BIRZEIT UNIVERSITY
FACULTY OF ENGINEERING
AND TECHNOLOGY

PROTECTION AND AUTOMATION IN ELECTRICAL POWER SYSTEMS

RADIAL SYSTEM PROTECTION

OVERCURRENT RELAYS, FUSES, AND RECLOSERS

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RECLOSERS

Automatic circuit reclosers are commonly used for distribution circuit protection. A recloser is a self-controlled device for automatically interrupting and reclosing an ac circuit with a preset sequence of openings and recloses. Unlike circuit breakers, which have separate relays to control breaker opening and reclosing, reclosers have built-in controls. More than 80% of faults on overhead distribution circuits are temporary, caused by tree limb contact, by animal interference, by wind bringing bare conductors in contact, or by lightning. The automatic tripping-reclosing sequence of reclosers clears these temporary faults and restores service with only momentary outages, thereby significantly improving customer service.

RECLOSERS

Standard reclosers have minimum trip ratings of 50, 70, 100, 140, 200, 280, 400, 560, 800, 1120, and 1600 A, with voltage ratings up to 38 kV and maximum interrupting currents up to 16 kA

RECLOSERS

A typical distribution protection system consists of relays, re-closers and fuses. An over-current relay is usually placed at a substation where a feeder originates. Re-closers are usually installed on main feeders with fuses on laterals. Re-closers are necessary in a distribution system as 80% of all faults that take place in distribution systems are temporary; it gives to a temporary fault a chance to clear before allowing a fuse to blow.

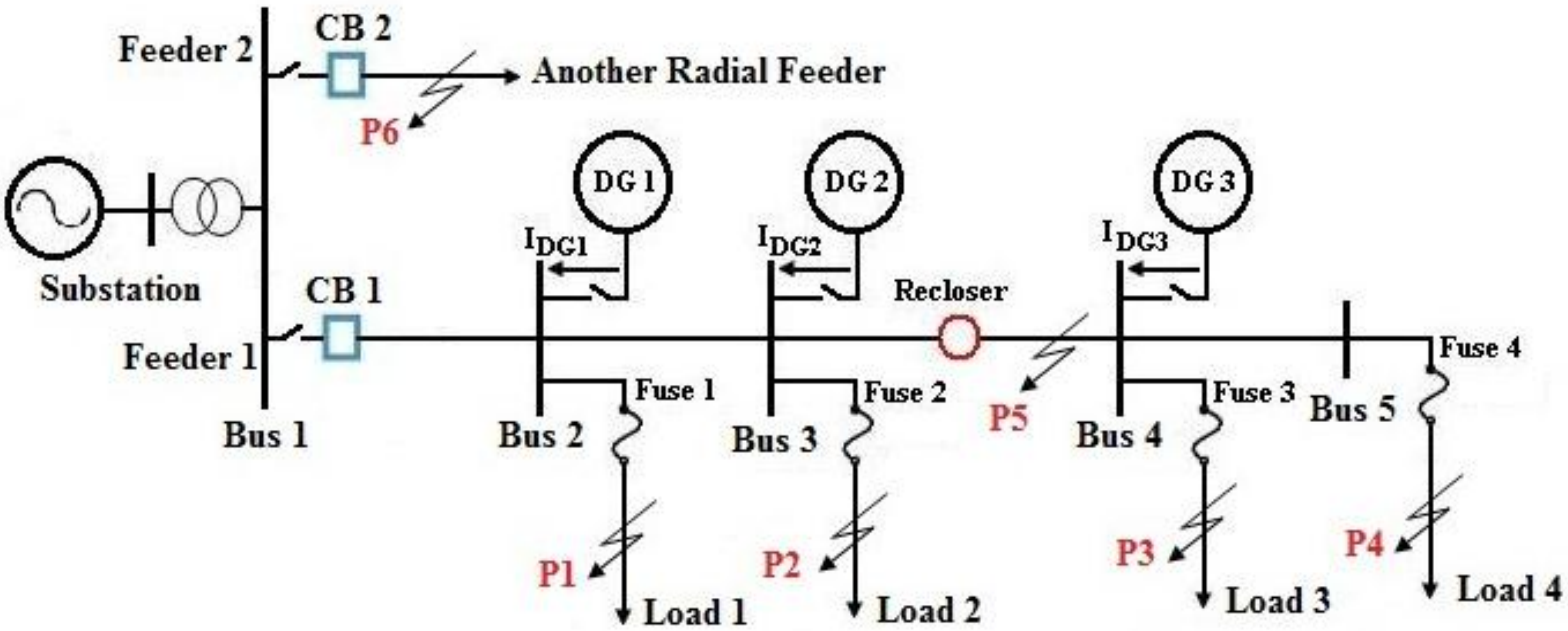
RECLOSERS

In typical distribution systems such as the network shown in the next figure, the general coordination consists of a circuit breaker, a recloser, and lateral fuse. A lateral fuse is responsible for the permanent fault that occurs in part of the lateral feeder. However, if the fault is temporary or the fault occurs on the main feeder in front the recloser, it will be the device that trips the circuit instead in order to confine the interrupted area. The operation of the recloser also includes the function of backup protection when a fuse fails to blow up. The breaker is responsible for the fault that occurs behind the recloser. In addition, the breaker is used as the whole backup protection for the whole feeder when both the recloser and lateral fuses fail in their functions. The time coordination between these protection devices is fulfilled in coordination margin Z3 shown; the descriptions TC and MM for the fuse denote total clearing and minimum melting characteristics, respectively, and the descriptions S and F for the recloser denote slow and fast operation modes, respectively.

RECLOSERS

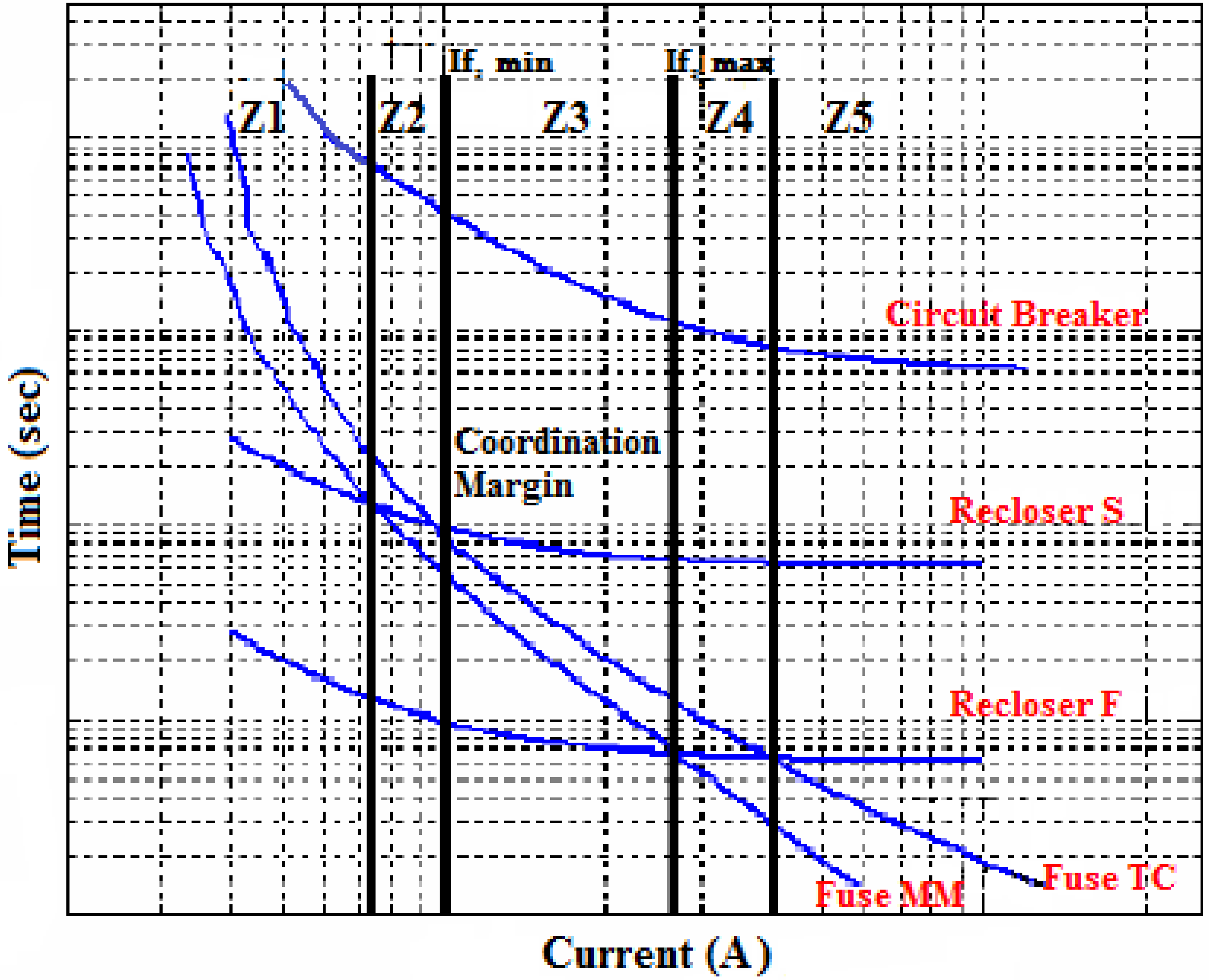
Typical operating sequence of a recloser is F-F-S-S (where F stands for fast and S for slow). There is an interval between each operation when the recloser remains open. If the fault is temporary, it will clear before the recloser closes after the second fast operation (if the 'open' time of recloser is assumed as one second, this time will be more than two seconds)

RECLOSERS



Feeder 2
CB 2
Another Radial Feeder
P6
DG 1
DG 2
DG 3
Substation
I DG1
I DG2
I DG3
CB 1
Recloser
Feeder 1
Fuse 1
Fuse 2
Fuse 3
Fuse 4
Bus 1
Bus 2
Bus 3
P5
Bus 4
Bus 5
P1
P2
P3
P4
Load 1
Load 2
Load 3
Load 4

RECLOSERS


If, min
If, max
Z1
Z2
Z3
Z4
Z5
Circuit Breaker
Coordination
Margin
Recloser S
Recloser F
Fuse TC
Fuse MM
Time (sec)
Current (A)

RECLOSERS

The selectivity rules for recloser and fuse coordination as shown in zone Z3 can be expressed as:

1) For all fault current values through a fuse in question (I_{Fuse_i}), the fuse operation time t(I_{Fuse_i}) should be greater than the recloser's fast operation time t($I_{Recloser_F}$).

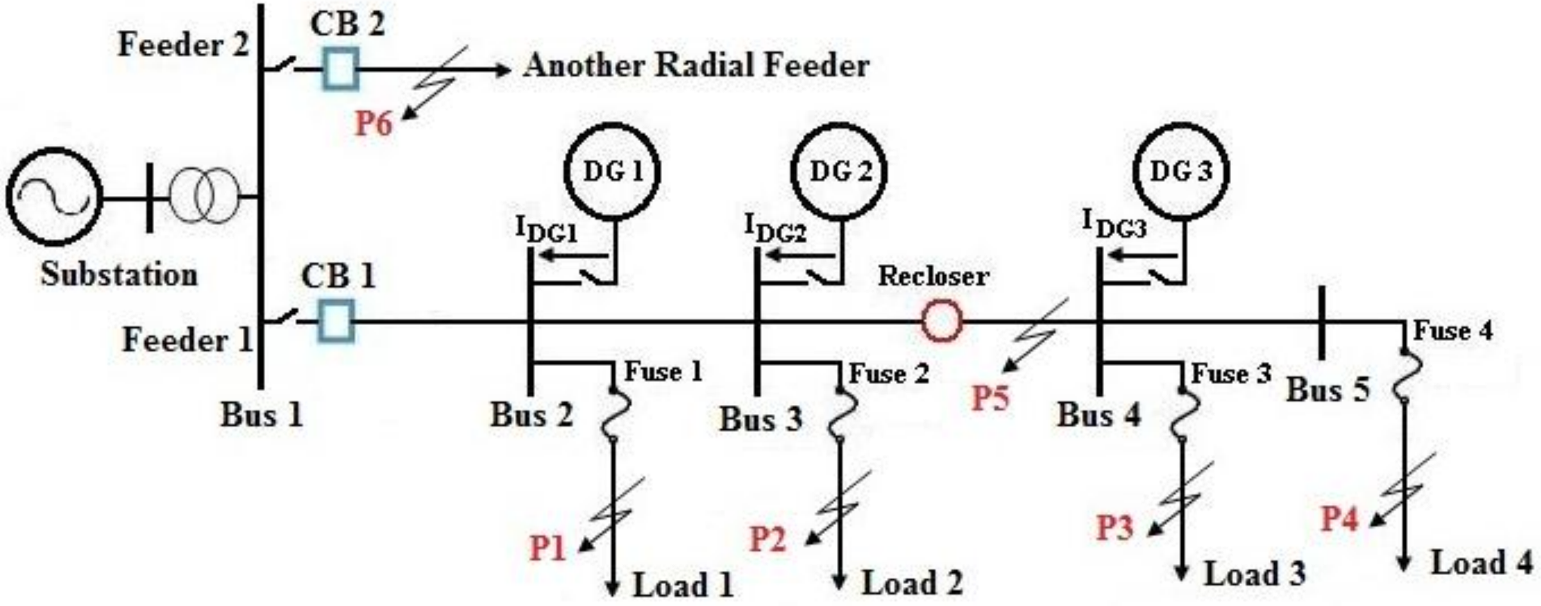
$$t\left(I_{(Fuse_i)MM}\right) > t(I_{Recloser_F});\ \forall\, I_{Fuse_i} \begin{cases} I_{f,min_i} \leq I_{Fuse_i} \leq I_{f,max_i} \\ I_{f,min_i}, I_{f,max_i} > 0 \end{cases}$$

2) For all fault current values through the fuse in question (I_{Fuse_i}), the total clear time of the fuse, $t\left(I_{(Fuse_i)TC}\right)$ should be less than the recloser's slow operation time $t(I_{Recloser_S})$

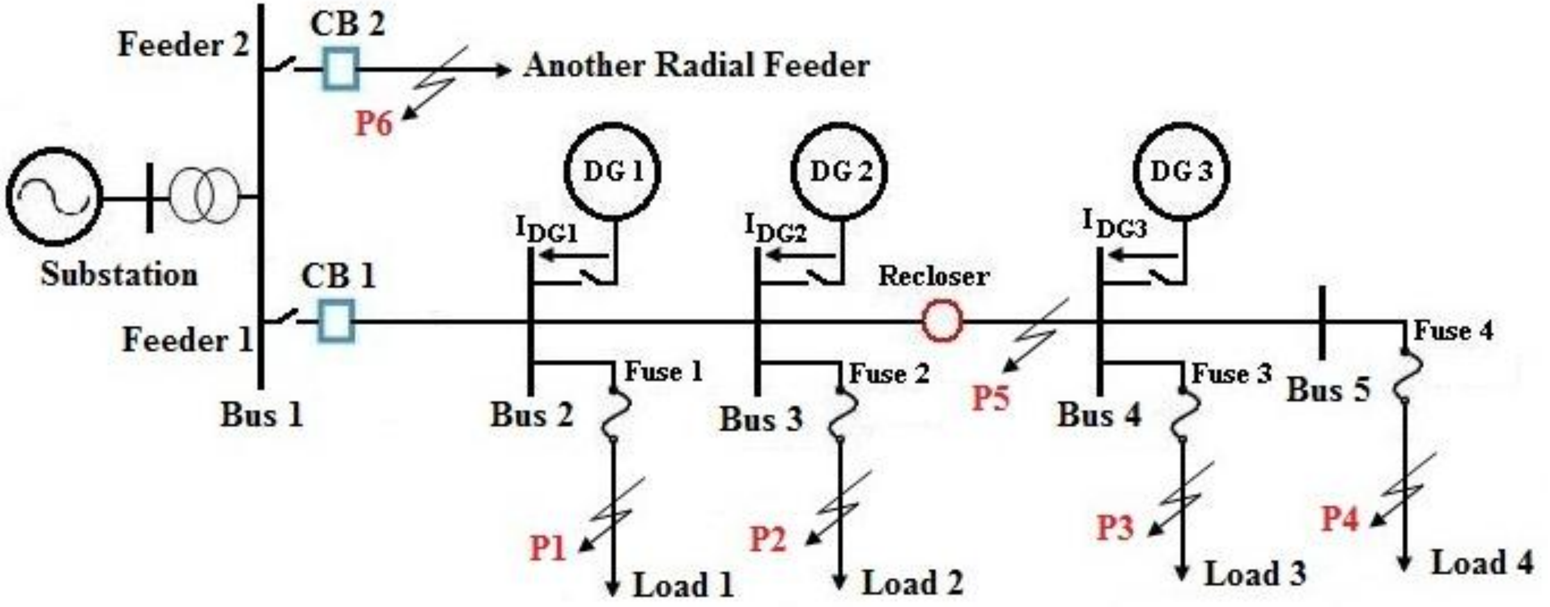
$$t(I_{Recloser_S}) > t\left(I_{(Fuse_i)TC}\right);\ \forall\, I_{Fuse_i} \begin{cases} I_{f,min_i} \leq I_{Fuse_i} \leq I_{f,max_i} \\ I_{f,min_i}, I_{f,max_i} > 0 \end{cases}$$

DG IMPACT ON DISTRIBUTION PROTECTION

Comprehensive studies are required to explore the problems related to the integration of DG in classical distribution networks. The characteristics of short circuit current and hence the rating and coordination of the protection devices are depending on the network structure. Considering the typical distribution network shown in Figure below, the following scenarios cover the most frequent changes regarding how the connection of DG units to the distribution networks may impact the protective devices coordination.



FAULT CURRENT PASSING THROUGH PD: DG1+DG2+DG3



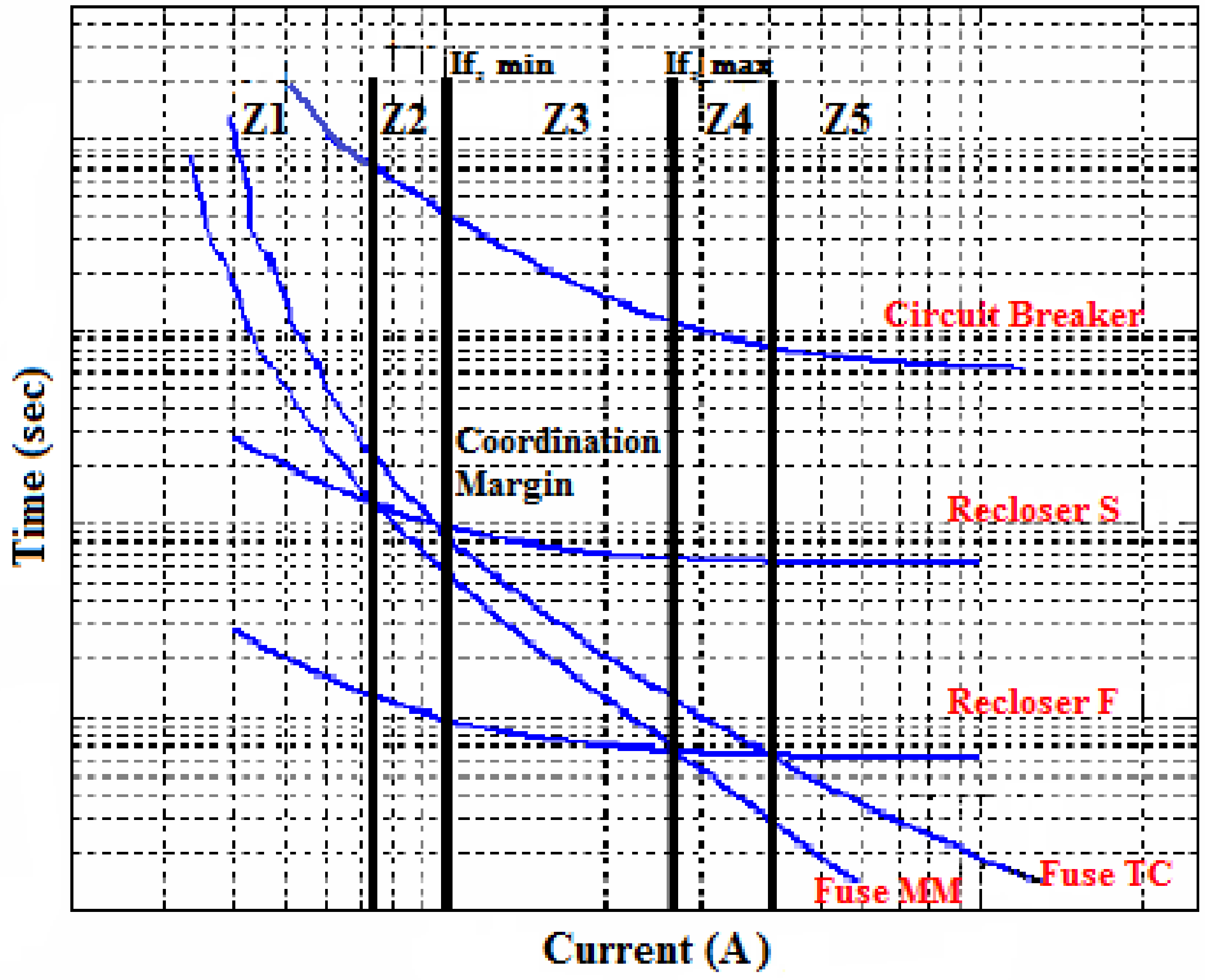
Fault Position	Description
P_5	$I_{CB}=I_S$, $I_R=I_S+I_{DG1}+I_{DG2}$, $I_{Fault}=I_S+I_{DG1}+I_{DG2}+I_{DG3}$
P_4	$I_{CB}=I_S$, $I_R=I_S+I_{DG1}+I_{DG2}$, $I_{Fuse4}=I_{Fault}=I_S+I_{DG1}+I_{DG2}+I_{DG3}$
P_3	$I_{CB}=I_S$, $I_R=I_S+I_{DG1}+I_{DG2}$, $I_{Fuse3}=I_{Fault}=I_S+I_{DG1}+I_{DG2}+I_{DG3}$
P_2	$I_{CB}=I_S$, $I_R=I_{DG3}$, $I_{Fuse2}=I_{Fault}=I_S+I_{DG1}+I_{DG2}+I_{DG3}$
P_1	$I_{CB}=I_S$, $I_R=I_{DG3}$, $I_{Fuse1}=I_{Fault}=I_S+I_{DG1}+I_{DG2}+I_{DG3}$

- ✓ I_{CB}, I_R, I_F mean fault current seen by circuit breaker CB, Recloser R, and fuse F respectively.
- ✓ I_S and I_{DG} mean fault current flowing from substation (after the transformer) and DG respectively.

DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 1

This scenario occurs when the fault current through the recloser and the fuse is the same; the increasing in the fault current, due to the presence of DGs, may cause that the total fault current exceeds the maximum coordination limit $I_{f,max}$ shown in the next figure and hence mis-coordination will occurred. The mis-coordination can be solved by selecting another fuse time-current curve and/or having new setting for recloser to correspond with fault current from DG. Another solution is to determine the maximum capacity of the DG in order to keep the existing protection scheme for distribution network unchanged.

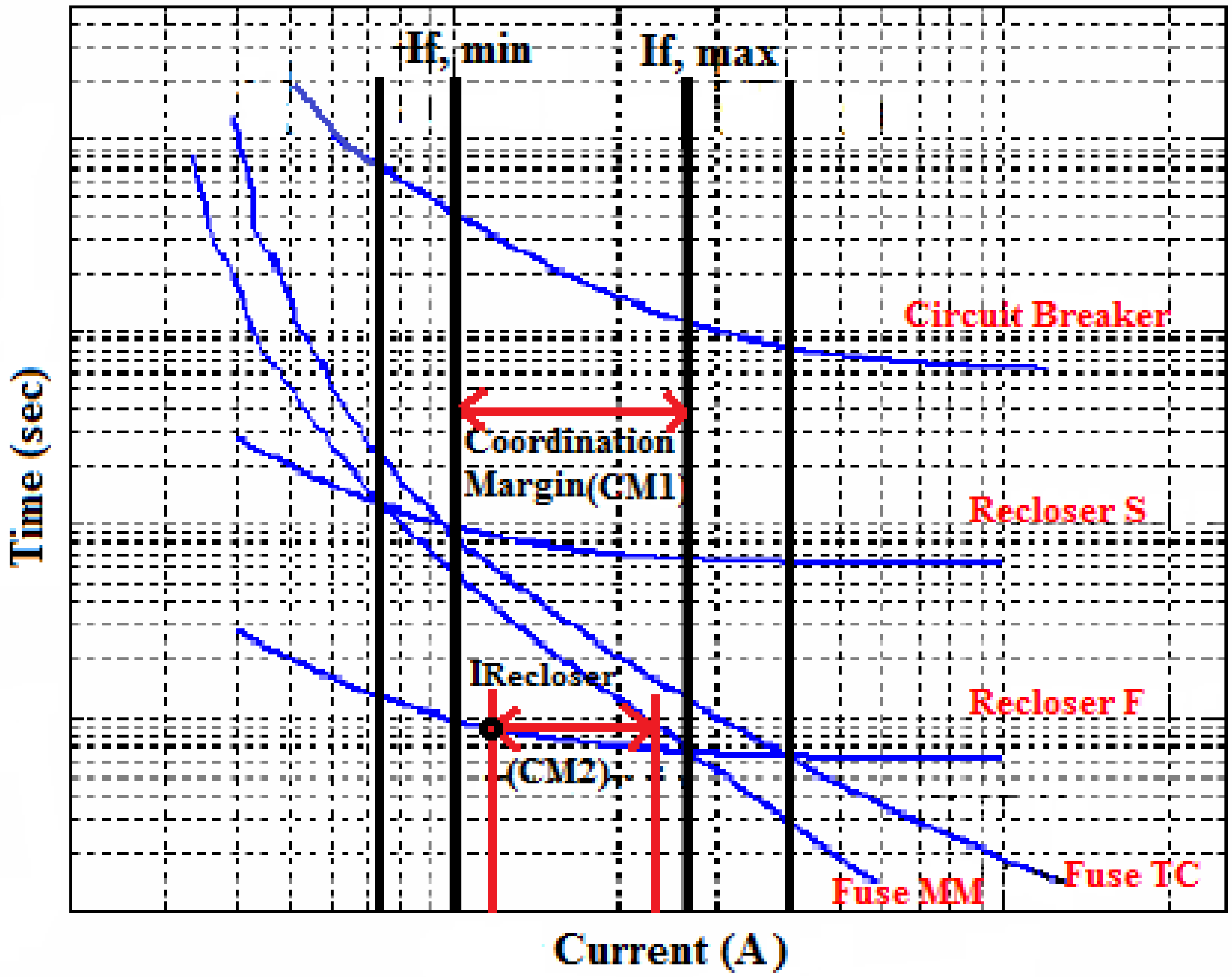
DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 1



DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 2

In this scenario, the fault currents still lie within the allowed range, also, the fault current seen by the fuse is different and higher than the fault current seen by the recloser. In order to maintain the coordination between protection devices, the recloser F curve must disconnect the circuit before fuse MM. Hence, the margin for DG fault current can be calculated from the points that fuse MM operates at the same time as the recloser F. Naturally, the disparity between these currents will depend on the size and type of DG and its placement on the main feeder. Larger size, more fault injection capacity and shorter distance of DG from load feeder will result in greater disparity and vice versa. As shown in the next figure, for a given fault current in fuse (I_{Fuse}), if the disparity between I_{Fuse} and the corresponding recloser current ($I_{Recloser}$) is more than the margin shown (CM2), the coordination will be lost.

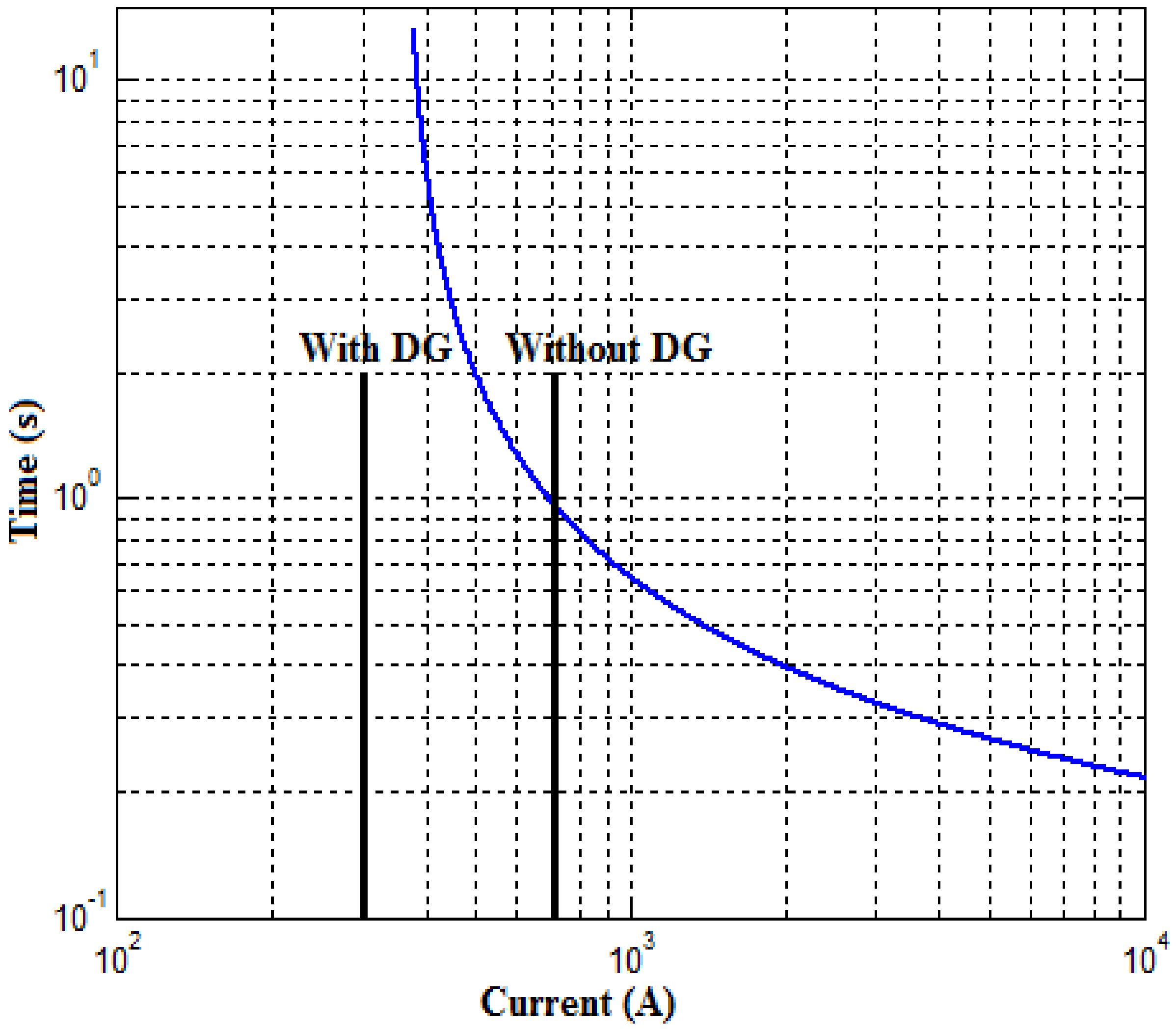
DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 2



DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 3

As the penetration of DG increases, the value of fault current flowing from substation will decreases; this situation may result in recloser or circuit breaker not responding to the fault. The next figure describes this scenario; it shows an example of fault current in which the protection device may not operate in presence of DG. This problem may be solved by either selecting a new time-current curve or by installing a smaller generation unit that will not significantly decrease the short-circuit current through the recloser or CB.

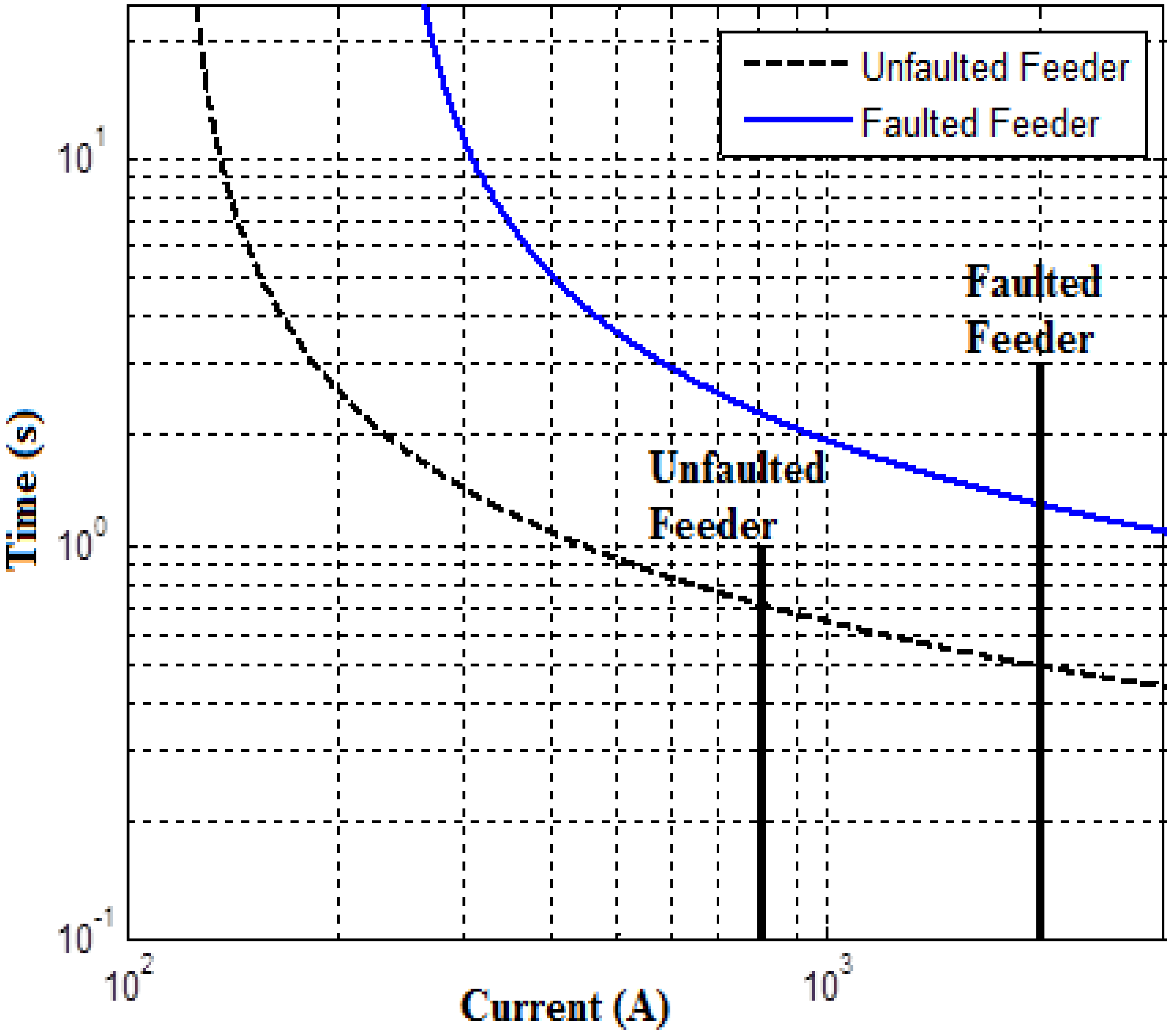
DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 3



DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 4

In this scenario, the resulting current flow due to the presence of DG may result in an undesirable tripping of the CB in non faulted feeder. The breaker at the healthy feeder may trip first, depending on the distribution system structure, distributed generators, load characteristics, and time-current curves of each feeder. The possibility of occurrence for this scenario is higher when the size of DG is very large, determining high fault currents. The next figure shows a case in which this scenario may be occur; in this situation the faulted and healthy feeders have different time-current curves which leads healthy feeder to trip first, although the current is much smaller than the fault current at the faulted feeder. This problem may probably solve by using directional over-current relays at substation breakers; this suggestion is possible and does not require a great investment. However, if both faulted and healthy feeders have similar circuit breakers and setting, the operating time of the circuit breaker in the faulted feeder will be faster and the operating sequence of both circuit breakers can be discriminated.

DG IMPACT ON DISTRIBUTION PROTECTION-SCENARIO 4

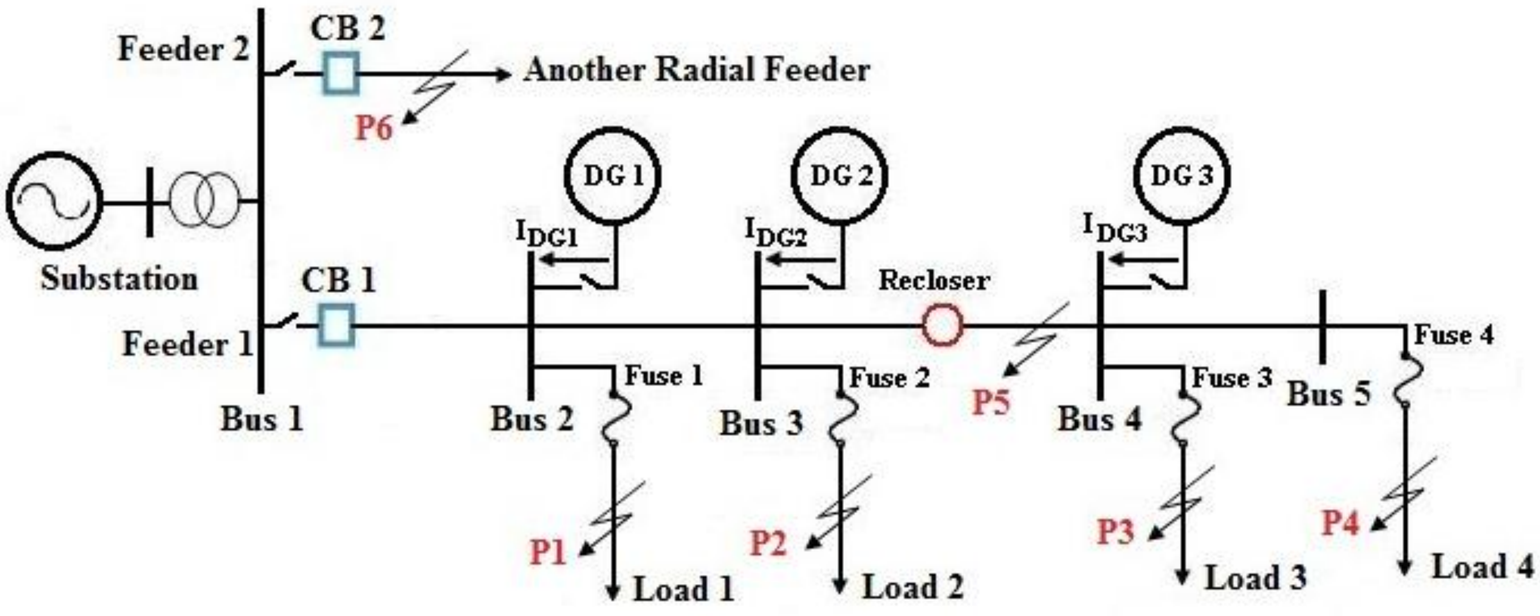


SINGLE DG INTERCONNECTED CASE

Case	Fault location	Description	Fuse-Recloser coordination margin (CM1 or CM2)
With DG1	P3	$I_{CB}=I_S$, $I_R=I_S+I_{DG1}$, $I_F= I_S+I_{DG1}$	$I_R= I_F$, CM1 needed
	P2	$I_{CB}=I_S$, $I_R=0$, $I_F= I_S+I_{DG1}$	No need
	P1	$I_{CB}=I_S$, $I_R=0$, $I_F= I_S+I_{DG1}$	No need
With DG2	P3	$I_{CB}=I_S$, $I_R=I_S+I_{DG2}$, $I_F= I_S+I_{DG2}$	$I_R= I_F$, CM1 needed
	P2	$I_{CB}=I_S$, $I_R=0$, $I_F= I_S+I_{DG2}$	No need
	P1	$I_{CB}=I_S$, $I_R=0$, $I_F= I_S+I_{DG2}$	No need
With DG3	P3	$I_{CB}=I_S$, $I_R=I_S$, $I_F= I_S+I_{DG3}$	$I_R < I_F$, CM2 needed
	P2	$I_{CB}=I_S$, $I_R= I_{DG3}$, $I_F= I_S+I_{DG3}$	$I_R < I_F$, CM2 needed
	P1	$I_{CB}=I_S$, $I_R= I_{DG3}$, $I_F= I_S+I_{DG3}$	$I_R < I_F$, CM2 needed

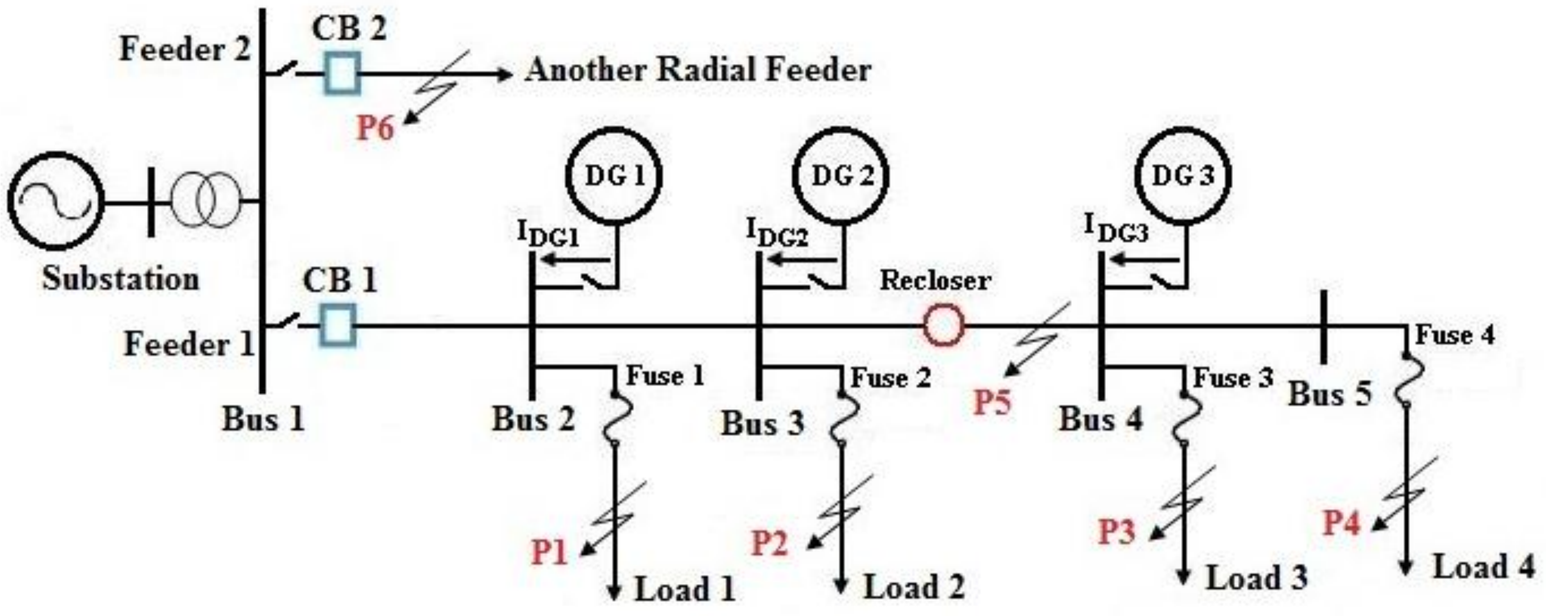
DG IMPACT ON DISTRIBUTION PROTECTION - EXAMPLE

A typical 22kV radial distribution system with the topology shown in Figure below has been considered. All bus loads are 1 MW with power factor 0.92. The distributed generator buses are modeled as PQ bus with power factor of 0.92. For each feeder segment the following values have been considered for resistance and reactance: R=0.2066 per unit and X=0.64876 per unit. MATLAB and PowerWorld software has been used to simulate the proposed system.



WITHOUT DG CASE- RESULT ANALYSIS

The system is simulated in normal case before adding any DG to determine the normal currents flow in each branch after that the proposed network is simulated for three phase fault type at different buses and different locations in order to find the maximum fault current passing through each protection device. Based on those currents, the appropriate protection devices are selected. The obtained results are summarized in the next Table. Coordination of the protection devices is shown via the time-current curves.



WITHOUT DG CASE- RESULT ANALYSIS

RESULTS OF NORMAL OPERATION AND FAULT ANALYSIS WITHOUT DG

PD	Max. Load Current (A)	Max. Fault Current (kA)
Circuit Breaker	120	2.2449
Recloser	60	0.9358
Fuse 1	30	1.1990
Fuse 2	30	0.8763
Fuse 3	30	0.6871
Fuse 4	30	0.5623

WITHOUT DG CASE- RESULT ANALYSIS