C_0 - \frac{1}{\omega\cdot L}\right)^2}}}$$

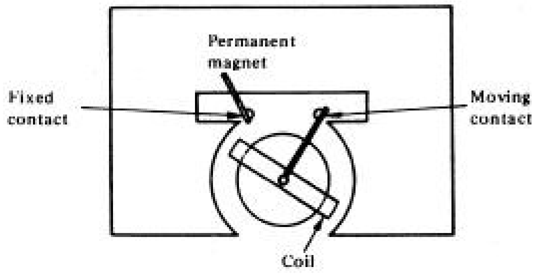
100% compensated network

Protection Methods

The very first protection relays had an electromechanical construction. The simplest electromechanical relays are of attracted-armature type. They operate by the movement of a piece of iron into the field produced by a coil.

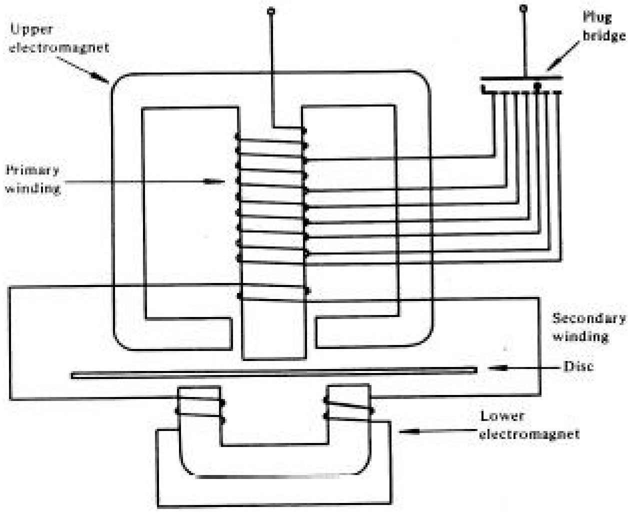


Moving-coil relays are another type of relay that is used for measuring and operating based on a single quantity like the magnitude of earth-fault current.



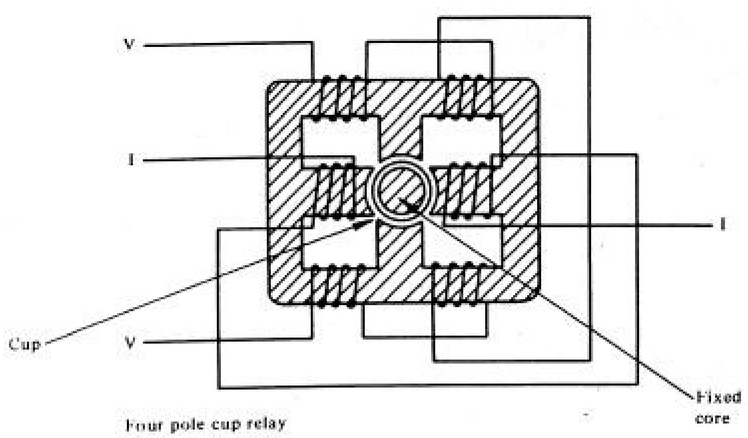
In a moving-coil relay, the "motor" action of a coil (carrying the current) in a magnetic field (created by a permanent magnet) together produces a torque and moving system. This kind of mechanism is used both in measuring instruments and electromechanical relays.

If we go further in the mechanical design of electromechanical relays, yet another type is an induction disc relay based on a disc which is moved by the torque produced by the coil. In the figure below, a winding arrangement for an induction disc relay is shown. This relay measures only one quantity.



Winding arrangement

One design of induction element is a symmetrical four pole structure, resembling a small motor.



Four pole cup relay

In the induction type of relay, as both previous pictures shows, there is no permanent magnet. Thus the torque produced in the mechanism is a function either on the magnitude of the single quantity, or in case of two-quantity relay like directional earth-fault relay, a function of magnitudes of both quantities and the phase angle between them.

With certain arrangements, the torque equation will become as

$T = kVI\cos(\square)$

where V and I are the earth-fault voltage (Uo) and current (Io). Factor k depends on the construction.

The equation of a WATTMETRIC relay is $P = Uo \times Io \times \cos(\square)$. As we can see, it is basically same equation as for the equation of a induction type relay. We can therefore conclude that the Wattmetric principle is quite much a natural consequence of using a mechanism similar to a measuring instrument as a basis for an electromechanical relay.

In comparison to static (electronic) and numerical (microprocessor) relays, these relays are not confined to a kind of mechanical boundaries previously presented. From the directional earth-fault protection point of view, only the $Io \times \cos(\square)$ part of the equation is important. The Uo term bacially does not give any added value.

Test results of simulations on a compensated networks also shows that the difference between $Io \times \cos(\square)$ and Wattmetric principles is relatively small.

The most common method we have used for earth-fault protection in compensated network (networks having a Petersen coil) for many decades, and with great success, is the *I* o´cos(j) principle.

*I*o´cos(j) principle

In this principle, the residual voltage U_0 is used to polarize the earth-fault relay and the relay sensitivity depend both on the magnitude of the neutral current Io as well as the phase angle between U_0 and I_0. Only when the I_0 magnitude multiplied with the cos of the phase angle (j) exceeds the setting, the relay operates. I.e.

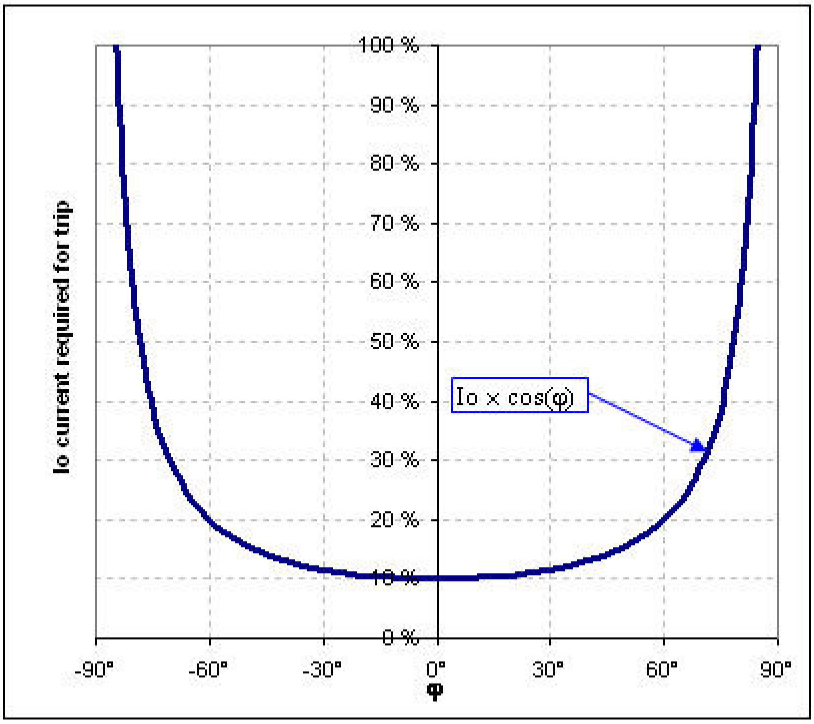
$I_0{´}\cos(j)\ ^{3}\ I_{0\text{setting}}$

Further, for the operation it is required that the magnitude of U_0 exceeds its setting point.

If the phase angle is known, the Io current required to cause relay operation is

$I_0 = I_{0\ \text{setting}} / \cos(j)$

For example, having $I_{0\ \text{setting}}$ = 10% and phase angle j = 45 degree, the I_0 magnitude must exceed 10% / cos(45) = 14%. Other values can be seen from the next figure.



Watt Metric principle

In the watt metric principle, the earth-fault power U_0 x I_0 x cos(j) is measured. The relay setting is given in VA or per cent of relay's rated VA. For relay operation

$U_0 ´ I_0 ´ \cos\ (j)\ ^3\ P_{0\ \text{setting}}$

But the U_0 in the compensated network depends on the I_0:

$U_0 = I_0\ ´\ Z_0$, where the Z_0 depends on the network (feeder types, length, Petersen coil etc)

Thus the equation for watt metric relay can also presented as

$(I_0 ´ Z_0) ´ I_0 ´ \cos\ (j)\ ^3\ P_{0\text{setting}}$

$=> I_0\ ^{2}´ Z_0 ´ \cos\ (j)\ ^3\ P_{0\text{setting}}$

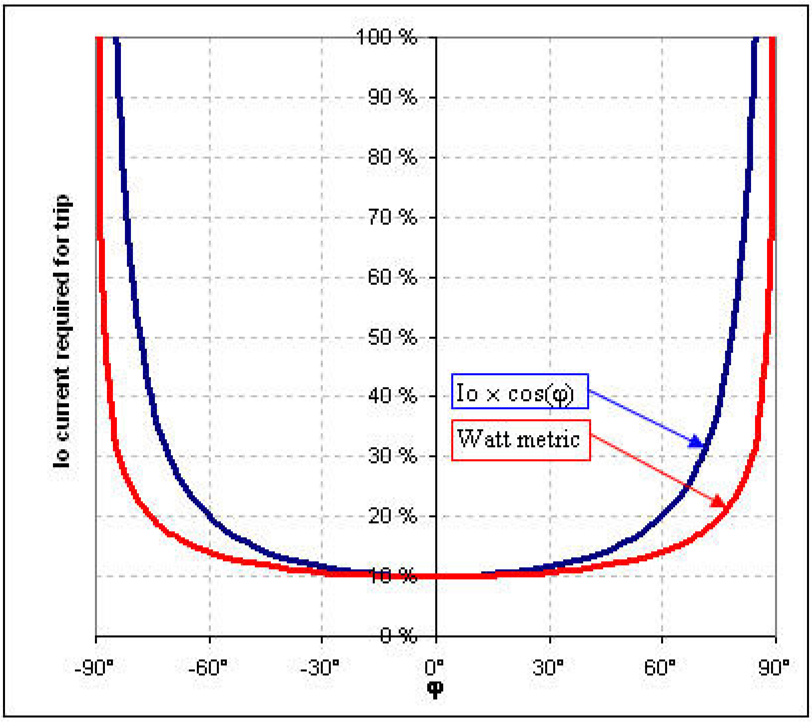
Assuming that Z_0 and phase angle is know, the relay will operate is the I_0 current

$I_0 = \text{sqrt}(\ P_{0\text{setting}} / (Z_0\ ´\ \cos(j))\ )$

But $P_{0\text{setting}}$ can also be presented with I_0 and U_0, where U_0 depends on I_0.
I.e. $P_{0\text{setting}} = I_{0\ \text{setting}}^{2}\ ´ Z_0$. Combining the last two equations

$I_0 = \text{sqrt}(I_{0\text{setting}}^{2}\ ´ Z_0 / (Z_0\ ´ \cos\ (j))) = \text{sqrt}(I_{0\text{setting}}^{2} / \cos\ (j\ ))$

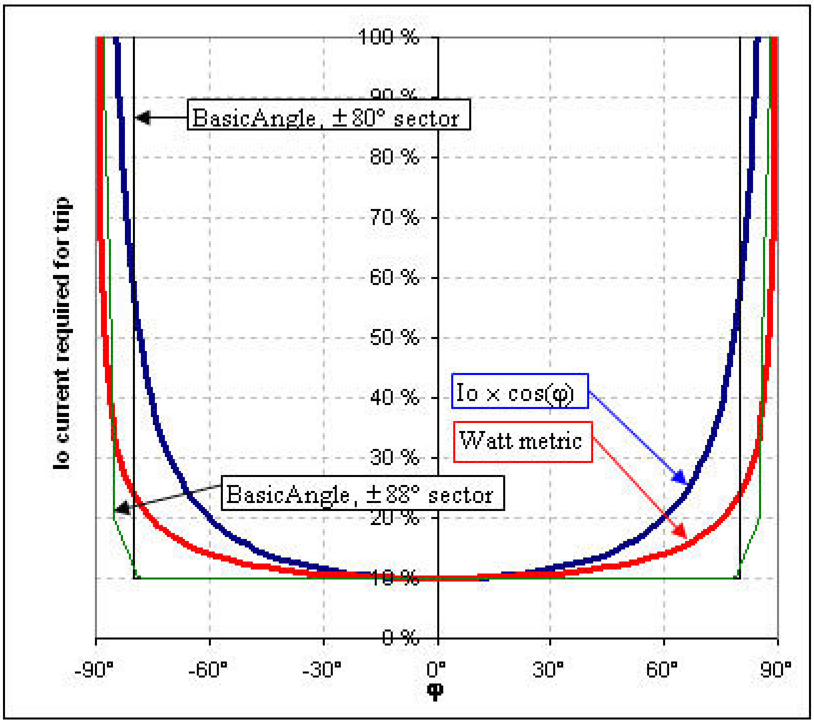
I.e. because of the relation between U_0 and I_0, the watt metric principle and I_0 ´cos(j) principle are not so different. The operation curve is somewhat different as can be seen from the next figure.



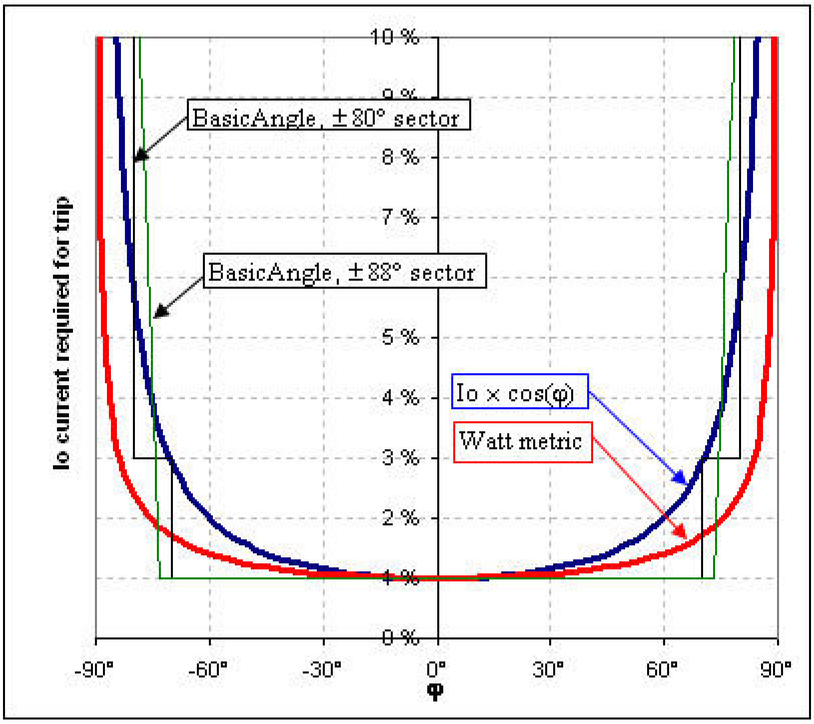
In this study, the effect of the compensation degree to the U_0 is not considered. The U_0 depends on the fault resistance and the degree of compensation. This will even further brings the two curves shown in the previous figure, close to each other.

Other principles: Basic angle

Our relays also support the Basic Angle principle. In this principle, for the relay operation, it is required that the U_0 exceeds its setting, I_0 exceeds its setting and the phase angle is within the given phase sector. The middle point of the phase sector is defined with the basic angle setting. For compensated network the basic angle = 0 degree. Further, it is possible to select ±80 or ±88 degree sector.

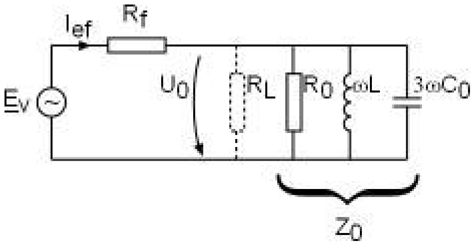


Note that with sensible settings and low I_0 magnitudes, there are some reductions in the phase sector. The aim is to avoid unwanted operations because of CT phase displacement error at low currents.



What is Z_0?

The equivalent circuit for the earth-fault in a compensated network, based on Thevenin's theorem is shown in the next figure.



R_f is the fault resistance, R_L is the parallel resistance (in parallel with the Petersen coil) used for increasing the fault current ,R_0 is the system leakage current, wL is the reactance of the Petersen coil and the $3wC_0$ is the reactance of the network earth capacitances. The I_{ef} is the current at the fault location (the current I_0, seen by the relay is not exactly same).

The Z_0 is the combination of R_0, wL and the $3wC_0$. Should the R_L be used, it can be taken into account too.