Protection System Adjustment for High Penetration of Distributed Generation

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ABSTRACT

Excessive number and capacity of Distributed Generation (DG) may cause problems to distribution systems. To maintain existing protection coordination, the system can generally allow DG to be connected at a limited capacity. In case of more DGs are to be connected, it is a challenging issue for distribution system engineers to conduct protection adjustment for which the system can allow increased level of DG penetration. This paper proposes three methods, concerning protection system adjustment, to allow high DG penetration, consisting of over-current protection resetting, directional recloser application, and fuse replacement with recloser. The first method will help relieve the system constraint from existing pick-up current settings whereas the second one helps solve the problem of mis-operation of the mid-line recloser caused by DG back feed fault current. The final method will be used to maintain fuse saving scheme. In this paper, the developed methods are simulated with a test system to illustrate their effectiveness on allowing higher penetration of DG to the system.

Keywords: Distributed generation (DG), Protection coordination, Distribution systems.

1. INTRODUCTION

The number of Distributed Generations (DGs) connected to a distribution feeder is continually increased. DG generally provides benefits to society and distribution systems, e.g. increase indigenous resource utilization, voltage support and loss reduction. However, it does increase fault level in the system and change the network configuration to a non-radial type. Consequently, it has impact on existing protection system coordination [1, 2]. With open and non-discriminatory access to the network, utility generally cannot strictly control the entry of a DG with respect to its capacity and location on a feeder. As a result, it is a difficult task for utility officers to plan for an optimum DG capacity in a distribution system.

In general, a distribution network operates with radial configuration with application of over-current protection scheme. The protection coordination is usually designed based on typical time-current coordination, i.e. protective device must not operate under a maximum loading condition and must clear fault in its operational zone before the operation of upstream protective devices.

With high penetration of DG, the fault level usually increases and the path in which the fault current flows is altered. As a result, the distribution network is no longer a passive circuit, i.e. becoming active due to the embedded DG sources. Therefore, the DG may cause adverse effects to the existing protection system, resulting in coordination failure, and consequently reducing system reliability. In addition to the protection system, it is widely understood that high level penetration of DG can also increase feeder power loss. Moreover, it may cause system voltage profile to violate the required range [3, 4].

Currently, utilities apply several criteria to allow a DG to be connected to their distribution network [5-7]. Most criteria place their major concerns on loading capacity and fault levels, without explicit consideration on protection system coordination. However, a few methods [8-10] were developed to determine maximum DG allowable capacity. Most of them take into account only power loss and voltage regulation. A method for determining the maximum allowable DG capacity taking into account protection coordination was proposed in [11], which clearly demonstrated that protection coordination settings was an important factor on the maximum allowable capacity. In this paper, three methods are proposed to relax the limitation from protection coordination, comprising the resetting of protection system coordination, the application of directional recloser, and the replacement of fuse with recloser.

This paper is divided into five sections. The next section reviews the determination of maximum allowable DG capacity with protection coordination consideration, followed by protection adjustment method to allow a larger DG capacity. Simulation results and discussion of the proposed method are provided in the following section. Conclusions are drawn in the final section.

2. MAXIMUM ALLOWABLE CAPACITY OF A DG WITH PROTECTION COORDINATION CONSIDERATION

To verify whether the protection coordination has to be adjusted to allow a DG to be connected, it is

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necessary to firstly determine the maximum allowable DG capacity which does not cause violation of protection coordination to the current system. An optimization based methodology [11] is presented below.

The problem in determining maximum allowable DG capacity can be formulated as a minimization problem. The objective function can be written as shown in (1).

$$Max(P_{DG}) = -Min(-P_{DG}) \tag{1}$$

where P_{DG} is MW output of the DG, with following constraints.

1) Voltage constraint: The voltage at each node should remain within an acceptable range, which is defined to be 0.95-1.05 p.u. The conditions can be written as

$$V_i - 1.05 \leq 0, \quad \forall i \in \mathbf{B} \tag{2}$$

$$0.95 - V_i \leq 0, \quad \forall i \in \mathbf{B} \tag{3}$$

where V_i is the voltage at bus i^{th}, and $\mathbf{B}$ is a set of bus number.

2) Loss constraint: DG connection should not lead to an increase of power loss compared to the case without the DG. The condition can be defined as

$$L - L_{base} \leq 0 \tag{4}$$

where L and L_{base} are the system power loss for the cases with and without the DG.

3) Protection coordination constraint: Three patterns of protection mis-coordination are recognized based on analysis of DG and fault locations. First, if an increase in fault level due to a DG is too high, the distribution system may lose its fuse saving scheme application as described in [12]. In brief, the scheme is applied where the temporary fault is of high frequency such as a long overhead distribution circuit passing wooded terrain, to save fuse from unnecessary operation. The fail of the scheme therefore will result in system reliability degradation. Secondly, the increase in fault level may exceed fault interrupting capacity and cause damages to electrical equipment, e.g. drop-out fuse. Finally, the presence of a DG changes radial configuration of the distribution system. This change may have impacts on the operation of protective devices which are mostly non-directional type. When a fault occurs, the device may unnecessarily operate, especially when a large back-feed fault current is fed from a DG. All these three mis-coordinating patterns may result in degradation of system reliability.

To cope with protection coordination, protection constraints are formulated based on DG and fault locations with respect to the mid-line recloser. Fig.1 presents a simple system with a connected DG behind recloser and a fault is occurred on a lateral in front of the recloser. The fault current is contributed from the substation and DG. It is also shown that the fault currents flow through all protective devices, i.e. circuit breaker, recloser, and fuse. It should be noted that $I_{F,Sub}$ is the fault current from substation whereas $I_{F,DG}$ is the fault current from the DG.

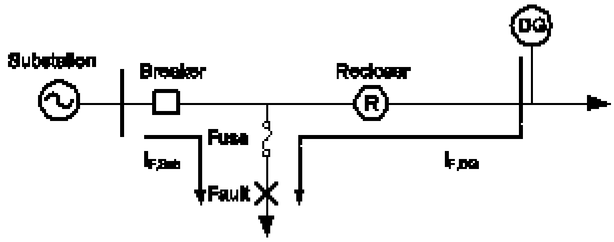

Fig.1: *A network with fault in front of recloser and DG located behind recloser.*

Table 1: *Summary of protection constraints.*

Case	DG position	Fault location	Constraint
1	Behind recloser	Behind recloser	(5),(6)
		In front of recloser	(7),(6)
2	In front of recloser	Behind recloser	(5),(6)
		In front of recloser	(6)
		Behind recloser (Nearby feeder)	(5),(6)

The constraints for protection coordination are listed in (5)-(7). In (5), the operating time of recloser fast curve must be less than the minimum melting time of fuse for a successful fuse saving application, whereas (6) is a constraint on fuse interrupting rating which is defined as 10kA in this paper. Finally, (7) is the constraint preventing mis-operation of the mid-line recloser due to back feed fault current from the DG, which does not allow the back-feed fault current through the recloser to be higher than its pick-up current.

$$T_{Rf}(I_R) - MMT_f(I_{Fuse}) \leq 0 \tag{5}$$

$$I_{Fuse} - 10,000 \leq 0 \tag{6}$$

$$I_R - I_{R,pickup} \leq 0 \tag{7}$$

where T_{Rf} (I_F) is the operating time of recloser's fast curve for the fault current of I_F; *MMTF* (I_F) is the minimum melting time of the fuse for I_F; I_R is fault current through recloser in backward direction; I_{Fuse} is fault current through fuse; $I_{R,pickup}$ is pick-up current of recloser. Table 1 summarizes various cases of protection coordination constraints to be active according to DG and fault locations.

Based on all the above constraints, the maximum allowable DG capacity at a certain location can be obtained by conducting a search process taking in account system voltage, power loss from a power flow solution, and protection coordination for faults at every bus.

The proposed method has been successfully tested and the results are shown in [11]. A part of the results will be reviewed in Section IV.

3. PROTECTION ADJUSTMENT FOR A LARGER DG

In this section, the methods of protection adjustment to allow larger DG, i.e. increase the maximum capacity obtained from the previous section, will be presented. The methods are consisted of protection resetting, application of directional recloser, and fuse replacement by recloser. The first method will help the system in coping with a larger DG unit located behind recloser without any hardware change. The second method relieves the problem occurred from back-feed fault current of the DG. The final method will be mainly used for coping with high fault current for fuse saving scheme.

It should be noted that the cause of protection failure due to the presence of DGs can be classified into two cases based on their locations, i.e.

- DG in front of recloser: impact on fuse saving scheme,
- DG behind recloser: impact on fuse saving scheme and mis-operation of recloser due to back-feed fault current.

In the case that fault level exceeds interrupting rate of equipment, the only solution to the problem is to upgrade the effected devices, and will not be brought up for discussion in this paper.

A. Resetting Protective Devices

It is shown by (7) that the maximum allowable capacity of a DG located behind a mid-line recloser is primarily limited by the pick-up current setting of the recloser. Hence, raising recloser pick-up current setting can help allow larger DG capacity. Consequently, existing protection coordination also needs to be reset accordingly. However, it should be noted that the pick-up current must not be raised beyond equipment rating.

With typical over-current protection coordination [12], three constraints are considered for resetting protective devices. The first constraint is equipment rating. The setting of protective devices must cover an overload condition of the equipment. Therefore, the equipment rating is set as the limit for the pick-up current as (8).

$$I_{pickup} \leq I_{spec} \tag{8}$$

where I_{pickup} is pick-up current setting and I_{spec} is of a specified current of which the maximum value is equipment rating.

Secondly, current setting of the downstream devices should be less than that of the upstream by some safety factor. This is to ensure a proper coordination between the two over-current protective devices.

$$I_{pickup-down} \leq K \cdot I_{pickup-up} \tag{9}$$

Where $I_{pickup-up}$, $I_{pickup-down}$ is pick-up current settings of the upstream and downstream devices, and K is a safety factor with a value of less than 1.

Finally, operating time of the downstream devices must faster than that of the upstream by an appropriate margin. The previous statement can be written in an equation form as

$$T_{up}(I_{down}) - T_{down}(I_{down}) \geq t_{margin} \tag{10}$$

where $T_{up}(I)$ and $T_{down}(I)$ is operating time of upstream and downstream devices for fault current I, I_{down} is fault current magnitude at the location of downstream devices, e.g. recloser, and t_{margin} is a required operating time margin.

From all the above constraints, i.e.(8)-(10), the pick-up current of the recloser can be raised up. The maximum setting which can be raised depends on the setting of the upstream circuit breaker, which generally is located at the distribution substation and provides backup protection function [12]. As a result, if the pick-up current and time multiplier setting of the circuit breaker are to be adjusted, the coordination between these two circuit breakers must also be considered. Accordingly, the procedure for resetting the protective devices can then be developed and described below.

1) Calculate fault current at circuit breaker and recloser location.
2) Raise pick-up current setting of the circuit breaker to that of the feeder or of a defined capacity, i.e. Eq.(8).
3) Determine operating time of the incoming circuit breaker for the fault from 1).
4) Raise time multiplier of circuit breaker using Eq.(10).
5) Raise pick-up setting of recloser using Eq.(9).
6) Verify coordination between circuit breaker and recloser using Eq. (10). If not valid, reduce the value in 5).
7) Verify coordination between recloser fast operating sequence and fuse MMT. If not valid, reduce the value in 5).

In 2), the pick-up current setting can be raised to feeder capacity without safety margin since in normal system operation, it is typically defined as 80% of line thermal limit. As a result, the pick-up setting is less than the equipment rating according to (8).

B. Directional Recloser Application

Another protection adjustment is to replace the existing mid-line recloser with a directional type which allows the recloser to be able to distinguish between fault in the forward and backward directions. This capability can help utility solve the problem of misoperation of the mid-line recloser caused by the DG back feed fault current. This is achieved through the setting of recloser to operate for the fault in the forward direction only. Therefore, the setting adjustment of other protective devices is not required.

Correspondingly, in determining the maximum allowable DG capacity, eq.(7) can be discarded by which the result of a larger DG capacity can be expected.

C. Replacement of Fuse with Recloser

If the DG capacity is sufficiently large, it can increase the fault level to exceed that of the design for fuse saving scheme. As a result, the mid-line recloser will not be able to save a lateral fuse from unnecessary operation due to a temporary fault. Consequently, those temporary faults will result in a permanent outage to the lateral feeder. None of the two previously mentioned methods can help solve this problem.

In order to maintain benefits from the self-clear of a temporary fault with an auto-reclose function, replacement of fuse with recloser may be considered. Once the lateral fuse is replaced by the recloser, the fast operation of the mid-line recloser can be turned off and transfer that function to the replacing lateral recloser. In this way, instead of using the mid-line recloser to restore the circuit from a temporary fault, the lateral recloser will perform this function. This replacement is applied to all the lateral fuses located behind the mid-line recloser.

At present, newly developed equipment, e.g.dropout recloser [15] has emerged. These devices can also be installed in place of the lateral fuse to resolve the above problem in almost the same way but with lower cost. In addition, since the fast operation of mid-line recloser can be turned off, the problem from a large back-feed fault current due to a DG is also disappeared. Consequently, both Eq. (5) and (7) can be removed during the search process for the maximum allowable DG capacity. Hence, it should result in a larger allowable DG capacity.

4. RESULTS AND DISCUSSION

This section begins with the determination of the maximum allowable DG capacity based on the methodology presented in section II, followed by the application of the proposed protection adjustment methods. All the simulation will be conducted on a test system, i.e. a modified RBTS BUS 2 shown in Fig. 2. A 200MVA fault level is assumed at the station bus, i.e. 25MVA transformer with impedance voltage equal to 12.5%. To clearly demonstrate the impact of the protection coordination on DG capacity, the line length of the test system is increased by five times of the original test system [13], whereas the operating voltage is modified from 11 to 22 kV

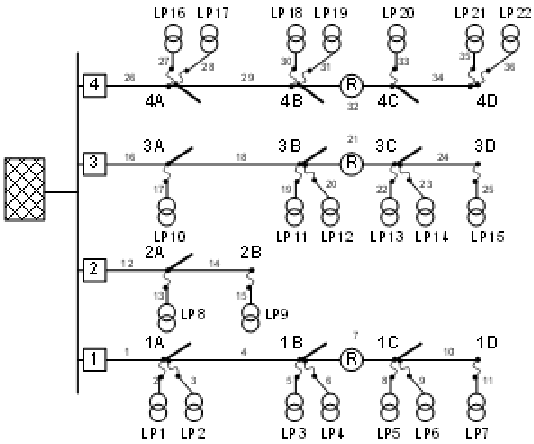

Fig.2: *Modified RBTS BUS 2 test system.*

Table 2: *Maximum Allowable Capacity of a DG.*

Feeder	Location	DG capacity (MW)
1	1A	10.00
	1B	10.00
	1C	2.56
	1D	2.63
2	2A	7.22*
	2B	5.70*
3	3A	10.00
	3B	8.51
	3C	2.64
	3D	2.74
4	4A	10.00
	4B	10.00
	4C	2.66
	4D	2.74

*the result is limited by loss constraint.

to reflect actual distribution system in Thailand. All the protection devices shown in Figure 2 are of non-directional type. The setting of all devices is provided in Appendix and are set by general rules such as those presented in [12]. In Fig. 2, LP represents load point, and “R" symbolizes a mid-line recloser. The number followed by capital letters indicates possible DG locations on each feeder. For example, “2B" represents the possible DG location at point B on Feeder 2. In this study, possible locations for DG connection are restricted to the main feeder. In addition, only three phase fault and synchronous type of DG are considered in this paper.

A. Maximum Allowable Capacity

The maximum allowable DG capacity of the test system is set at 10 MVA, in accordance with the definition in [14]. The constraints from Eq.(5)-(7) are selected in accordance with the DG and the fault locations as shown in Table 1. Z-bus method is applied

Table 3: *Summary of protection resetting*

Feeder	Circuit Breaker		Recloser	
	Before	After	Before	After
1	I_{pickup}=411A TM=0.10	I_{pickup}=500A TM=0.21	$I_{R,pickup}$=260A	$I_{R,pickup}$=400A
3	I_{pickup}=349A TM=0.15	I_{pickup}=500A TM=0.21	$I_{R,pickup}$=270A	$I_{R,pickup}$=400A
4	I_{pickup}=383A TM=0.10	I_{pickup}=500A TM=0.21	$I_{R,pickup}$=270A	$I_{R,pickup}$=400A

for fault calculation [16] whereas power flow solution is simulated using MATPOWER [17].

Accordingly, the results of maximum allowable DG capacity at each location can be shown in Table 2, which will be used as references for the protection adjustment comparison.

In the above table, the results of DGs at locations 2A and 2B are limited by system loss constraint, while others are limited by protection coordination constraint. It is obviously seen that protection coordination plays a major role on limitation to the maximum allowable DG capacity especially for those locations behind the mid-line recloser.

B. Protection Adjustment

From the above results, the proposed protection adjustment methods will be applied for DG of which its capacity is larger than the maximum allowable capacity studied in Table 2. These methods, i.e. protective device resetting, directional recloser application, and fuse replacement with recloser, which are presented in section III will be presented.

B.1 Protective device resetting

In this case, feeder 1 is selected for illustration. Based on the proposed algorithm, it needs following calculation steps.

1) Fault currents at circuit breaker and recloser location are calculated as 5,248.6 and 2,209 A respectively..

2) Suppose that the feeder capacity is 500A, then raise circuit breaker pick-up setting from 411 to 500A.

3) It is assumed that the setting of the incoming circuit breaker is Curve = SI, $I_{pick-up}$ = 820A, TM = 0.25; where SI is Standard Inverse, TM is time multiplier by which it is set at 125% of 25 MVA transformer rating and the operating time of 1s. for the maximum fault current in 1). Based on the above settings, the operating time for the fault at circuit breaker is 0.93s (see Appendix).

4) Assuming t_{margin} is 0.3s, TM setting at the circuit breaker is raised from 0.1 to 0.21 (the operating time of new setting for the fault at circuit breaker is 0.63s).

5) Suppose that K is equal to 0.8, new $I_{R,Pick-up}$ is 400A.The new protection coordination can be plotted as Fig.3.

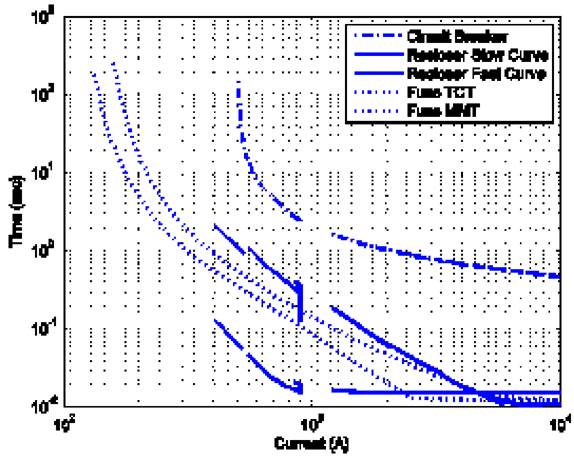

Fig.3: *Protection coordination after resetting.*

6) From the figure, coordination time between circuit breaker and recloser slow curve is valid.

7) From the figure, coordination between recloser fast curve and fuse MMT is valid.

The above process is repeated for Feeders 3 and 4 to complete the protection resetting for every feeder. The setting in Feeder 2 remains unchanged since there is no mid-line recloser, i.e. constraints based on Eq.(5)-(7) are not applied.

In this case, it shows that the new setting values of Feeders 3 and 4 are equivalent to that of Feeder 1. In other cases, the settings can be different due to feeder capacity. The protection resetting of the test system can be summarized in Table 3.

B.2 Directional Recloser

Next, the existing recloser is replaced by a directional recloser. In addition, new devices will be set to respond for the fault only in a forward direction. Again, the maximum allowable DG capacity is recalculated. Similar to the protective device resetting, only the capacity of a DG located behind the recloser will be affected. The obtained results are shown in Table 5.

From the Table, it can be seen that the maximum

Table 4: *Maximum allowable capacity after protection resetting.*

Feeder	Location	DG capacity (MW)	
		Base case	New results
1	1C	2.56	4.00
	1D	2.63	4.18
3	3C	2.64	3.97
	3D	2.74	4.18
4	4C	2.66	4.00
	4D	2.74	4.18

Table 5: *Maximum allowable capacity with direction recloser.*

Feeder	Location	DG capacity (MW)	
		Base case	New results
1	1C	2.56	5.85
	1D	2.63	6.18
3	3C	2.64	5.32
	3D	2.74	5.66
4	4C	2.66	6.11
	4D	2.74	6.47

allowable DG capacity can be increased significantly to 5-6 MW compared to the results in Table 4.

B.3 Replacement of Fuse with Recloser

It is assumed that lateral fuses behind the mid-line recloser of Feeder 1 are changed to an auto-reclose capable device, e.g. recloser, drop-out recloser. Then, the fast operation of the mid-line recloser is turned off whereas those of the new lateral devices are turned on. The new maximum allowable DG capacity can be re-calculated as shown in Table 6.

Table 6: *Maximum allowable capacity with fuse replacenent recloser.*

Feeder	Location	DG capacity (MW)	
		Base case	New results
1	1A	10.00	10.00
	1B	10.00	10.00
	1C	2.56	8.62*
	1D	2.63	7.10*
2	2A	7.22*	7.22*
	2B	5.70*	5.70*
3	3A	10.00	10.00
	3B	8.51	9.56*
	3C	2.64	8.33*
	3D	2.64	6.54*
4	4A	10.00	10.00
	4B	10.00	10.00
	4C	2.66	8.44*
	4D	2.74	7.37*

In this case, the proposed method can help improve the results for those DGs located in front of the mid-line recloser as it resolves the problem of the fault level constraint on fuse saving scheme, which is clearly seen from the results at location 3B. In addition, as fast operation of the mid-line recloser is turned off, this method also resolves the back-feed current problem. Therefore, it can be seen that this methodology allows the highest DG penetration compared to the other two previous methods.

C. Results Discussion

The results show that the proposed protection adjustment methods can help increase maximum allowable DG capacity. Nevertheless, each method has its own characteristics.

Protection resetting and directional recloser application can help increase the capacity for those DGs located behind the mid-line recloser. The obtained results from the application of the directional recloser tend to be greater than those of the protection resetting since it completely eliminates the mis-operation of the mid-line recloser from a back-feed fault current. The protection resetting can help alleviate the back-feed current problem, however it depends on the level of existing pick-up current which can be increased.

Replacement of fuse with recloser can solve both the back-feed current problem and the fault current constraint on the fuse saving scheme. It should be noticed that only this method can improve the results for the DGs located in front of the mid-line recloser. As a result, this method allows highest DG penetration improvement. Figure 4 compares the results of all methods based on the same DG locations, i.e. 3B and 3C representing in front and behind the recloser, which clearly shows that the fuse replacement method is the most promising one to allow more DG penetration than the base case, especially for the DG located behind the recloser.

Table 7 summarizes the characteristics of each protection adjustment method. It is found that the protection adjustment method can be selected in accordance with system conditions and utility requirement. For example, using the test system for illustration, if a DG capacity of 3 MW is requested for a connection at location 1C, utility may consider resetting the protective devices. However, if a DG capacity of 5 MW requests for connection, utility may apply a directional recloser method since it will be less costly than the replacement of fuse with recloser. However, for a proper justification, a pre-study of each method should be conducted to realize current status and potential increase of maximum allowable DG capacity.

Finally, considering system operating voltage and loss, the voltage of all solutions lie between 0.95 and 1.05 p.u. according to Eq. (2)-(3) of the proposed method. Similarly, the power loss will not exceed that of the case without the DG according to Eq. (4). Since the maximum sizes of DG limited by loss constraint (marked with asterisk sign) will be larger than

Table 7: *Summary of characteristic of each protection adjustment method.*

	Protection Resetting	**Directional Recloser**	**Replacement of Fuse with Recloser**
Effectiveness	DG behind recloser	DG behind recloser	DG behind and in front of recloser
Implementation consideration	No cost of new equipment equipment	Installation of one directional recloser	Replace all lateral fuse with Recloser or dropout recloser

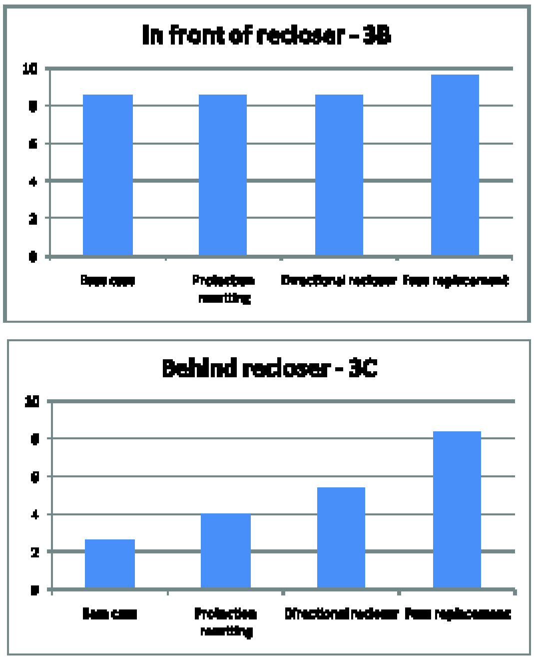

Fig.4: *Comparison of all protection adjustment methods.*

those of limited by protection constraint as shown in Table 6, it implies that the power loss will be some value below the case without the DG. For example, at location 1C, the DG capacity of 8.62 MW will have 0% loss reduction while the DG capacity of 2.56 will have 13.14% loss reduction. Therefore, applying the proposed method and increasing the maximum DG capacity will reduce some loss reduction benefits. Nevertheless, this may become unavoidable situation in some countries due to regulator or government policy. In addition, it does not increase power loss and the utility can enjoy other benefits from DG such as power back-up and deferring capacity investment.

5. CONCLUSION

This paper proposes and demonstrates the protection adjustment method to allow a larger DG capacity to be connected to a distribution system. The methods consist of protection resetting, application of directional recloser and replacement of fuse with recloser. The simulation results show that the proposed methodology can be used to alleviate the problem of system connection request from the DG of larger capacity than the maximum one of the original system.

The protection resetting method can be implemented with little or no cost to the utility while increasing allowable DG capacity at the location behind the mid-line recloser. Directional recloser application is a more effective method however with the cost of upgrading the existing recloser and installation of potential transformer. The replacement of fuse with recloser method provides the highest penetration result however, requiring highest cost as all lateral fuse devices has to be upgraded to an auto-reclose device, e.g. recloser or drop-out recloser. Nevertheless, the method can also increase the capacity of DG which is located in front of the recloser.

The selection of the protection adjustment method depends largely on the utility and feeder requirement. A combination of the method is also possible within a substation. The study result can also be applied to improve the process of screening DG projects and for planning purposes.

APPENDIX

Original Protection Setting of Modified RBTS Bus2 System The protection system of the Modified RBTS Bus2 comprises of circuit breaker, recloser and fuse device. The circuit breaker must equip with protective relay. The time-current characteristic of the relay is typically selected from IEC standard curve [18]. Three types of curve are defined according to the following equations.

$$\text{StandardInverse(SI)} := t_{op}\frac{0.14\cdot TM}{\left(\frac{I_F}{I_{pick-up}}\right)^{0.02}-1}$$

$$\text{VeryInverse(SI)} := t_{op}\frac{13.5\cdot TM}{\left(\frac{I_F}{I_{pick-up}}\right)-1}$$

$$\text{ExtremelyInverse(SI)} := t_{op}\frac{80\cdot TM}{\left(\frac{I_F}{I_{pick-up}}\right)^{2}-1}$$

Where t_{op} is relay operating time and I_F is fault current magnitude. For recloser device, the operating curve is generally selected from non-standard curve [19] which is specified by a number. The curve consists of fast and slow curve which are used in fuse saving scheme application. As for fuse, the operating curve consists of minimum melting time (MMT) and

Table 8: *Protection setting of the test system.*

Feeder	Circuit Breaker	Recloser	Fuse Type K (Branch)		
			40A	65A	100A
1	Curve=SI I_{pickup}=411A TM=0.1	Fast curve=101 Slow curve=116 $I_{R,pickup}$=260A	2, 3, 5 6	8, 9, 11	-
2	Curve=EI I_{pickup}=300A TM=0.2	None	-	-	13, 15
2	Curve=SI I_{pickup}=349A TM=0.15	Fast curve=101 Slow curve=116 $I_{R,pickup}$ =270A	17, 19 20	22 23 25	
4	Curve=SI I_{pickup}=383A TM=0.1	Fast curve=101 Slow curve=116 $I_{R,pickup}$ =270A	27, 29 30, 31	33 35 36	

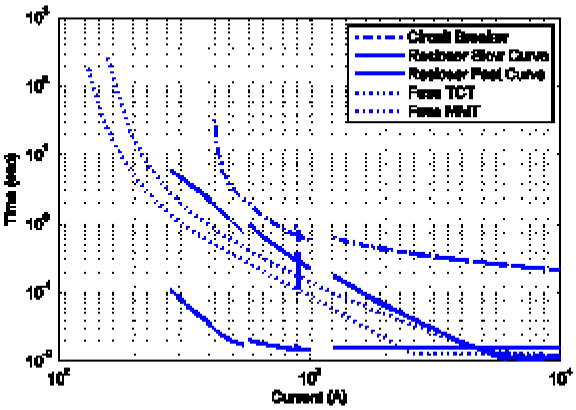

Fig.5: *Protection coordination with fuse saving scheme application.*

total clearing time (TCT) which is used for coordination study [20]. Fuse device in this study is a K-type, i.e. a fast operating fuse.

Table 8 provides the original setting of the modified RBTS Bus 2 system. An example of protection coordination of the device in Feeder 1 is illustrated in Fig. 5.

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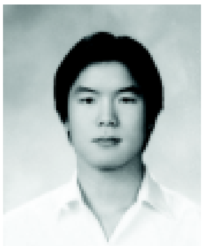

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