The Analysis of Renovation Criteria for Protective Relay in Power Substation

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Abstract— *This paper proposes the renovation criteria for protective relay in control and protection system within power substation. The important criteria consist of age, stress, symptom, obsolescence and failed type. The procedure for the renovation of protective relay is presented. Firstly, the basic information of the existing protective relays in the utility is analyzed. Secondly, the data analyzes are performed such as the classification of different technologies, number manufacturers, ages, future trends, and etc. In this stage, the total of 25,370 protection relays from 221 high voltage substations is analyzed. Finally, the performance evaluation for the sample protective relay is given as example.*

Keywords— **Protection relay, renovation, age, stress, symptom, obsolescence, failed type.**

1. INTRODUCTION

In high voltage substation, the primary equipment, such as power transformer, power circuit breaker, instrument transformer, and surge arrester, are the main components for energy transfers in the network. Whereas the secondary equipment; control and protection system and communication system, are used to support the primary equipment in order to incorporate all functions and maintain the acceptable reliability in power system as effectively as possible.

In control and protection system of high voltage substation, one of the most important devices is the protective relays. The main function of protective relays is to monitor the electrical activity and trip the circuit breakers whenever electrical fault is detected within the system. The technology of protective relay in high voltage substation has been improving over the past decades. Electromechanical relay has been operated in the late 19th century by using magnetic attraction [1]. Then, the protective relay has been developed into static relays in the early 20th century. Static relays have higher sensitivity than electromechanical relays because of a separate supply that generates power to operate the output contacts instead of signal circuits. Static relays offer low contact bounce, fast-long-life operation, and low maintenance. In the present depending on renovation strategy, most electromechanical relays have been replaced with microprocessor-based digital relays or sometimes called numerical relays. By using microprocessor, the digital relays have the ability to combine the functions of many electromechanical relays into one device. They also provide additional features; such as communications interface with SCADA, waveform analysis, and metering.

Because of fast pace in technology, some outdated equipment have to keep up with modern system. By just refurbishing from old to new equipment using the same technology may not be enough to fulfill the function of modern technology in protection system. Therefore, method of renovation is required to upgrade the relays in protection system in order to be compatible with other communication systems within high voltage substation. In this paper, the performance evaluating criteria for renovation of protective relay in a control and protection system are proposed. Then the decision of renovation can be achieved.

2. IMPORTANT ASPECTS FOR PROTECTION SYSTEM IMPROVEMENT

The following aspects are a guideline for proper renovation criteria of protection system improvement, which would cover the equipment that is either in used or in stock. These aspects should be carefully analyzed and compared in terms of both technical and economical aspects.

1. *Customer Impact*: any malfunction of the equipment that causes service interruption or supply outage to the customers. For example, equipment malfunction causing power outage can affect the industry's productivity, which results in the lost of revenue.
2. *Maintenance Expense*: when the lifetime of the equipment passes over its average lifetime, the equipment's condition and performance degrade rapidly. Therefore, it is uneconomical to renovate or refurbish because of the higher maintenance cost.
   2.1 *Preventive Maintenance* (PM) refers to the maintenance of the equipments periodically. The main purpose is to check the readiness of equipments' functional performance. Therefore, the time-based maintenance must rely on the equipments' malfunction statistic and the

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manufacturer recommendation for specify the period of maintenance.

2.2 *Corrective maintenance* (CM) occurs when the equipment is malfunctioning. This type of maintenance is separated into two categories.

- *Initial Maintenance*: This type of maintenance is usually done immediately at the site. The majority of this maintenance is often referred to slight damage only.
- *Critical Maintenance*: This type of maintenance could not be performed immediately at the site. It requires the replacement of the damaged equipment with the new equipment from the stock. The maintenance of the damaged equipment has to be performed elsewhere in the maintenance facility.

3. *Equipment Performance*: the increasing number of equipment malfunction can affect the supply service quality and increase the maintenance cost.
4. *Environmental Change and Support*: the variation in fault current and load growth from the increasing of power demand.
5. *Spare Part*: some manufacturers could have no longer produced the spare part for the particular equipment or could have upgraded to different model; therefore, the manufacturers would increase the price of the spare part.
6. *Safety*: the safety issue of equipment operation affects the safety of the employees as well as the nearby equipment in case of explosion.
7. *New Technology*: the employee could not keep up the maintenance process with the fast growing new technology. Thus the training is required.

3. CRITERIA FOR RENOVATION OF PROTECTIVE RELAY

The criteria for renovation of the secondary equipment in control and protection system as well as communication system can be classified into five categories such as age, stress, symptom, failed type, and obsolescence [3]. The details are described as follows.

Aging refers to the deterioration of the equipment's strength over the chronological time. Certain materials in the equipment deteriorate over time until some types of failures occur. The aging of the equipment can start from the beginning of usage or as it comes out of factory.

Electrical stress can cause parts to fail whilst in service both during test and/or the assembly is in the field. Some of these failures occur due to faults in manufacture, test or operation; others are the result of external events.

Symptom means any signs of power disturbance that could lead to electrical failure in the system. These symptoms can be inspected through visual or other electrical devices. Some parts of the equipment can also show the sign of failure symptom that leads to equipment failure as a whole.

Failed types are based on the statistic data of the equipment model that has problems or has failure in high voltage substation. In order to avoid the interruption within the system, certain failed type model would be removed or replaced by other more reliable model into the system.

Obsolescence involves spare parts unavailability, technology modernization, and after sale service, are sample criteria of problems in obsolescence of electrical power equipment.

The problem of protection system in traditional high voltage substation is that some of protective relays are out of date. Thus, the planning for renovation of protective relay generally refers to the age and failed-type criteria. However, other criteria such as electrical stress, electrical symptom, and obsolescence are unavoidable.

4. WEIGHTING AND SCORING OF SOLID-STATE RELAYS

The details of weighting and scoring for evaluation criteria of solid-state relays are shown below as example for protective relay in secondary system in HV substation.

4.1 Age Criterion

The aspects for age criterion are such as age, application, and warranty period. The weight and score of each aspect are given in Table 1 and Table 2, respectively.

Table1. Weighting for age criterion

Criteria	Weight %
Age	40
Application	30
Warranty period	30

Table 2. Scoring for age criterion

Criteria	Scoring for Aging Aspects				
	0	1	2	3	4
Aging	0-30	-	-	-	> 30
Application	Backup	-	-	-	Primary
Warranty period	Valid	-	-	-	Expired

4.2 Electrical Stress Criterion

The aspects for stress criterion are such as electrical system requirement, testing and maintenance after installation, installation model, temperature in cubicle, humidity in cubicle and thermostat in cubicle. The weight and score of each aspect are shown below in Table 3 and Table 4, respectively.

Table 3. Weighing for Electrical Stress Criterion

Criteria	Weight %
Electrical system requirement	20
Testing and maintenance after installation	5
Installation model	15
Temperature in cubicle	20
Humidity in cubicle	20
Thermostat in cubicle	20

Table 4. Scoring for Electrical Stress Criterion

Criteria	Scoring for Electrical Stress Aspects				
	0	1	2	3	4
Electrical system requirement	Operational	-	Emerging limitatior	-	Maintenance requirec
Testing and maintenance after installation	1	-	2	-	> 2
Installation model	Indoor with air condition	Outdoor with air condition	Indoor without air condition	-	Outdoor without air condition
Temperature in cubicle	Low	-	Medium	-	High
Humidity in cubicle	Low	-	Medium	-	High
Thermostat in cubicle	Available	-	-	-	Unavailable

4.3 Electrical Symptom Criterion

For electrical symptom criterion, weighting factors are shown in Table 5 whereas scoring factors of those aspects are given in Table 6.

Table 5. Weighing for Electrical Symptom Criterion

Criteria	Weight %
Visual inspection	15
Functional operation	60
Power supply failure	25

Table 6. Scoring for Electrical Symptom Criterion

Criteria	Scoring for Electrical Symptom Aspects				
	0	1	2	3	4
Visual inspection	Normal	-	-	-	Damaged
Functional operation	Normal	-	-	-	Damaged
Power supply failure	Normal	-	-	-	Damaged

4.4 Failed-type Criterion

The failure rates must be calculated in terms of failure frequency. The scorings of failed-type aspect are classified into five levels depending on the failure rate which are defined in Table 8. Because of the failed-type criterion has only one aspect, the weighting factor of failure rate is equal to 100%.

Table 7. Weighing for Failed-type Criterion

Criteria	Weight %
Failed-type	100

Table 8. Scoring for Failed-type Criterion

Criteria	Scoring for Failed-type Aspects				
	0	1	2	3	4
Failed-type	Low	-	Moderate	-	High

4.5 Obsolescence Criterion

There are four aspects such as availability of spare parts, after sale service quality, technology obsolescence, and maintenance expense in obsolescence criterion. Each aspect is weighted and scored as presented in Table 9 and Table 10, respectively.

Table 9. Weighing for Obsolescence Criterion

Criteria	Weight %
Availability of spare parts	35
After sale service quality	15
Technology obsolescence	30
Maintenance expense	20

5. PERFORMANCE INDEX CALCULATION

The scoring and weighting techniques are in the form of multi-attribute or multi-criterion analysis. It involves identification of the non-monetary factors that are relevant to the project. The allocation of weights to each of them reflects their relative importance. The allocation of scores to each option reflects how it performs in relation to each attribute. The result is a single weighted scored for each option, which may be used to indicate and compare the overall performance of the options in non-monetary terms.

Table 10. Scoring for Obsolescence Criterion

Criteria	Scoring for Obsolescence Aspects				
	0	1	2	3	4
Availability of spare parts	Easy to find	Required time	Slowly producing	Insufficient, No longer produce, High price	No longer produce particular spare part
After sale service Quality	Good	-	Moderate	-	Bad
Technology obsolescence	Operational	-	Becoming obsolete	-	Obsolete
Maintenance expense	Low	-		-	High

The scoring technique is used for classifying the condition of HV circuit breaker into several levels such as healthy, moderate/need caution and risk. The weighting technique is used for ordering an importance of each criterion. Percent factors are obtained by utilized the scoring and weighting factor. The health index (HI) can be achieved by comparing with the percent factors and finally the evaluated condition is presented according to traffic light sign: green as healthy, yellow as moderate/need caution, and red as risk. The equations of health index and renovation index are shown in Eq. (1) and Eq. (2) respectively [2].

$$HI(\%)=\frac{\sum_{i=1}^{n}(s_i \times w_i)}{\sum_{i=1}^{n}(s_{i,\,max} \times w_i)} \times 100 \quad (1)$$

$$RI(\%)=\frac{\sum_{j=1}^{m}(\%HI_j \times W_j)}{\sum_{j=1}^{m}(S_{j,\,max} \times W_j)} \times 100 \quad (2)$$

$$PI\ (\%) = 100 - RI(\%) \quad (3)$$

High renovation index refers to the high requirement of equipment renovation. The performance index of equipment is calculated as given in Eq. (3). Similarly, the higher performance index is the better condition.

For overall renovation criterion, five aspects are considered as given in Table 11. Each aspect is weighted and subsequently used to calculate the overall performance.

Table 11. Weighing Results for Renovation Criteria

Renovation Criteria	Overall Weight (%)
Age	40
Electrical stress	5
Electrical symptom	5
Failed-type	40
Obsolescence	10
Total	100

Table 12 shows the determination criteria of performance index as color bands representing green as good or healthy condition, yellow as moderate or required maintenance planning, and red as poor or risky condition requiring reparation or renovation as soon as possible.

Table 12. Performance Index

Performance Index		
Healthy	> 75%	Green
Moderate	50% - 75%	Yellow
Risk	< 50%	Red

6. ECONOMIC ANALYSIS

After the techinical evaluation of protective relay is done, the decision of different renovation options will be further depending on the economic analysis. Three basic renovation strategies, which are big-bang, progressive change, and refurbishment, have been proposed [2]. The first is big-bang method that includes removing and rebuilding the entire system. This method is cheaper than the progressive change because there is no long term development of specific interoperation interface and requires only a single configuration and test effort. The second is progressive change method, which refers to the renovation of one bay or a set of bays without interfering with other bays. This method would improve continuously with rapid installation on each bay. It also facilitates into yearly budget. The third is refurbishment that involves retrofitting modern technology with the existing protection system. It allows a reduction of cost, but improves the system's performance. Some options of refurbishment include device replacement, rack replacement, extension of existing installation, and complete scheme replacement. The decided method will depend on the appropriate situation among cost reduction of the user.

7. CASE STUDIES OF PROTECTIVE RELAY

This section proposes the procedures for the renovation of protective relay in high voltage substation as an example. To renovate the protective relay, the basic information of the existing relays in the utility must be firstly analyzed. Secondly, the data analysis should be performed such as the classification of different technologies, number manufacturers, ages, future trends, and etc. Thirdly, the obsolescence criteria should also be taken into consideration. Finally, the economic analysis must be evaluated for selecting the best renovation method.

7.1 Basic Information

Protective relay in high voltage substation has its own aging duration. Protection ageing refers to the usage duration of the relay in the protection system. The maximum aging of relays depends on the type of technologies and the usage.

Electromechanical relay is a conventional type of protective relay [4]. It has the longest aging because of its magnetic mechanical that has no random failure rate. In many high voltage substations, this type of relay has been installed for over 35 years. However, this electromechanical technology has limitation of multi-function for operating with other modern equipment in the control and protection system. Therefore, this type of technology has been slowly obsolete and has been replaced by the modern technologies. Solid state relay was then introduced into the protection system in order to reduce the operation of the moving parts causing to failure from electromechanical relay. However, by the fast discovery of numerical technology of protective relay with the better multi-function, then the number of solid state relay has been reduced. Then most of solid state relay has been aged of 15 years. In the present, numerical relays are the modern technology that equip with many functions in a compact design. With their advantages, this technology has been increasingly used in any modern substation. Especially in smart grid and automation system, these relays provide more benefits for overall capability. In contrast, when different types of relay are simultaneously used in high voltage substation, their functions or parts of any equipment would have chance of incompletely functional or fully nonoperational, which could lead to failure within the system. Therefore, the best technology should be selected for installation. Then obsolete equipment must be evaluated in terms of technological and economical aspects. In order to evaluate the obsolescence criteria, extensive data gathering has to be done. Failure rate criteria and critical network risk are examples that require gathering the fault record over the long period of time. Cost, spare arts, and new performance requirements are the criteria that may require restricted financial data. However, protection age and technology obsolescence criteria can be easier to evaluate by just using the model number, the type of technology, and the startup date in the database.

The methodology to determine the protection aging and technology obsolescence of protection relays in high voltage substation is as shown in Fig. 1.

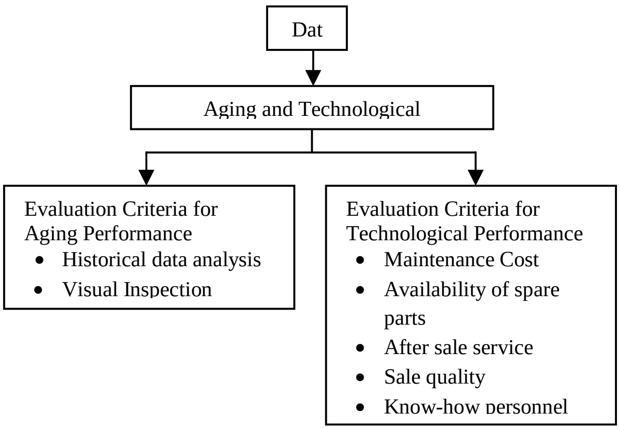

Fig.1. Protection Relay Renovation Method

Firstly, the gathering equipment data from major high voltage substation database is classified and prepared data such as the type of relay, installation date, location, manufacturers for further analyses. Secondly, the technical data from several criteria as aging and obsolescence of protection relays in database is analyzed. Thirdly, aging performance is evaluated based on historical data and visual inspection such as condition and function operation in good, moderate or bad condition. Next, evaluate technology obsolescence based on historical data, availability of spare parts, after sale service, sale quality, know-how personnel, and manufacturers. Then, the economic aspect of maintenance strategies, such as refurbishment or renovation with the present or modern technology as well as replacement the equipment or whole system because of technology obsolescence, are analyzed. Lastly, the best renovation option can be decided.

7.2 Data Analysis of Existing Protective Relay

The total of 25,370 relays in 221 power substations at 115 kV, 230 kV, and 500 kV level are given as examples on the age and technology obsolescence criteria for the renovation of the protective relay. The total number of different technologies of protective relays in the electric utility in Thailand is shown in Fig. 2. It shows that the modern technologies as solid state relay and numerical relay are replacing the old technology as electromechanical relay.

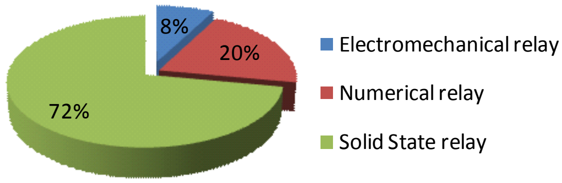

Fig.2. Types of Protective Relay from 115 kV up to 500 kV

7.2.1 Technology Usage

Fig. 3 shows the numbers of different relay technologies in different manufaturers. The utility mostly uses static relay because they are funtional and compatible to the present control and protective devices as shown in manufacturers A and B. Whereas, the manufacurer C mostly supply the highest number of numerical relay comparing with other technologies. In addition, this numerical relay keeps steadily incresing into to the modern system. However, the number of electromechanical is significantly low comparing to the others. This is because of its obsolete technology and limitation of functionalty.

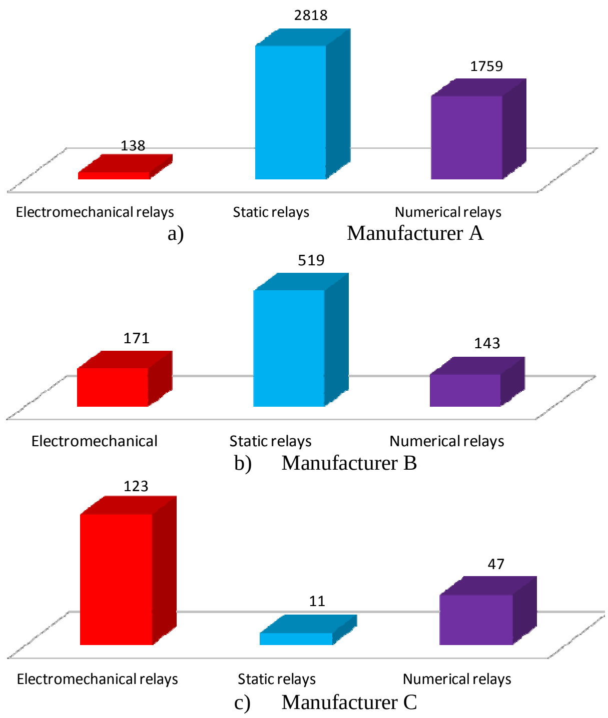

Fig.3. Number of Relays in Different Technologies

7.2.2 Aging Evaluation

Aging is one of the performance criteria that can easily be used as evaluation for renovation decision. That can refers to the deterioration of the equipment's strength over the chronological time. In general, the end of life for protective relay depends on their technologies; normally 20 years for electromechanical relay, 15 years for solid state relay, and 10 years for numerical relay.

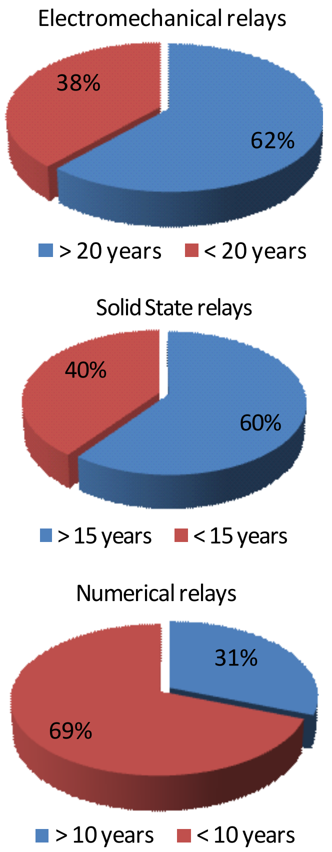

Fig.4. Aging Percentage of the Protective Relay

Fig. 4 shows the percentage of the age of protective relay separated by types as electromechanical relay, solid state relay and numerical relay. Majority of age as 62 % for electromechanical relay are more than 20 years whereas 60 % of solid state relay are more than 15 years. However; numerical relay is the latest technology in the system, then only 31% are used more than 10 years.

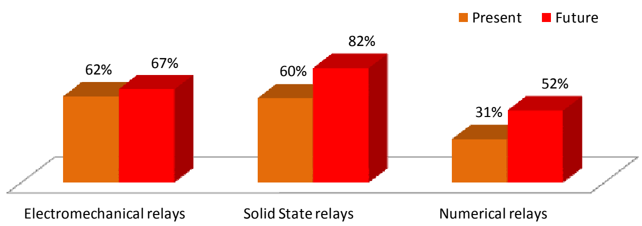

Fig.5. Aging Trend of Protective Relay in the Next Decade

The future aging trend of protective relay in the next decade is shown in Fig. 5. It shows that the number of electromechanical relay aging (>20 years) keeps slightly increasing from 62% to 67%. Whereas the usage of solid state relay (>15 years) and numerical relay (>10 years) are significantly increasing for 60% to 82% and 31% to 52%, respectively. This means the electromechanical relay is nearly obsoleted due to its disadvantage on operational function while numerical relay is dispersing in the modern protection system due to its advantage on mutiple operational function.

7.2.3 Performance Index Calculation

In Table 13, using Eq. (1) health indices of all renovation criteria are given. Using Eq. (2), the renovation index is equal to 30% that means the performance index is equal to 70% by using Eq. (3). Therefore, overall performance of the sample protective relay in HV substation is concluded. The overall performance is in the moderate zone that implies to require maintenance planning for such relay.

Table 13. Performance of a Sample Protective Relay

Criteria	HI (%)	Overall Weight (%)	RI (%)	PI (%)
Age	40	40	30%	70% = Moderate condition
Electrical stress	20	5		
Electrical symptom	40	5		
Failed-type	20	40		
Obsolescence	30	10		
Total		100%		

8. CONCLUSION

The criteria for renovation of protective relay in HV substation include age, stress, symptom, obsolescence and failed type. The most influent criteria affecting to the renovation decision are age and failed-type, which both criteria have the weights as of 40 percent. From the statistical record of a Thai utility, it is clearly that electromechanical relay is now considered to be obsolete comparing to static and numerical relay. Therefore, the renovation process should be performed either refurbishment or renovation. The renovation criteria, method implementation and performance evaluation of solid-state relay are given as example. To fullfill the optimum decision, both of technical and economical aspects must be analyzed. The proper option with the highest cost reduction is choosen. Finally, the appropriate renovation of protective relay in high voltage substation can be accomplished.

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