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ELIMINATING NEGETIVE EFFECT OF INVERTER-BASED DGs ON FUSE-RECLOSER COORDINATION IN DISTRIBUTION SYSTEMS

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Abstract: *Despite many advantages of distributed generation (DG) sources, they may have a negative effect on the protection of distribution systems. In a distribution system, fuse-recloser protection scheme is designed such that the recloser could operate faster than the fuse to prevent fuse burning; but, the presence of DGs in fault conditions may lead to increased fuse current and thus faster performance of the fuse than the recloser and lack of coordination. In this paper, effect of DGs on fuse-recloser coordination was studied using analytical relations and simulation. A useful control method was presented for reducing the effect of DG on fuse-recloser coordination. Accordingly, direction of DG current was changed by controlling DG reactive power at the fault time, which reduced the fuse current. Results of the simulation on IEEE 13-bus system showed that the proposed control method was able to remove the negative effect of DG on fuse-recloser coordination.*

Keywords: *Distributed generation (DG), distribution system, fuse-recloser coordination.*

1. Introduction

Distributed generation (DG) systems such as microturbines, solar cells, and photovoltaic systems are constantly increasing their penetration into electrical power networks [1]. Also, DGs have a suitable effect on different network aspects through meeting load demand increase without any need for developing transmission system, transmission losses, voltage regulation, reactive power compensation, and active power injection [2, 3]. However, despite many advantages of DGs for networks, they may have negative effects on the protection of distribution systems. For example, DGs can damage elements of the network in the case of islanding and cause problems for utilities [4].

DGs can have a negative effect on fuse-recloser coordination. Fuse-recloser protection scheme is designed such that the recloser acts faster than the fuse to prevent fuse burning; but, the presence of DGs in fault conditions may lead to increased fuse current, which causes faster performance of the fuse than recloser and thus lack of coordination [5-7]. To reduce effect of DG on the protection scheme, different methods have been proposed. In [8-10], attempts have been made to specify the maximum capacity by limiting DG capacity to reduce effect of DG on the protection system. In some references such as [11,12], the protection system has been modified and the grid is restructured using additional reclosers and breakers or directional and distance relays. Indeed, this method is less common in distribution systems. In [13-15], fault current limiters (FCLs) have been used to reduce the effect of DG on the protection coordination of the distribution system. FCLs are the tools which show negligible impedance grid in conventional performance; but, their impedance rapidly increases in fault conditions. In [16], DG current size was limited based on fault intensity at the fault time.

In this paper, effect of DG on fuse-recloser coordination was first studied. Then, a new control method was presented for eliminating the effect of DG on fuse–recloser coordination. Accordingly, DG current direction was changed by changing the reactive power injected by DG into the grid at the fault time, which reduced the fuse current; as a result, the fuse did not operate before the recloser and coordination was maintained. Results of the simulation on the standard IEEE 13-bus system showed accuracy and usefulness of the proposed method.

2. Effect of DG on fuse – recloser coordination

Studies have shown that most of the faults in air distribution systems are temporary, and will be cleared during fast reclosing actions [10]. Figure (1) shows a sample of radial distribution feeder along with DG and protective equipment, i.e. fuse and recloser. When a fault occurs in the specified part, first, recloser R rapidly operates on the fast current–time curve for one or more times. If the fault exists after the first performance of the recloser, it should be removed by the fuse; in case the fuse cannot interrupt the fault current, then the recloser with

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slow current–time curve removes the fault. For suitable coordination, current-time curve of the fuse and recloser is selected and regulated so that their fault current can be specified for all possible faults according to Figure 2. In the absence of DG, when a fault occurs with the fault current of I_{fault} within the range between Imin and Imax, fault currents are equal in the protective equipment; i.e.:

$$I_{fault} = I_R = I_F \qquad (1)$$

Where I_R is the fault current seen by the recloser and I_F is the fault current seen by the fuse. In such a case, according to Figure (2), it is evident that the recloser acts faster than the fuse and the fuse-recloser coordination is always established. However, in the presence of DG in fault current, other currents of fuse and recloser are not equal and the current of the fuse is higher than that of the recloser. In this state, the fuse is more likely to act faster than the recloser against temporary faults and thus balance is lost according to Figure (3):

$$I_F = I_R + I_{Margin} \qquad (2)$$

In which I_{Margin} is the difference between the currents of recloser and fuse for establishing fuse-recloser balance.

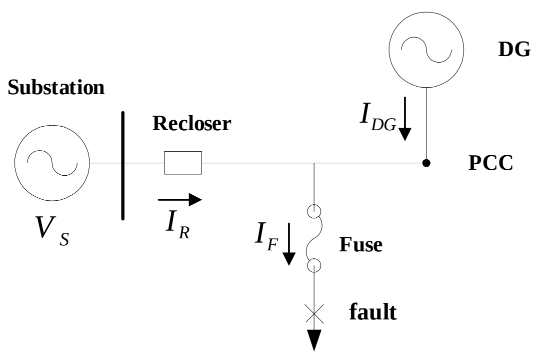

Figure 1. Sample typical distribution system.

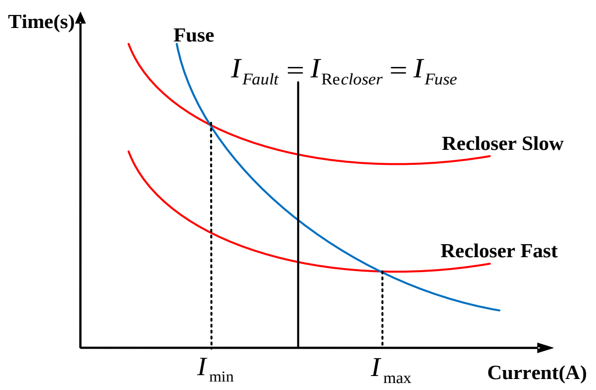

Figure 2. Sample coordination between recloser and fuse

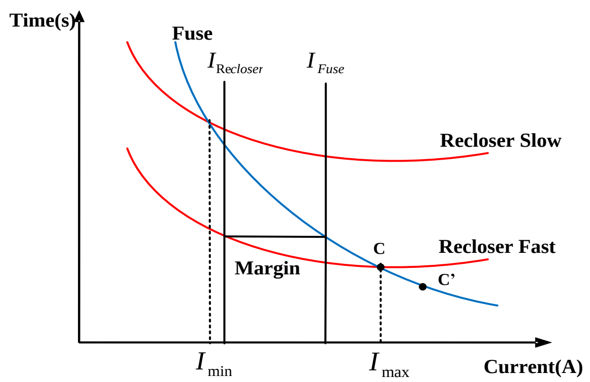

Figure 3. Fuse-recloser protection scheme in distribution feeder

On the other hand, according to Figure (1):

$$I_F = I_R + I_{DG}\frac{Z_{eq}}{Z_{eq}+Z_f} \qquad (3)$$

Where I_{DG} is fault current of DG. Z_{eq} is equivalent impedance of substation and Z_f is fault impedance. Thus, to ensure the fuse-recloser coordination, it is necessary to:

$$I_{DG} < I_{Margin} \qquad (4)$$

When DG capacity is higher or reactive power in injected into the network while fault impedance is low [16], equation (3) is not established and the current of the fuse increases and exceeds the coordination limit. According to Figure 3, point C is moved toward the right side, i.e. point C' and fuse-recloser coordination is lost. Thus, it is necessary to properly control DG current at fault moment in order to maintain the fuse-recloser coordination.

Another point is that, according to voltage and current vector diagram in Fig. 4, when DG supplies reactive power of the grid, a more negative effect is made on the fuse-recloser coordination than the case when DG injects active power into the grid. Based on Fig. 5, in the injection case of active power by DG, DG current (I_{DG}) is in phase with the PCC voltage (V_{PCC}) and almost 90 degrees of phase difference are observed between recloser current (I_R) and V_{PCC}. Therefore, the relationship in (5) can be obtained:

$$I_R + I_{DG} < I_R + I_{DG} \qquad (5)$$

In the injection case of reactive power by DG, 90 degrees of phase difference are observed between DG current (I_{DG}) and the PCC voltage; also, the following equation is obtained:

$$I_R + I_{DG} \approx I_R + I_{DG} \qquad (6)$$

These equations demonstrate that the fuse current is larger in the injection case of reactive power by DG, representing that DG in reactive power supply has a higher effect on fuse - recloser coordination than that in the active power supply.

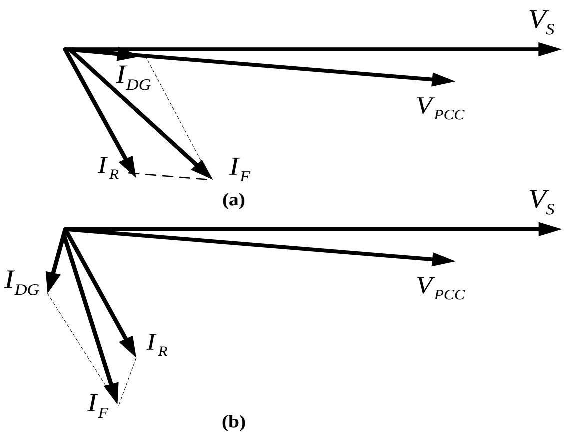

Figure 4. Voltage and current vector diagram (a) DG generates active power, (b) DG generates reactive power

3. The proposed method for reducing DG effect on fuse-recloser coordination

The proposed method for reducing DG effect on fuse-recloser coordination in this paper was based on the point that, change in the DG current direction leads to reduced fuse current. In fact, this task was performed by changing the direction of the reactive power injected by DG at the fault time. In the case of fault with low impedance ($Z_f \ll Z_{eq}$), the following equation can be written according to (3):

$$I_F = I_R + I_{DG} \tag{7}$$

Considering the above equation, the fuse current can be reduced by changing the direction of DG current; but, the way I_{DG} changes at the fault time for inducing coordination should be considered. If I_{DG} changes at the fault time into I'_{DG} so that the fuse current and recloser becomes equal ($I_F = I_R$), then, fuse-recloser coordination will be definitely maintained within the current limit between I_{min} and I_{max} as demonstrated in Fig 2. Therefore, equation (9) is obtained by placing $I_F = I_R$ in the equation (8):

$$I_F{}^2 = I_R{}^2 + I'_{DG}{}^2 + 2\, I_R\, I'_{DG} \cos\alpha \tag{8}$$

$$\cos\alpha = -\frac{I'_{DG}}{2\, I_R} \tag{9}$$

This equation states that α (the angle between two vectors I'_{DG} and I_R) should be more than 90 degrees; i.e. DG absorbs reactive power from the grid at the fault time, which can be done in different states according to Fig. 5. In other words, it is performed for different DG currents ($I_{DG1}, I_{DG2}, I_{DG3}, \ldots$) and θ_i angles ($\theta_1, \theta_2, \theta_3, \ldots$); in all of these states, fuse current should be equal to recloser current and placed on the radii of the circle centered at O. Considering that $\alpha_i = \theta_i + 90$:

$$\sin\theta_i = \frac{I_{DGi}}{2\, I_R} \qquad i=1,2,3,\ldots \tag{10}$$

Assuming that I_d and I_q are active and reactive components of DG current and I_{DG} and I'_{DG} are DG short-circuit currents before and after applying the control, then, DG reactive current component is obtained using (11) according to Fig. 6:

$$I'_q = \frac{\tan\theta'}{\tan\theta}\, I_q \tag{11}$$

In this equation, angle θ indicates the reactive power which DG injects into the grid before applying the control and angle θ′ shows the reactive power which DG absorbs after applying the control at the fault time from the grid. As discussed above, angle θ′ can have different values. In a special case, if DG current is changed so that its active component remains constant and only its reactive component changes and θ = θ′; then, DG control structure will be simplified; i.e. only the direction of DG reference current component changes at the fault time. The above state was simulated in this paper. On the other hand, components of the reference DG active and reactive currents could be obtained based on the reference DG active and reactive power as follows [2]:

$$P_{ref} = V_d I_{dref} \tag{12}$$

$$Q_{ref} = -V_d I_{qref} \tag{13}$$

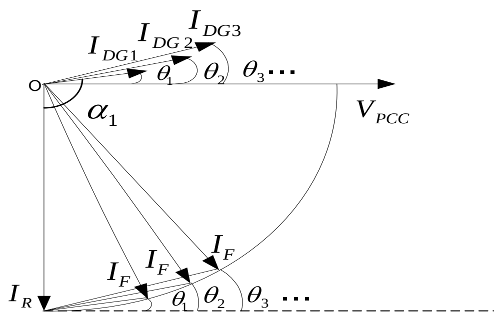

Figure 5. Vector diagram of fuse, recloser, and DG current in different states

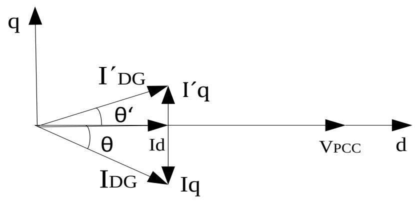

Figure 6. Vector diagram of DG current in the proposed control method

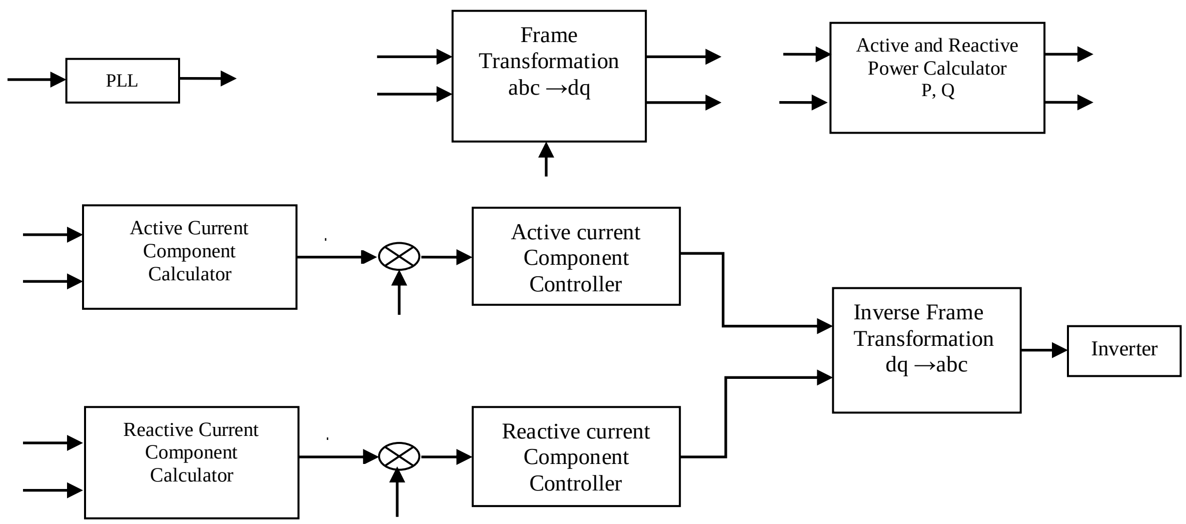

Figure 7. DG control structure based on current-controlled inverter

In (12) and (13), V_d is voltage component of V_{PCC} on axis d. Therefore, DG control structure is expressed as Fig. 7. Based on standard IEEE.1547 [17], when $V_{PCC} < 0.88\,pu$, the grid is in an abnormal state. Accordingly, DG detects the fault and the proposed control method can be applied. The proposed algorithm for controlling DG current to establish fuse-recloser coordination is shown in Fig. 8.

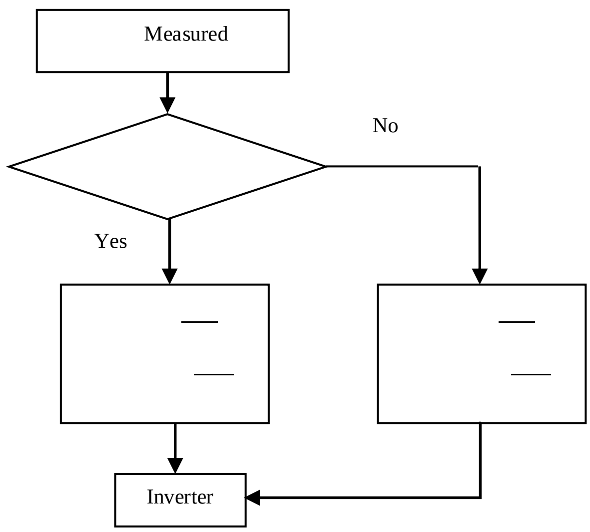

Figure 8. The proposed algorithm for determining DG reference current

4. Simulation results

To evaluate the proposed method, IEEE 13-bus distribution system [18] (Fig. 9) was simulated in MATLAB software and an inverter-based DG [11] with the control structure shown in Fig. 7 was connected at node 645. To study fuse-recloser coordination a three-phase fault was applied to bus 646. Characteristic current-time curve of the fuse and recloser which was used in this simulation is shown in Fig. 10. In this simulation, before the presence of DG, point A occurs for fault resistance of 11Ω , and point B occurs for fault resistance of 0.01Ω. In other words, the recloser and fuse operate correctly for fault resistances between 0.01 to 11.5 Ω. Fig. 11 shows the consequence of adding DG at low and high penetration levels ($\text{penetration level} = P_{DG}\ \ P \times 100$) on the fuse and recloser current when a 0.01Ω fault occurs. As Figure 11 reveals, after adding DG at two penetration levels, recloser current remained almost constant; but, fuse current increased. Fig. 12 demonstrates the difference between fuse and recloser fast operation times after adding DG at different penetration levels for a 0.01 Ω fault.

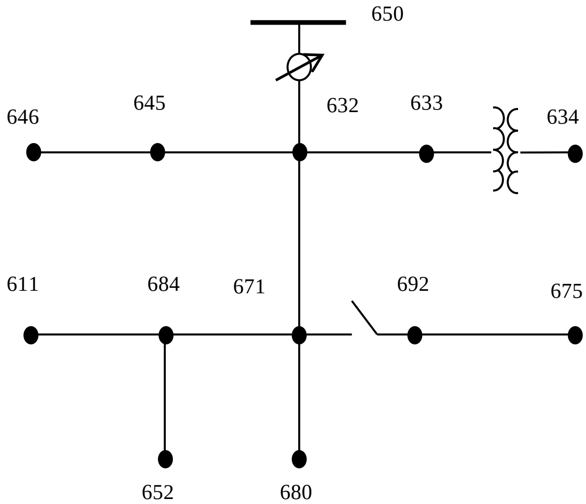

Figure 9. IEEE 13-node test feeder system

Fig. 12 represents that, in the presence of DG, the fuse would opreate faster than the recloser and the coordination would be removed. The fuse current was higher when DG injected reactive power than the case in which active power was injected. Difference in operation time between fuse and recloser in this case is shown in Fig. 13.

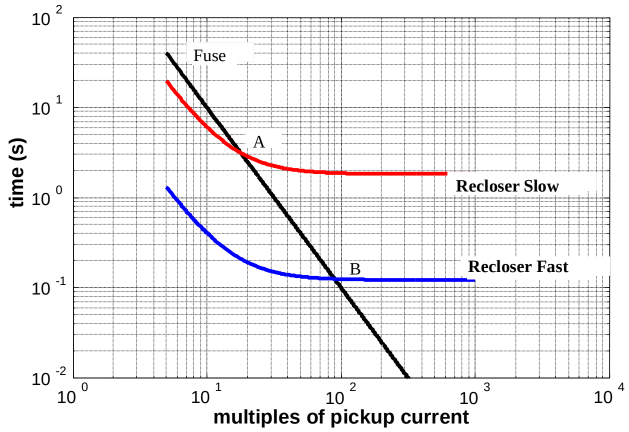

Figure 10. Fuse-recloser coordination in the simulated system

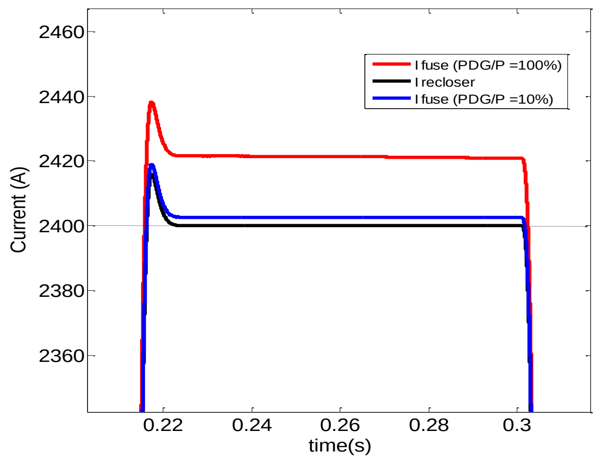

Figure 11. recloser and fuse currents in the presence of DG

By comparing Figs. 12 and 13, the negative effect of DG on fuse-recloser coordination was revealed to be higher than the injection case of the reactive power by DG. Fig. 14 demonstrates that the presence of DG had a lower effect on coordination at high fault impedance (0.1 ohm); this effect was more evident when DG supplied more power of the grid. Fig. 15 shows fuse current with and without using the proposed control method in a fault with 0.1Ω resistance. It is clear that, as a result of applying the proposed control method, the fuse current was considerably reduced from the coordination limit.

Fig. 16 shows that, after applying the control method, direction of DG output reactive current component was reversed compared to its previous current at the fault time (t= 0.2 s). In other words, direction of the DG reactive power was changed in order to reduce the fuse current and maintain the fuse-recloser coordination.

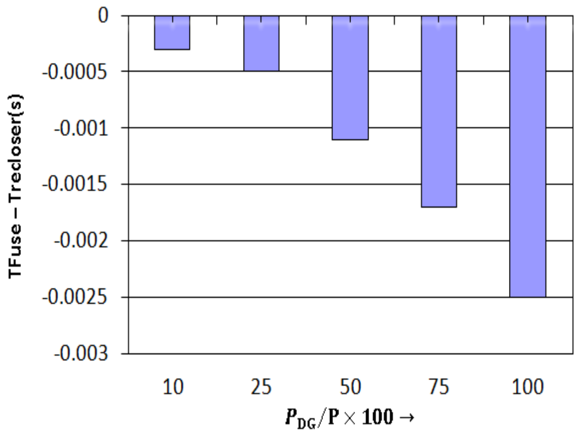

Figure 12. Difference between fuse and recloser operation time after adding DG for 0.01Ω fault (injection of active power)

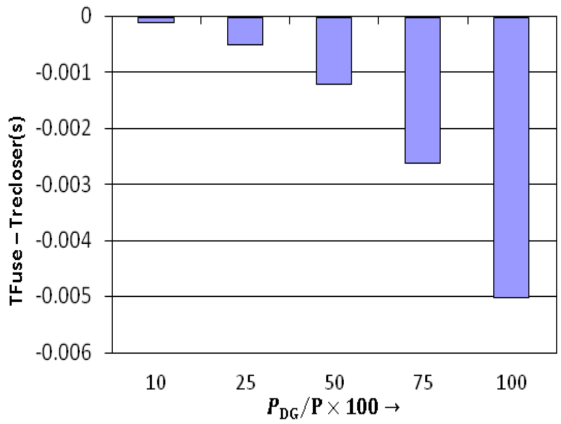

Figure 13. Difference between fuse and recloser operation time after adding DG for 0.01Ω fault (injection of reactive power)

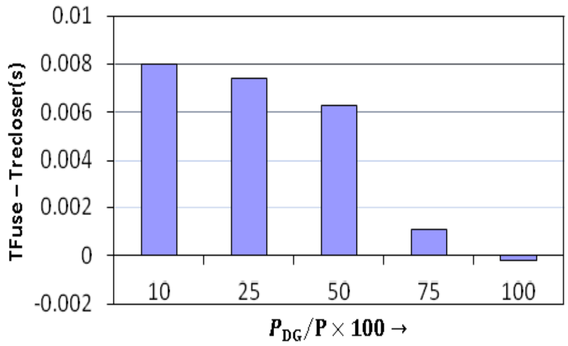

Figure 14. Difference between fuse and recloser operation time after adding DG for 0. 1Ω fault

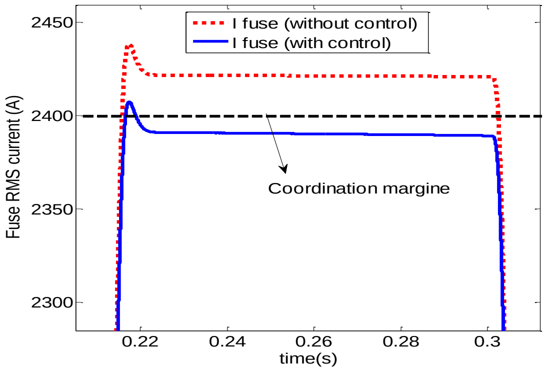

Figure 15. Fuse current with and without applying the control method at the fault impedance of 0.1 ohm in the presence of DG

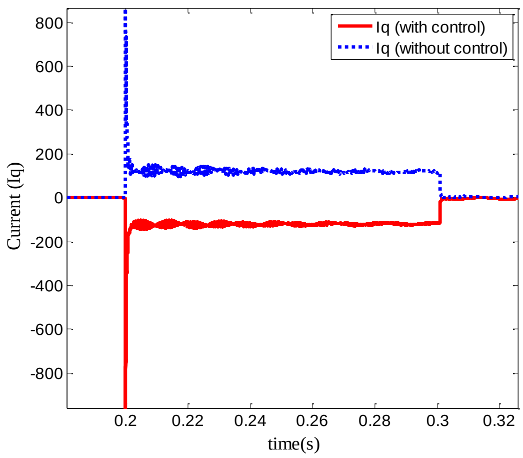

Figure 16. DG reactive current component before and after applying the control method

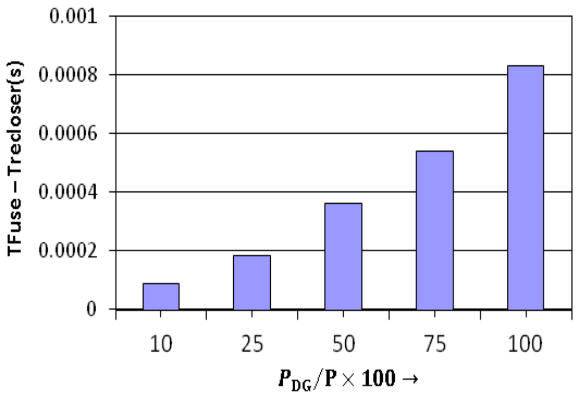

Figure 17. Difference between fuse and recloser operation time for 0.01 ohm fault by applying the control method

Fig. 17 shows effect of the proposed control method on the coordination. Accordingly, it is clear that the control method properly removed mis-coordination resulting from the presence of DG at low fault impedance.

5. Conclusion

In this paper, effect of DG on fuse-recloser protection coordination was shown using analytical relations and simulation. In fact, DG at low fault impedance can remove fuse-recloser coordination. It could also increase the current passing through the fuse at the fault time and cause faster performance of the fuse than recloser; this effect increased at the injection time of reactive power by DG. To overcome this problem, a simple and useful control method was presented, based on which the direction of DG current changed at the fault time in proportion to the fault intensity. Simulation results on an IEEE 13-bus distribution system showed that this method could properly reduce the negative effect of DG on fuse-recloser coordination. In addition to its simplicity, other advantages of the proposed method were that it could be applied on the DG side and did not need any changes in the main adjustments of the protection system.

6. References

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