System Study and Fault Level Reduction Techniques for a Small Scale Power Plant in Thailand

Sithiwoot Tongsrichantra, Thanapong Suwanasri, and Cattareeya Suwanasri

Abstract— *Nowadays, the increasing fault level in Thailand power system is of prime concern due to the increasing number of small power producers (SPPs) and independent power producers (IPPs). One of the SPP in Thailand is chosen to find the optimal solution for fault current reduction. Therefore, the data of existing system is comprehensively collected and all equipment was drawn in single line diagram with their associated parameters. Then the short circuit simulation at various locations was performed according to IEC60909 to verify the equipment rating. Practically, the fault current reduction techniques were performed by using current limiting reactor (CLR) and fault current limiter (FCL). These devices were evaluated in term of their function, fault current limiting capability, power losses and suitable installation locations. The evaluation procedure consists of short circuit study at various locations in the plant to determine their fault current limiting capability. Moreover, load flow analysis was performed to evaluate the associated losses in case of the CLR. Loss evaluation is a necessary part for the CLR consideration. Consequently, the suitable installation location was determined based on effective fault current reduction, possibility of installation and their generated losses. Finally, from the technical and cost comparison, the optimum solution can be determined.*

Keywords— **Fault level, short circuit, current limiting reactor (CLR), fault current limiter (FCL), Load flow.**

1. INTRODUCTION

Fault is defined as a physical condition that causes a device, a component, or an element to fail in performing its required manner, for example a short circuit or broken wires [1]. Electric power system designers often face fault-current problems when expanding existing buses because the power demand continues to grow due to economic growth and increasing in electricity consumption. In some areas, additional generation from co-generators, small power producers (SPPs) and independent power producers (IPPs) raises the fault duty throughout a system. In addition, industrial use of computers and other power-quality-sensitive equipment has forced the utilities to provide higher quality and more reliable power. As a result, generation capacity as well as power interconnection keeps increasing for more efficient system. Increasing power generation does, however, increase the maximum available fault current at any point in the system. Older but still operational equipment gradually becomes underrated through system growth.

Unfortunately, there is no available record of annual number of faults occurring at SPP in Thailand. However the fault can be classified according to its associated causes as follow:

1) External system fault (electricity utilities)
2) Equipment failure, ageing or malfunction
3) Human errors

When fault occurred, the interrupting device must be able to interrupt such fault current. The significant fault types to be considered are;

1) Three - phase fault
2) Phase - phase fault
3) Phase to earth fault.

In this paper we consider mainly three phase fault, which is the worst and very rare case. However, its severity and consequential damages are very high and it is used to select the rating of interrupting devices.

Primary equipment, such as switchgear, transformers, cabling, and bus bar can be very expensive to be upgraded, replaced and reconfigured to higher fault level. There is a challenge to work out on this problem while keeping the additional costs in economics. In Thailand, according to the revised power development plan (PDP 2007), the total generation capacity in 2009 will reach 32,456 MW while the generation capacity contributed by very small scale power plants (VSPP) is approximately 14%. Such a contribution becomes higher due to the nation energy policy promoting in renewable energy usage. As a result, the fault level throughout the system also increases accordingly.

In this paper, the sample case is one of the Thai SPPs facing the mentioned fault level due to the interconnected network growth. By system modeling and using short circuit calculation based on IEC 60909 standards; it was found that the most of existing equipment interrupting capacity are over duties. Therefore, the fault current reduction techniques were

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studied and discussed in order to avoid unsafe operation and consequential damages caused by short circuit current. In all possible study cases, the repeated short circuit calculation is also carried out to check their effective outcome. In addition, the loss evaluation by load flow calculation based on Newton – Raphson method is also performed in case of using Fault Current Limiter.

2. BASIC THEORY

In general, there are four techniques to lower the short circuits such as;

1) Pre-planned for power circuit breaker (CB) and equipment uprating
2) Replacement by high impedance power transformer
3) Installation of series current limiting reactor (CLR)
4) Installation of fault current limiter (FCL)

The last two techniques will be proposed and discussed in this paper. The CLR is a typically and widely used technique due to its simple construction, reliability and proven technology. Nevertheless, the application of FCL is increasingly implemented in industrial plants in Thailand especially in case the system power (kW) losses are of prime main concern.

2.1 Current Limiting Reactor (CLR)

The CLR introduces higher impedance to the system by series–connected reactance in order to protect the equipment during fault condition. It reduces short circuit level to meet the system needs as well as stresses on busses, insulators, circuit breakers and other high voltage devices. It is, sometimes, connected between the neutral of the system and earth for limiting the phase to earth current under system fault conditions. It is also used as load sharing reactor for balancing the current in parallel circuits [2], [3].

Current Limiting Reactor Types

1. Air core reactor with the advantage of no saturation under fault condition, low losses, and long life
2. Dry type reactor
3. Indoor/outdoor reactor
4. Single phase /three phase reactor

A Sample Calculation

$$X_R = \frac{V_S}{\sqrt{3}}\left[\frac{1}{I_{SCA}} - \frac{1}{I_{SCB}}\right] \quad (1)$$

where

X_R = reactor reactance [Ω]

V_S = system voltage [V]

I_{SCA} = S/C current after series – connected reactor [kA]

I_{SCB} = S/C current before series – connected reactor [kA]

Advantages

1. Reduce fault current
2. Match impedance of parallel feeders
3. Increase equipment and capacitor life
4. Perfect mechanical strength to withstand high short circuit force
5. Limited temperature rise enables longer lifetime
6. Special surface protection against UV and pollution class 5 area
7. Simple design for determining an appropriate impedance
8. Maintenance-free design

Disadvantages

1. Energy costs increase as losses become a more significant component of total operating cost
2. Operating losses consist of
   a) the resistance and eddy-current loss in the winding due to load current,
   b) losses caused by circulating current in parallel windings,
   c) stray losses caused by magnetic flux in other metallic parts of the reactor
3. Minimum magnetic clearance for the reactor is required as shown in Fig. 1.
4. Voltage drop due to its connection, thus voltage regulation is required (maybe shunt capacitor bank).
5. Magnetic flux effects to human life and metallic structure in vicinities

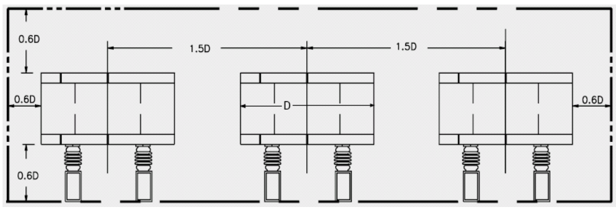


Fig.1. Minimum of magnetic clearance to other reactors and metallic parts [4].

2.2 Fault Current Limiter (FCL)

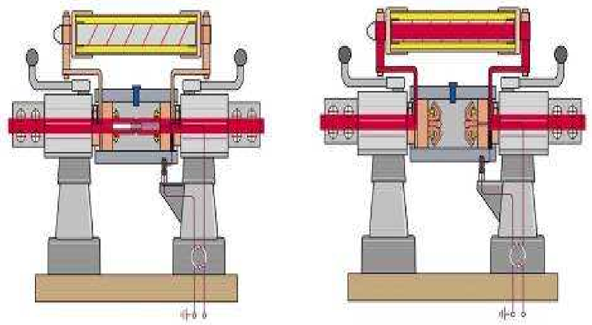
Technical Principle/Function

Fault current limiter is very quickly capable of detecting and limiting a short circuit current by use of a small explosive charge to open a conductor. This diverts the current to a parallel fuse which quenches the short circuit current.

Types

Fault current limiter of ABB is one of the FCL products in the FCL industrial market. ABB current limiting device (Is – limiter) consists of 2 components as shown in Fig. 2.

A. Current path uninfluenced
B. Current commutated to fuse



(A) (B)

Fig.2. Current limiting devices by ABB [5], [6].

Operation

In Fig. 3, when a short circuit is detected and exceeding the pre-determined magnitude and the rate of current rise, an explosive charge in the main current carrying conductor is detonated. This ruptures the main current carrying path thus diverting the current to the fuse which quenches it. The entire operation takes place within a few milliseconds [8]. After operation, the devices are isolated and insert containing the fuses and the ruptured conductors are removed and replaced with spares. One device is installed in each phase of a three phase system, and a circuit breaker is always required in series with it, in order to perform normal circuit opening and closing duties. Moreover, there is another supplier who supplies FCL as well. G&W produces the so-called triggered current limiter (TCL) [9]. It offers a high continuous current alternative to the technique by providing effective fault current limitation without the significant losses, and without equipment upgrade or replacement.

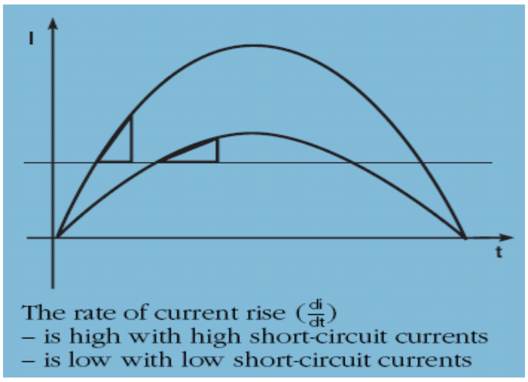


Fig.3. Rate of current rise [7].

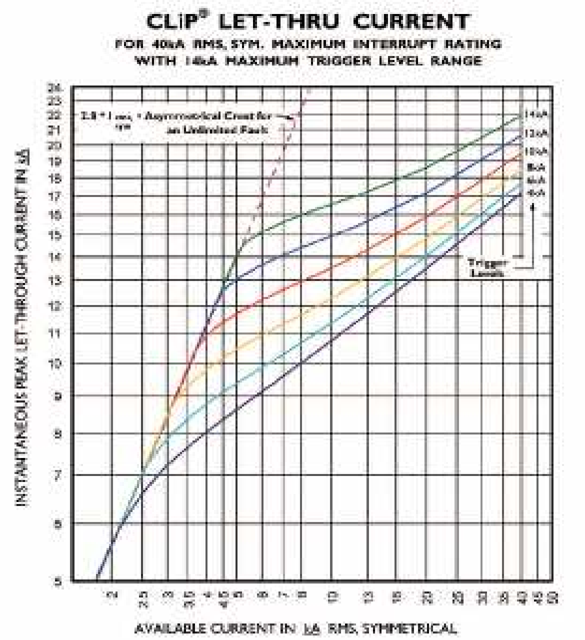
The fuse characteristics of both suppliers are shown in Fig. 4. Note that the multiple breaks in the main current path provide faster commutation of fault current to the current limiting fuse element, while providing improved dielectric withstand of the broken gaps.

Co-ordination

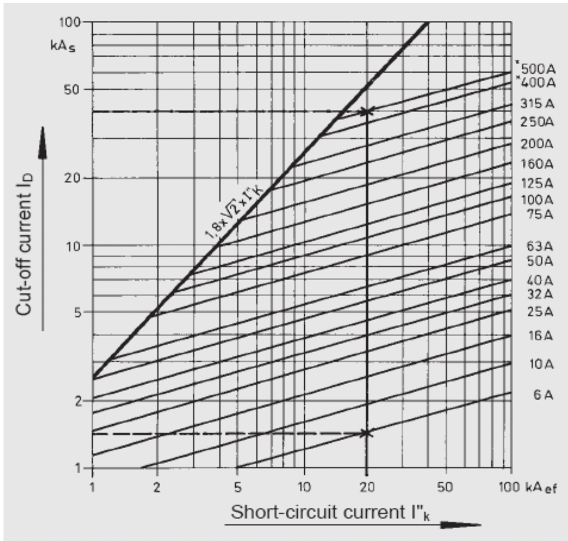
From a coordination standpoint, the triggered current limiter is catastrophic protection devices. Since these are electronically sensed and triggered units, their operating criteria is pre-set and not dependent on time versus current, temperature, element size (or melting I^2t) or preconditions [10], [11], [12]. In addition, the FCLs as per G&W design are not dependent on rate-of-rise of fault current, but instead, are responsive to magnitude only.

Calculation of Tripping Value [13]

The tripping value is the expected rms value of the first half wave of a short-circuit current flowing through the Is – limiter, in which case the Is – limiter must trip during the first current rise. Since the use of this device is still relatively rare, the calculation of the tripping value is not generally known. Practical experience to date shows the tripping value should be greater or equal to twice the operating current in order to prevent it from tripping on unintentional fault.



(A) The Let-Through current plot of 40kA rated CLiPs unit (G&W)



(B) cut-off characteristic of HRC fuse of ABB.

Fig.4. Example of fuse characteristic, peak let - through current VS symmetrical fault current.

The *Is* – limiter trips when the rate of current rise (di/dt) reaches or exceeds a specified level, while the current flowing through it has instantaneous values between the upper and lower measuring range limit or i_1 and i_2 respectively. The lower measuring range limit i_2 should be selected at approximately 1,000 to 3,000A above the peak value of the operating current. The measuring range (i_1-i_2) is in general 1,000 to 4,000A. As a result, the advantages and disadvantages are concluded bellows.

Advantages

1. Faster operation than relay
2. Technical and economic advantages when used in transformer or generator feeders, in switchgear sectionalizing and connected in parallel with reactors.
3. In comparison with reactors, the Is-limiter avoids voltage drops and does not contribute to the peak short-circuit current.
4. Voltage in the part of the system is not affected by the operation of an Is-limiter
5. The series network impedance remains unchanged.
6. Improvement of the current distribution at the feeder transformers.
7. The load dependent losses of the feeder transformers are reduced.
8. Increased reliability of the power supply. On failure of one feeder transformer, the load is taken over by the other feeder transformers without current interruption.
9. The cost for a required new switchboard with higher short-circuit capacity will be saved.

Disadvantages

1. Analysis of the proper and reliable thermal technique is still required.
2. Spare part and 'back up' system are needed.
3. Skill of worker
4. Failure consequence: any possibility that a failure of the current limiting device to operate could overstress switchgear.
5. Any legal constraints that could prevent the use of this type of current limiting device
6. Co-ordination with other protective devices is not possible.
7. Their intrinsic safety
8. Testing of operation
9. Triggering integrity

3. WORK PROCEDURE

In the study, the system in question consists of a fully condensing steam turbine generator with its capacity of 55MW at 11.4kV rated voltage, its local loads and the interconnected line synchronizing with the Provincial Electricity Authority (PEA) of Thailand. In this system, summary of simulation results concerning all critical possible short circuit cases are carried out and summarized as the technical references for further study or action by project and engineering teams in the future. The normal operating loads and supply of the SPP are shown in Fig. 5.

At first, all possible short circuit cases and fault current reduction studies are modelled and simulated by commercial simulating software namely ETAP based on IEC 60909 standards.

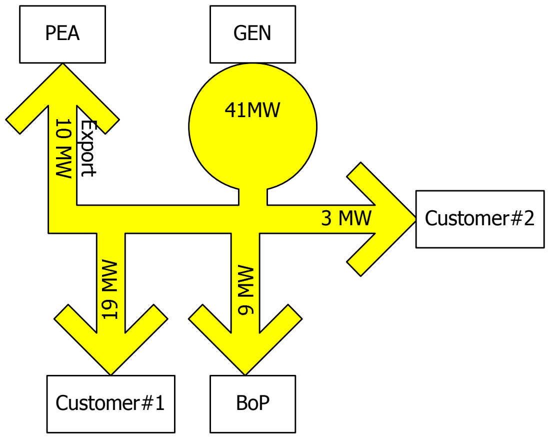


Fig.5. Load flow diagram of a chosen SPP

This study will help the SPP in the selection process of appropriate fault current reduction devices. All fault study cases are determined so as to help the SPP crystal clear in detail of bus fault current at all possible locations. Moreover, study reports also provide the voltage information on the healthy buses in the system. This can similarly help the SPP to perform the proper setting of under voltage relay in order to avoid nuisance tripping.

Short circuit simulations are divided into two main scenarios which are "with" and "without" fault current reduction devices such as the FCL and CLR. Precisely, both cases are simulated with full possible connected loads and actual operating loads by ETAP. According to operating record, actual operating loads are based on the total plant generation of 41MW with 10 MW exporting power to utility (PEA). In additions to short circuit study, load flow analyses using Newton-Raphson method are also performed in order to evaluate the reactor losses in the relevant cases.

4. RESULTS

Current Limiting Reactor (CLR) Cases

In CLR simulation cases, additional reactor(s) shall effectively reduce short circuit current contributed from short circuit sources such as generator, large rotating machine and utility grid. Obviously, reactor should be connected in front of generator, utility grid or between switchgear bus-1A and bus-1B as shown in Fig. 6.

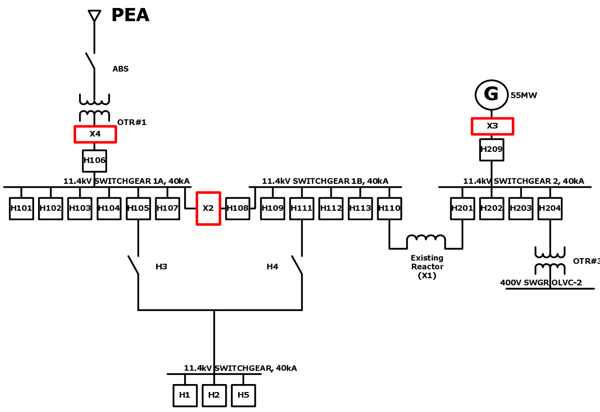


Fig.6. Installation diagram of additional reactors.

where:

X1 = Existing reactor (between Bus-1B and Bus-2)

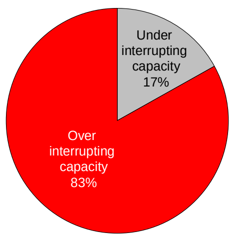
X2 = New reactor#2 (between Bus-1A and Bus-1B)

X3 = New reactor#3 (between Generator and Bus-2)

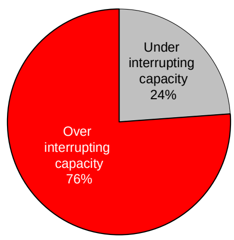
X4 = New reactor#4 (between OTR#1 and Bus-1A)

Ideal (full) Operating Loads with Reactor

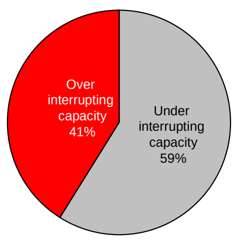
In case of ideal operating loads (the case where all installed loads are in service) the short circuit simulation results are summarized in Fig. 7.



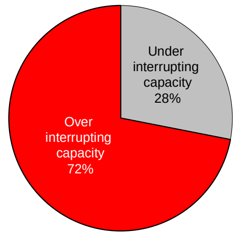
A) Ideal operating load without existing reactor (X1)
Over interrupting 83%, Under interrupting 17%



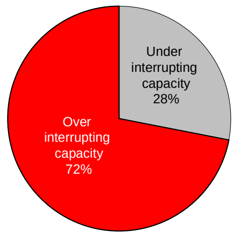
B) Ideal operating load with existing reactor (X1)
Over interrupting 76%, Under interrupting 24%



C) Ideal operating load with existing reactor (X1) and the new one (X2)
Over interrupting 41%, Under interrupting 59%



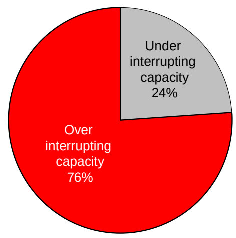
D) Ideal operating load with existing reactor (X1) and the new one (X3)
Over interrupting 72%, Under interrupting 28%



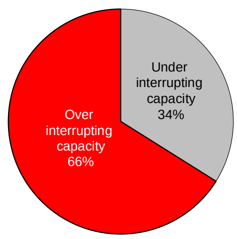
E) Ideal operating load with existing reactor (X1) and the new one (X4)
Over interrupting 72%, Under interrupting 28%

Fig.7. Full load short circuit summary: Reactor(s).

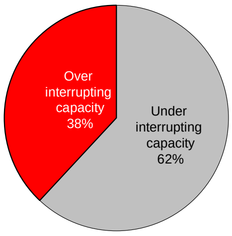
In ideal operating load case, the additional reactor (X2) located between Switchgear bus-1A and bus-1B can effectively reduce the short circuit current and it can increase the percentage of survival buses from 24% to 62% as presented in Fig.7, Case A-C. Therefore, X2 location is the best location to lower the prospective short circuit current in case we use CLR as the fault current reduction device.



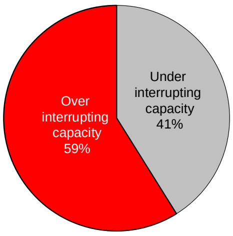
A) Actual operating load without existing reactor (X1)
Over interrupting 76%, Under interrupting 24%



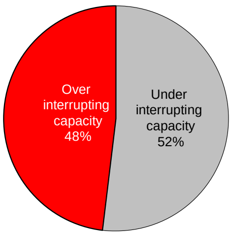
B) Actual operating load with existing reactor (X1)
Over interrupting 66%, Under interrupting 34%



C) Actual operating load with existing reactor and X2
Over interrupting 38%, Under interrupting 62%



D) Actual operating load with existing reactor and X3
Over interrupting 59%, Under interrupting 41%



E) Actual operating load with existing reactor and X4
Over interrupting 52%, Under interrupting 48%

Fig.8. Actual load short circuit summary: Reactor(s).

Actual (real) Operating Load with Reactor

In actual operating load case (the case where the actual loads, as given from TPTUC field information are practically in service), the short circuit simulation summary results are summarized in Fig. 8. In case of actual operating load, the additional reactor (X2) located between Switchgear bus-1A and bus-1B can also effectively reduce short circuit current and increase healthy bus bar number from 24% to 62% as full possible connected load operating presented in Fig. 8, Case A-C. Therefore, X2 location is still the best location to lower the prospective short circuit current in case we use CLR as the fault current reduction device. Moreover, in all cases of CLR, load flow simulations using Newton-Raphson method are carried out in order to check the system bus voltage drops and losses. The simulation shows that, with an additional reactor at a time, the voltage drops at all buses are still in allowable limit. Lastly, system losses were also evaluated and shown in Figs. 9 and 10 below.

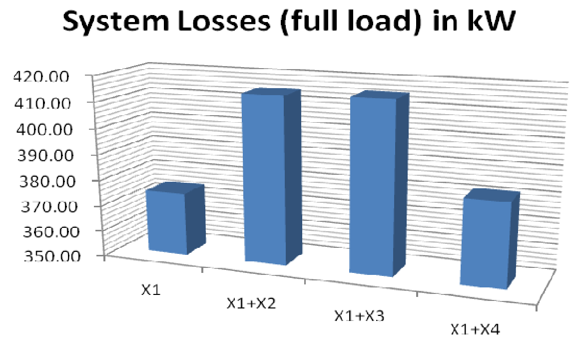


Fig.9. System losses: Full operating load.

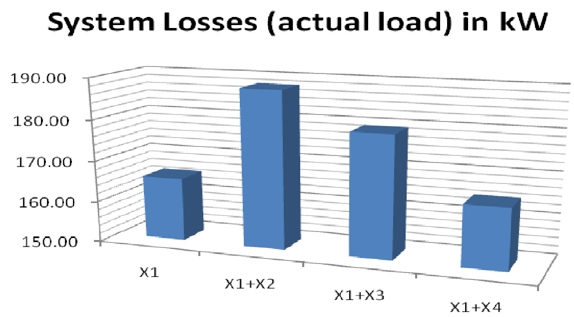


Fig.10. System losses: Actual operating load.

Fault Current Limiter (FCL) Cases

In FCL simulation cases, the additional FCL shall effectively reduce short circuit current contributed from short circuit sources such as generator and utility grid in the same manner as CLR (reactor) cases. As a result, the best locations of FCL to reduce the short circuit current to the lowest value are the combination of those connected between Switchgear bus-1A and bus-1B, after H3 and H4 and after H204 as Fig. 11.

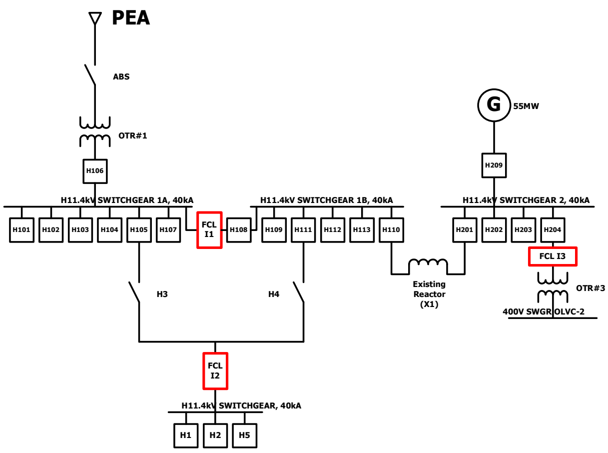


Fig.11. Installation diagram of FCL (I1, I2 and I3).

where:

X1 = Existing reactor (between Bus-1B and Bus-2)

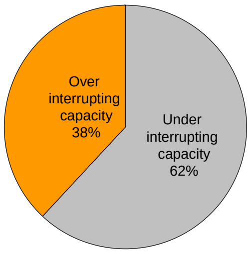
I1 = New FCL#1 (between Bus-1A and Bus-1B)

I2 = New FCL#2 (located in series with H111)

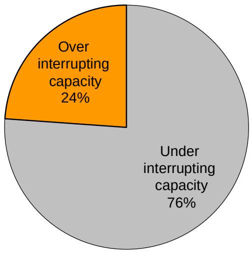
I3 = New FCL#3 (between Bus-2 and OTR#3)

Ideal (Full) Operating Loads with FCL

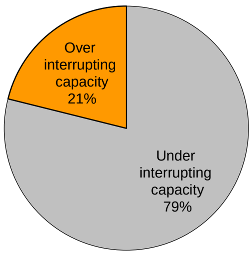
In case of ideal (full) operating loads, the short circuit simulation results are summarized in Fig.12.



A) Ideal operating load with existing reactor and I1
Over interrupting 38%, Under interrupting 62%



B) Ideal operating load with existing reactor, I1 and I2
Over interrupting 24%, Under interrupting 76%

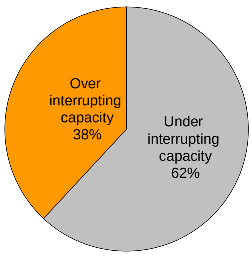


C) Ideal operating load with existing reactor, I1, I2 and I3
Over interrupting 21%, Under interrupting 79%

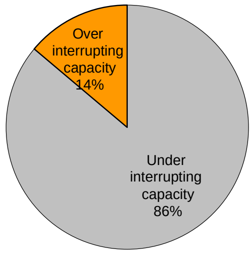
Fig. 12. Full load short circuit summary: FCL(s).

Actual Operating Load Case with FCL

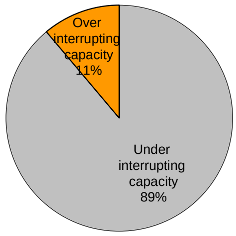
In actual operating load case, the short circuit simulation results are summarized in Fig. 13.



A) Actual operating load with existing reactor and I1
Over interrupting 38%, Under interrupting 62%



B) Actual operating load with existing reactor, I1 and I2
Over interrupting 14%, Under interrupting 88%



C) Actual operating load with existing reactor, I1, I2 and I3
Over interrupting 10%, Under interrupting 90%

Fig.13. Actual Load Short Circuit Summary: FCL(s)

It is obvious that the most effective scenario is the combined installation of FCL at I1 (one between bus1A and bus1B) and I2 (one in front of lower 11.4 kV bus) locations.

5. COST COMPARISON

Obviously, all simulation results return the best location of FCL and CLR at the one located between Switchgear 1A and 1B. Therefore, estimated investment comparison between those two fault-current reduction techniques is tabulated in table 1 as follows.

Table 1. Fault-current reductions of FCL and CLR

Additional protective devices	FCL (including spare parts)	CLR
Estimated total capital cost (THB)	20,000,000	12,000,000
Cost of additional annual system active power losses (THB)	-	328,320.00
Over interrupting rating before X2 (%)	76.00	76.00
Over interrupting rating after X2 (%)	38.00	38.00

Cost of additional annual system active power (kW) losses caused by insertion of reactor X2 (the one located between Switchgear 1A and 1B) are shown in the middle column above. The system loads are assumed to be constant throughout the whole operation period of 8640 hours per annum with average 2 THB/kWh unit charge. For FCL, the operation and maintenance (O&M) cost in particular of spare parts might play an important part of capital investment.

6. SUMMARY

Although there are many measures to reduce the fault level in the system but the most applicable techniques for the chosen SPP case are limited to those of Current Limiting Reactor (CLR) and Fault Current Limiter (FCL) applications. CLR is suitable for the system having no limited installation space and in case life cycle cost contributed from kW losses is not seriously taken into account. On the other hand, FCL requiring less space, seems to be one appropriate alternative when the issue of kW losses and voltage drop are of serious concern. In addition, the combination of those two techniques can also be used in order to meet the overall fault level reduction target. In such a study case, even with existing reactor (X1), the percentage of equipment facing through fault current above their interrupting capacities are more than 66%. With the new reactor (X2) or additional FCL (I1) connected between 11.4kV bus 1A and bus 1B, the aforesaid percentage can be improved to 38%. To lower the over-interrupting percentage even more, additional CLRs or FCLs can be put into other parts of the system. Nevertheless, the careful consideration of system losses and voltage drops are needed in the CLR application whereas the investment cost and spare parts are the major concern for the FCL one. The protection coordination aspect and the absence of relevant international standards are also the limit of using FCL application. Lastly, all relevant factors shall be carefully traded off in final decision making.

This study can be used as a guideline for engineers who are responsible for the small scale power plant operation and planning. The authors do hope that this can be the foundation of further study in the related or similar topics.

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