

ES 586b- Power System Protection

**Protection of Complex Transmission lines –
parallel feeders, multi-ended feeders, series-compensated lines**

Submit to Dr. Sidhu

By James Lee
250198067
M. Eng

PARALLEL FEEDERS



Figure 1: Example of Parallel Line System

Complicated transmission and distribution line such as parallel feeders which has terminals with more than one circuit carried on a common structure have been extensively utilized in modern power systems to enhance reliability and security for the transmission of electrical energy. The effect of mutual coupling makes parallel feeders protection challenging.

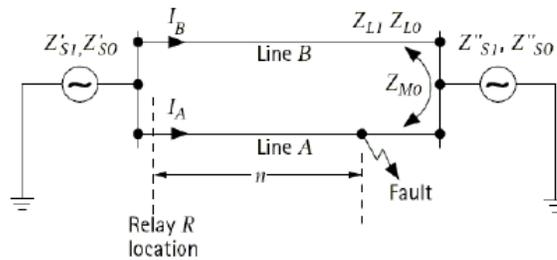


Figure 2: Mutual coupling on double circuit line

The coupling of positive and negative sequence between the parallel feeders for symmetrical lines is usually small and usually can be neglected.

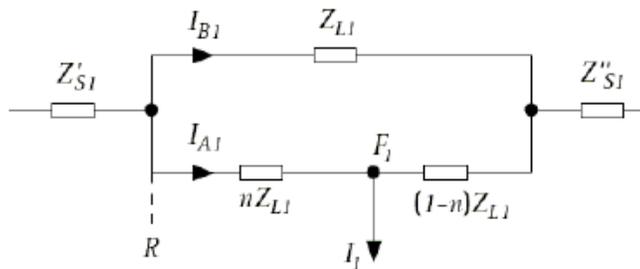


Figure 3: Positive Sequence diagram

This is not the case for zero sequence mutual coupling; the coupling effect is strong and cannot be ignored. Furthermore, when there is an earth fault on a feeder when the parallel feeder is out of service and earthed at both ends the mutual effect is also taken into account.

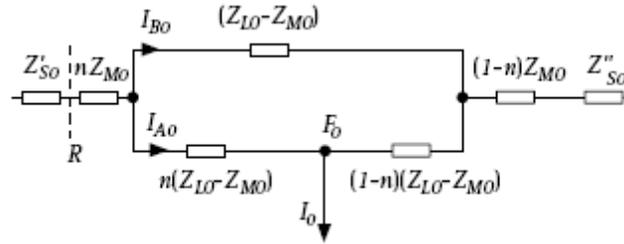


Figure 4: Zero Sequence diagram

The voltage applied in one circuit includes an induced voltage proportional to the zero sequence current in the other circuit when a ground fault occurs in the system.

For the impedance measurement, the current measured does not reflect the effect of mutual coupling and depending on the direction of the current flow in the circuit the relay's measured impedance could under-reach or over-reach.

Distance Relay Problems

Current Reversal on Double Circuit Lines

Current Reversal occurs when the current in the healthy line can reverse short period of time. This occurs when a fault clears sequentially on one circuit of a double circuit line with sources at both ends of the circuit. If a Permissive Overreach or Blocking type communication aided distance scheme is used, unwanted tripping of current breaker on the line can occur.

Under-reach on Parallel Lines

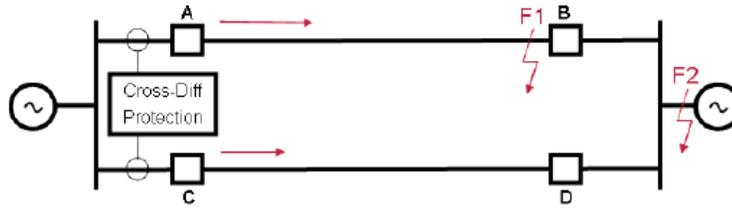
The distance relay will under-reach if a fault occurs on a line that lies beyond the remote terminal end of a parallel line circuit. The relay only sees 50% of the total fault current for a fault in the adjacent line section, the relay sees the impedance of the affected section as twice the correct value. It is not necessary to adjust Zone 2 impedance setting to compensate since minimum reach of Zone 2 is to the end of protected line section and under-reach effect only occurs for the fault in the following line section. Conversely, under-reach effect must be allowed in Zone 3 impedance calculation since Zone 3 is to provide back-up protection to the adjacent line.

To overcome various problems that associated with parallel line protection, a variety of modern day improvements are available such as improved distance protection schemes, unit type protection, distance protection accuracy and back-up protection.

Unit Protection Systems are not affected the coupling between the feeders, they are the type of protection that uses current only. But mutual compensation is required for accuracy if the relay has a distance to fault feature.

Line differential protection remains the most selective form of protection for multiple circuit line protection as it is resistant to mutual coupling effect. Communications

requirements may be costly; the cross-differential scheme principle is in the following figure.



MULTI-ENDED FEEDERS

Unit Protection

Definition of a multi-ended feeder is said to have three or more than three terminals. The terminals have either a generator or load or both. The three-ended feeder also known as tee'd feeder is the most simplest/common multi-ended feeders used. Multi-ended feeders uses unit protection and distance schemes for protection, and each uses several signaling channel such as pilot wires, power line carrier and fibre-optic cable.

A.C. Pilot Wire Protection

A.C. pilot wire relays offer low-cost fast protection with insensitivity to power swing. In an addition to, it had excellent reliability and simplicity. But due to the characteristics of the pilot wire, the length of the feeder that can be protected is limited.

'Translay' balanced voltage protection

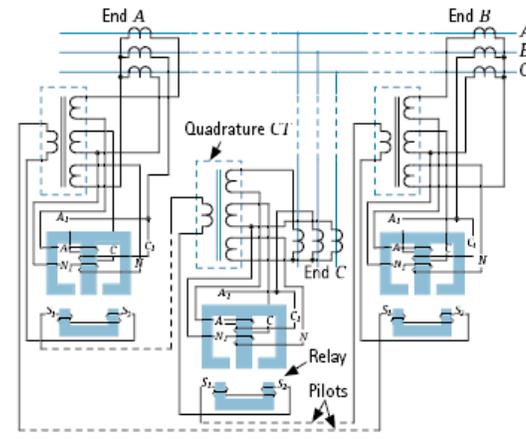


Figure 5: Balanced voltage Tee'd feeder scheme

A Balanced voltage protection is essentially the relative polarity of the CTs at two ends is such that there is no pilot current for the conditions of load or external fault. The CT secondary voltages will no longer balance and current will flow in the relays which will help trip the circuit breakers at two ends. For 'Translay' the plain feeders are increased in the tee'd scheme by 50% for one tee and 75% for two.

High speed Protection Type DSB 7

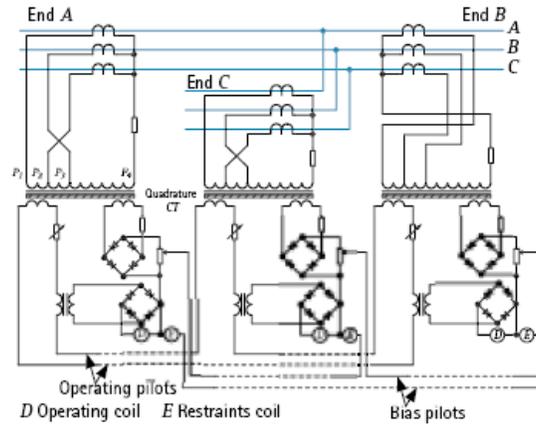


Figure 6: Type DSB7 tee'd feeder protection

This type of protection is of high speed and includes special features such as stability in both the inrush current flowing in the feeder zone and the distribution fault current.

Power Line Carrier Phase Comparison Scheme

This protection scheme involves comparing phase angles of signals obtained from a combination of the sequence currents at each end of the feeder. If the differences of the phase angle surpass a specific value, a tripping signal is sent to the corresponding circuit breaker. Furthermore, two different levels of detectors are used to prevent incorrect operation for external faults.

Differential Relay using Optic Fiber Signaling

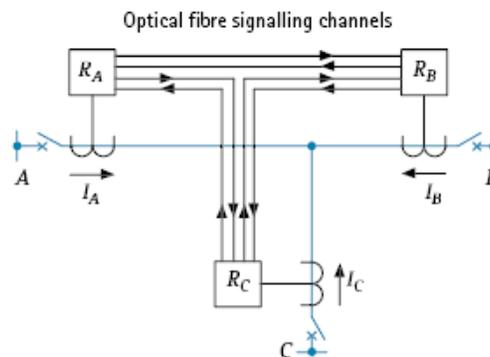


Figure 7: Current Differential Protection for tee'd feeders using optical fiber signaling

Optical fibers are fine glass strands, which behave as wave guides for light. They provide optical communication links with massive information carrying capacity and a natural immunity to electromagnetic interference and also the ability to transmit light over considerable distance. For multi-ended feeders, the current differential relay using optic fiber can offer unit protection without the restrictions in the other forms of protections. The relays at each line end in figure 7 are digital/numerical relays interconnected by

optical fiber links and in reality optical fiber links can be dedicated to the protection system or multiplexed.

Distance Relays

Presently the distance protection is used widely in multi-ended feeder protection, but the application requires careful consideration and systematic checking of all the conditions.

The impedance seen by the distance relays is affected by the current infeeds in the branches of the feeder. See the following figure 8 for an example of apparent impedance seen by the distance relay.

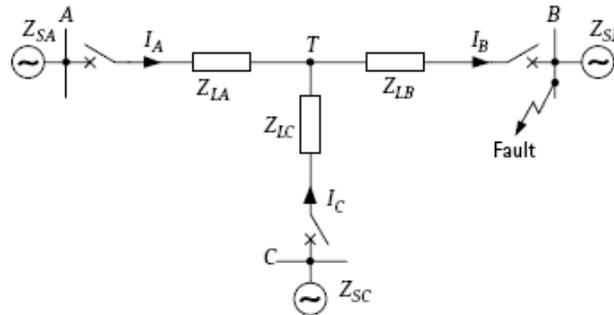


Figure 8: Fault at substation B busbars

The distance relay in the following figure 9 shows a mho characteristic located at A with a Zone 2 set to 120% of the protected feeder AB, fails to see a fault at remote busbar B. The relay appears to under-reach, the fault appears the relay to be located at B' instead of B. The under-reach effect in multi-ended feeders can be found in any kind of fault.

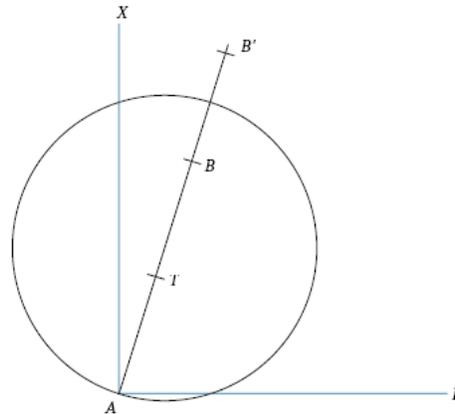


Figure 9: Apparent impedance presented to the relay at substation A for a fault at substation B busbars

Effect of Pre-fault Load

In the case if the power transfer between terminals of the feeder immediately before the fault current occurred was not zero, the fault currents in figure 8 may not be in phase and the impedance seen by the relay at A will be complex quantity with a positive or negative phase angle. For the fault conditions in figure 8 and 9, according to the phase angle and

the magnitude of the pre-fault load current, it may displace the impedance seen by distance relay to different points like $B'1$ or $B'2$ shown in the following figure 10.

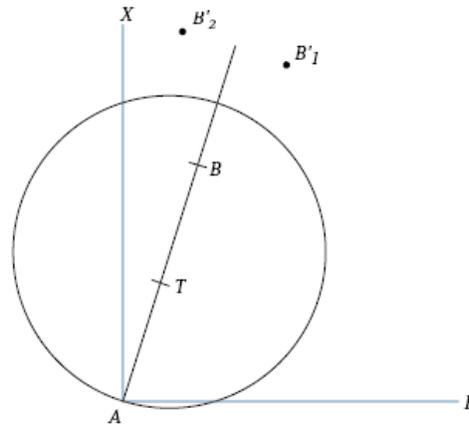


Figure 10: effects of pre-fault load on the apparent impedance presented to the relay

Effect of the Fault Current Flowing Outwards at One Terminal

In some conditions, the current at one of these terminals may flow outward instead of inwards. The following is a figure of a parallel tapped feeder with one of the ends of the parallel circuit open at terminal A is illustrating an effect of fault current flowing outwards at one terminal.

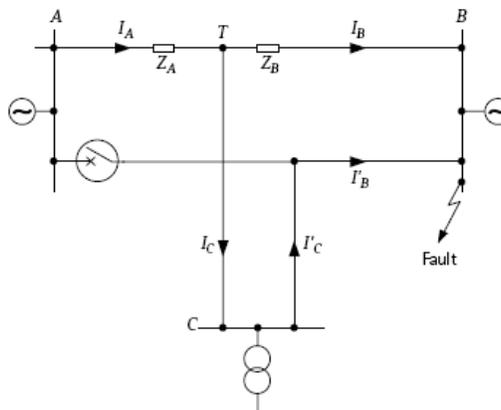


Figure 11: Internal Fault at busbar B with current flowing out at terminal C

The currents now have a different signs and has tendency to over-reach since the distance relay at terminal A sees an impedance smaller than that of the protected feeder, $(Z_A + Z_B)$. Furthermore, if there is internal fault near busbar B, the current may still flow outward of terminal C shown in the following figure 12. Consequently, the fault appears as an external fault to the distance relay at terminal C, which fails to operate.

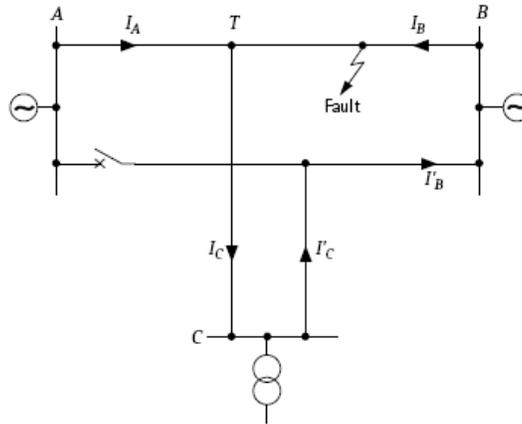


Figure 12: Internal fault near busbar B with current flowing out of terminal C

Maloperation with Reverse Faults

If the current flowing through the earth fault distance relay is high and the relay setting is relatively large, the relay's directional characteristics tend to lose their directional properties under reverse unbalanced fault condition. These circumstances occur mainly from earth faults

Application of Distance Protection Schemes

There are two main groups of distance schemes, transfer trip schemes and blocking schemes. When comparing these schemes the usual consideration is security and dependability. Furthermore, transfer trip schemes require fault current infeed at all terminals to achieve high-speed protection for any fault in the feeder, but this is not the case for blocking scheme.

Transfer Trip Under-reach Schemes

Zone 1 of the protection at least at one end shall see a fault in the feeder is the main requirement for transfer trip under-reach scheme. Zone 1 characteristics of the relays at the different end must overlap. Also, transfer trip schemes may be applied to feeders that have branches of similar length.

Transfer Trip Over-reach Schemes

Transfer trip over-reach schemes are unappealing for multi-ended feeder protection because of conditions such as under-reaching effect for internal faults due to current infeed at the T point, and incorrect operation for an external fault, due to high current fed from nearest terminal. Furthermore, the relay characteristics might infringe the load impedance.

Blocking Schemes

For the protection of multi-ended feeders, the blocking schemes are particularly well-matched, given that high-speed operation can be achieved with no fault current infeed at

one or more terminals. The only drawback of the blocking scheme is failure to operate for an internal fault, due to current flowing out at one terminal.

Signaling Channel Consideration

Depending on the type of scheme used will determine the requirement of the minimum number of signaling channels. For permissive over-reach scheme requires as many channel as there are feeder ends, as oppose to only one channel for under-reach and blocking scheme.

Directional Comparison Blocking Scheme

The theory directional comparison blocking schemes is the same as the distance blocking schemes. The major benefit of directional comparison scheme over distance scheme is their superior capability to detect high-resistance earth faults. But for reliability in terms stability for faults, directional scheme is lower than distance scheme.

SERIES COMPENSATED LINES

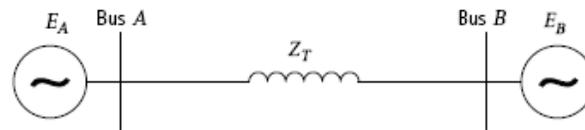


Figure 13: Power transfer in a transmission line

$$P_T \propto \frac{|E_A| |E_B|}{Z_T} \sin \delta$$

Basic power transfer equation

- Transmitted power is proportional to the system voltage level and load angle at the same time as being inversely proportional to system impedance

If the required level of transmitted power cannot be met, either from system stability requirement or load requirement than series compensated line are used in transmission network to compensate for the required level. Furthermore, they introduce a series connected capacitor, which reduces the overall inductive impedance of the line and therefore increases the power flow. There are relaying problems with the introduction of a capacitive impedance to a network such as voltage inversion shown in the following figure 14.

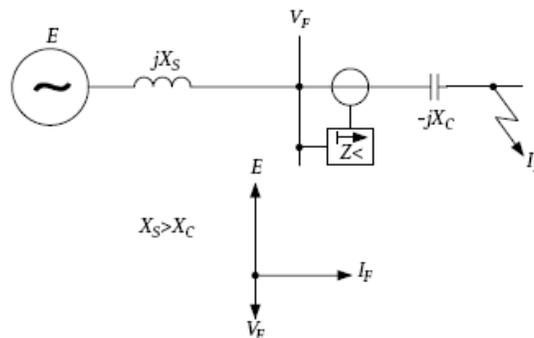


Figure 14: voltage inversion on a transmission line

For the example shown in figure 14, the fault take place on the protected line and the overall fault impedance is inductive and therefore the fault current is inductive. Furthermore, this resulted the voltage measured by the relay is in anti-phase to the system emf. Another relaying problem is current inversion, which the overall fault impedance is taken to be capacitive as shown in the following figure 15.

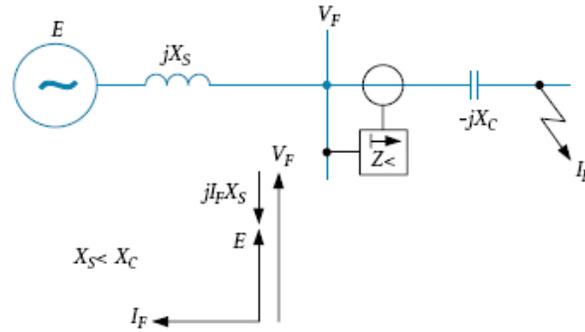


Figure 15: current inversion in a transmission line

From the example shown in figure 15, this condition can give rise to the directional stability problems. The measured fault voltage remains in phase with system emf at the same time the fault current leads the system emf by 90 deg.

The problems related with the introduction of a series capacitor can be overcome by a selection of relaying techniques. Overall, the application of protective relays to a series compensated power system needs careful evaluation. It is important to ensure the correctness of the selected protection.

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