CHAPTER 3
DECISION MODEL FOR LIFE CYCLE ASSESSMENT OF POWER TRANSFORMER

3.1 Chapter Overview

In the previous chapter, related issues of life cycle assessment of a power transformer were presented and discussed. The main focus in this chapter is on the framework and design of the proposed decision model for power transformer life cycle management. The chapter starts with the need of an alternative decision model by explaining the problems and challenges facing power utility companies.

This chapter reviews the problems associated with existing models with respect to the life cycle assessment of assets. This includes a review of current practices in the procurement, relocation and replacement of assets during their life cycle. Then, a general description of designed load demand and actual load demand are presented. Finally, an alternative life cycle assessment model of the power transformer is proposed. The key focus of this model is to meet the limitation of the financial resources with the utilization of hidden knowledge. The working procedures, benefits and limitations of this proposed model are described in this chapter.

3.2 Introduction

The management and decision making activities of the power transformer in a power system are based on the normal load growth with some degree of reserve capacity [S. G. Menon, 1986]. However, in reality the actual load profile does not always follow this designed load demand due to unexpected penetration. This includes for example, construction of new business and /or industrial areas, migration of population or sudden changes in economic conditions [M. Chow, 1997]. Ultimately, load violation will occur at some point during the life cycle of the power transformer for which the utility is required to make a strategic decision.

Moreover, an expansion of the utility infrastructure will be needed in the future due to the construction of new power houses. As a result, the power transformer will be required for supplying energy to consumers in rural region. In addition, financial subsidies are available to the utility so they need to survive within their available financial resources. In such a situation, the utility authority must make the optimal decision on power transformer considering both financial and technical constraints.

However, most existing models or practices have considered the case for those assets that have almost reached to their end of life. The existing models have not properly managed the asset on-stock. In addition, decisions are made on the basis of the cheapest market price of the assets without any consideration of investment budget limitations and thinking only in terms of the technical performance of the asset [A. Abu-Eanien, 2010] [J.J. Smith, 2006]. The reusable knowledge possessed within the assets have not been identified and utilized to make feasible decision from a financial perspective. Hence, the assets are not fully utilized during their life cycle.

In this context, this research aims to provide an alternative model for an effective life cycle assessment of the power transformer with the aim of maximizing its utilization during its life cycle. This model comprises of three components: a knowledge based model, financial model and decision algorithm. Thus, this model can systematically assess the whole assets within the network satisfying both financial and engineering requirements through the utilization of hidden knowledge.

3.3 Review of Existing Life Cycle Assessment Models

This section reviews the existing models or practices applied for assessing the life cycle of assets within the network. Leung et al. have proposed a mixed 0-1 linear programming model to determine optimal decisions for power transformer procurement and relocation in order to meet demand. The main objective of this model is to minimize the total cost of purchasing new power transformers and transporting spare transformers based on transformer type [L. C. Leung, 1995]. This optimization model is basically designed on the basis of the availability of power transformer on stock and has considered the distance between the substations as the main parameter. This model has not incorporated the stock keeping cost and whole life cycle cost of power transformer during decision making.

Life cycle management of power transformers has been improved with the utilization of refurbishment and condition based maintenance (CBM) techniques [M. Arshad, 2004b] [Y. Oue, 2002]. However, these practices are basically for those assets that have almost reached the end of their life and require diagnostic tools to assess the condition of the assets. The postponement of new transformer investment can be achieved by raising the temporary overload operational limits [Y. Hasegawa, 2004]. In addition, Arshad et al. have presented a fuzzy logic model to make a flexible decision on transformer retirement/replacement/or relocation with the inclusion of remnant life and aging factors of the transformer [M. Arshad, 2006]. This model has used all criticalities, which cause shortening of the transformer life to determine the ageing factors. Maintenance and outage costs and technical conditions such as electrical properties are used to make decision on replacement or relocation of the transformer. It requires investment on condition monitoring tools and techniques and emphasizes more on the technical aspects of the transformer without considering the limitation of financial resources.

Lucio et al. have proposed a decision support system based on asset management theory to simulate the performance of a power transformer [J.C.M. Lucio, 2009]. Different maintenance strategies, costs, risk analysis and reliability indexes are taken into account. The decision model is shown in figure 3.1. Schneider et al. have provided a comprehensive asset management approach for analyzing and optimizing the maintenance, reinvestment and fault elimination strategies considering all resulting life cycle costs associated with network equipment [J. Schneider, 2006]. Both have excluded the issue of financial constraints of power utility and considered more on the quality of supply as delivered by the system.

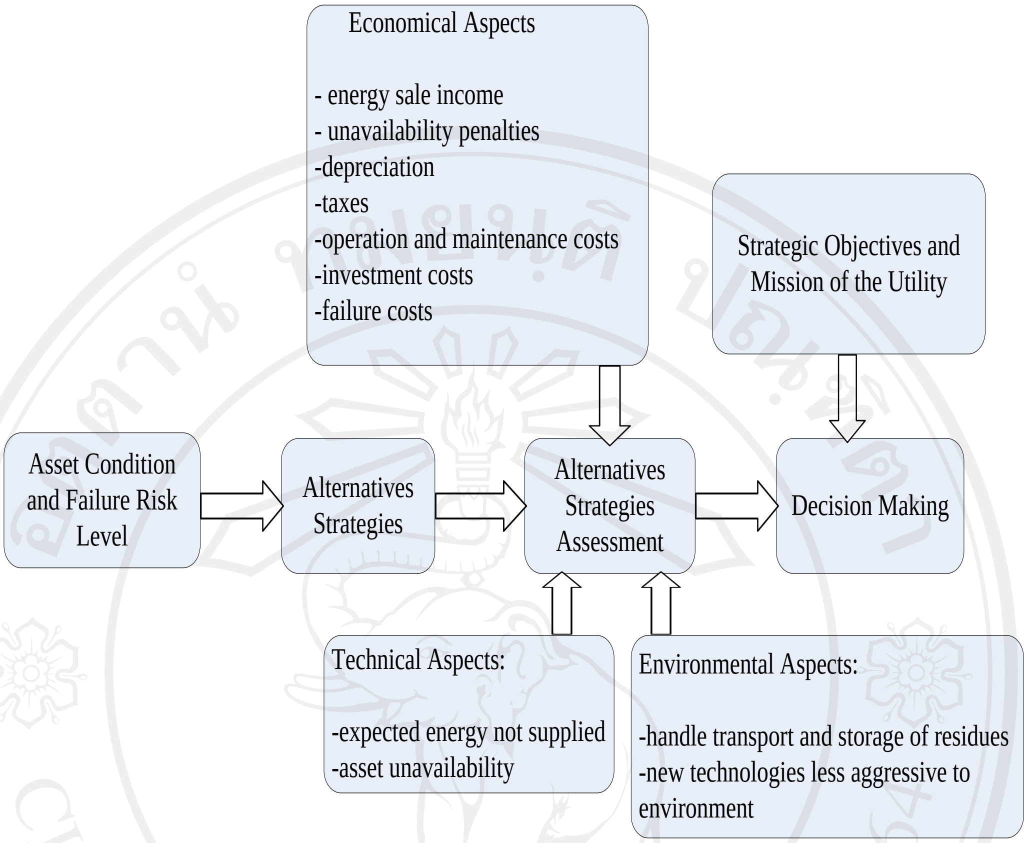

Figure 3.1 Decision Model for Power Transformer [J.C.M. Lucio, 2009].

Picard et al. have developed a financial model to assess the end of life of switchgears comparing future costs for use-up, retrofit, re-conditioning, and replacement. Depreciation, maintenance, outage, safety health and environment costs are included in this model to review investments [H. Picard, 2007]. Summereder et al. have proposed a lifetime management framework for a power transformer given in figure 3.2. The life time management of power transformer can be undertaken by using monitoring and diagnosis systems and maintenance strategies resulting in reduction in the life cycle costs and the postponement of reinvestment [C. Summereder, 2003].

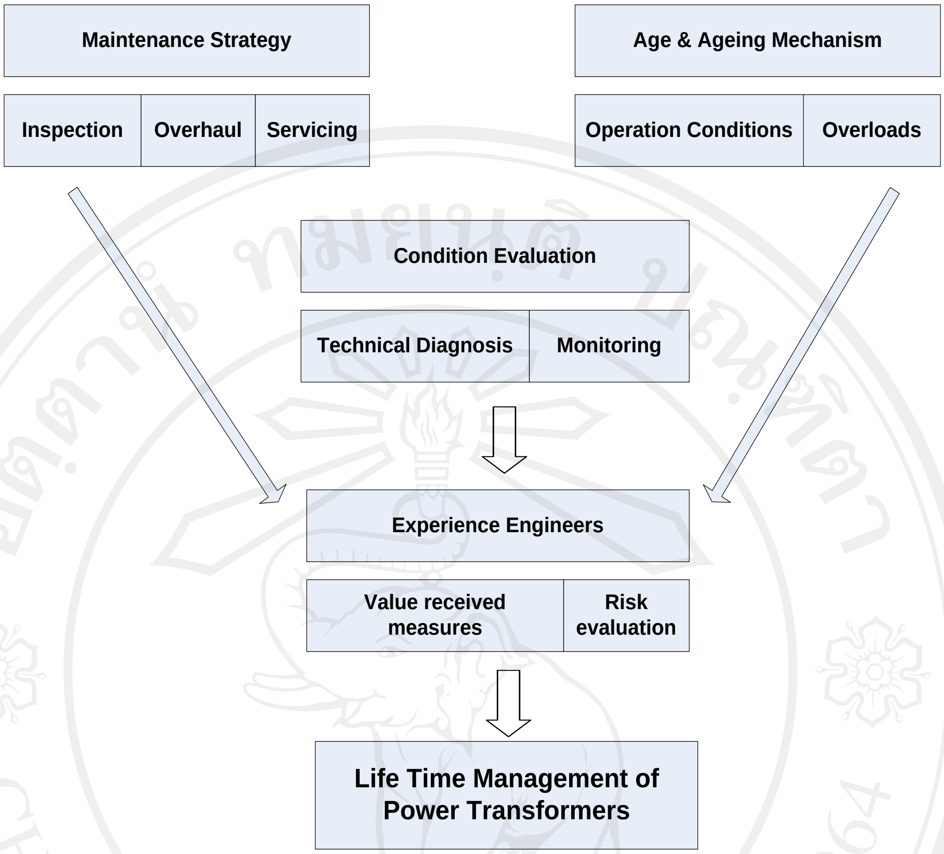

Figure 3.2 Lifetime Management of Power Transformer [C. Summereder, 2003].

It can be found that the problem of systematically assessing the life cycle of a power transformer within a financially designed life during load violation has not been addressed with the existing models. These models have not integrated the cost of keeping the asset on stock. In addition, budget limitations of the power utility have not been considered during decision making. Since power transformers are not fully utilized, these models have emphasized more on the technical aspects of the asset. They are suitable for assessing the life cycle of power transformers when they will reach their end of life.

3.4 Load Profile

A power transformer is put into the network to meet the demand of consumers based on its capacity. In general, utilities have planned the power transformer on designed load demand for the long term. Hence, the load reaches the rated capacity of the power transformer after the financial designed life. Utilities have their own model to evaluate designed load demand. The designed load demand is estimated using the mathematical equation below.

$$DLDt = (Dt * NSt)/ HS \qquad (3.1)$$

Where,

DLDt = Designed Load Demand at year t.

Dt = Average Consumption of Energy per Connection in KWh.

NSt = Number of Population in year t.

HS = Average Household size

However, the actual load demand is the real demand of any particular pocket or place where the power transformer is connected to supply the demand considering all the anticipated issues. The addition of new industrial areas, migration of people or sudden changes in an economic condition can cause penetration. Due to unexpected penetration, the actual load profile does not always follow the designed load. Alternatively, the actual load curve does resemble the designed load curve especially in rural region unless there is a chance of penetration. As a result, the load will meet the rated capacity of the power transformer in the early stage of the life cycle. The point in the load profile where the load will exceed the rated capacity of power transformer is called load violation. The actual load demand is estimated using a heuristic approach. In this research, the senior planning engineers of a power utility working in distribution center are interviewed to construct the actual load demand.

3.5 Proposed Model

An alternative decision model has been proposed to effectively assess the life cycle of power transformer during load violation. The main objective of this model is to maximize the profit and minimize the cost of keeping the power transformer on stock in order to maximize its utilization during its financial designed life. The decisions are made on the basis of financial values whilst keeping technical values in mind. The knowledge based model, financial model and decision rules are the main components of this proposed model. In this research, the following assumptions are made:

❖ The procurement of a power transformer is done from the international market through a soft loan payment.

❖ The transportation cost within the substations of the power utility is same since the distance travelled by crane has negligible effect on total transportation cost.

3.5.1 Proposed Conceptual Life Cycle Assessment Framework

The general framework of the decision model is presented in figure 3.3.

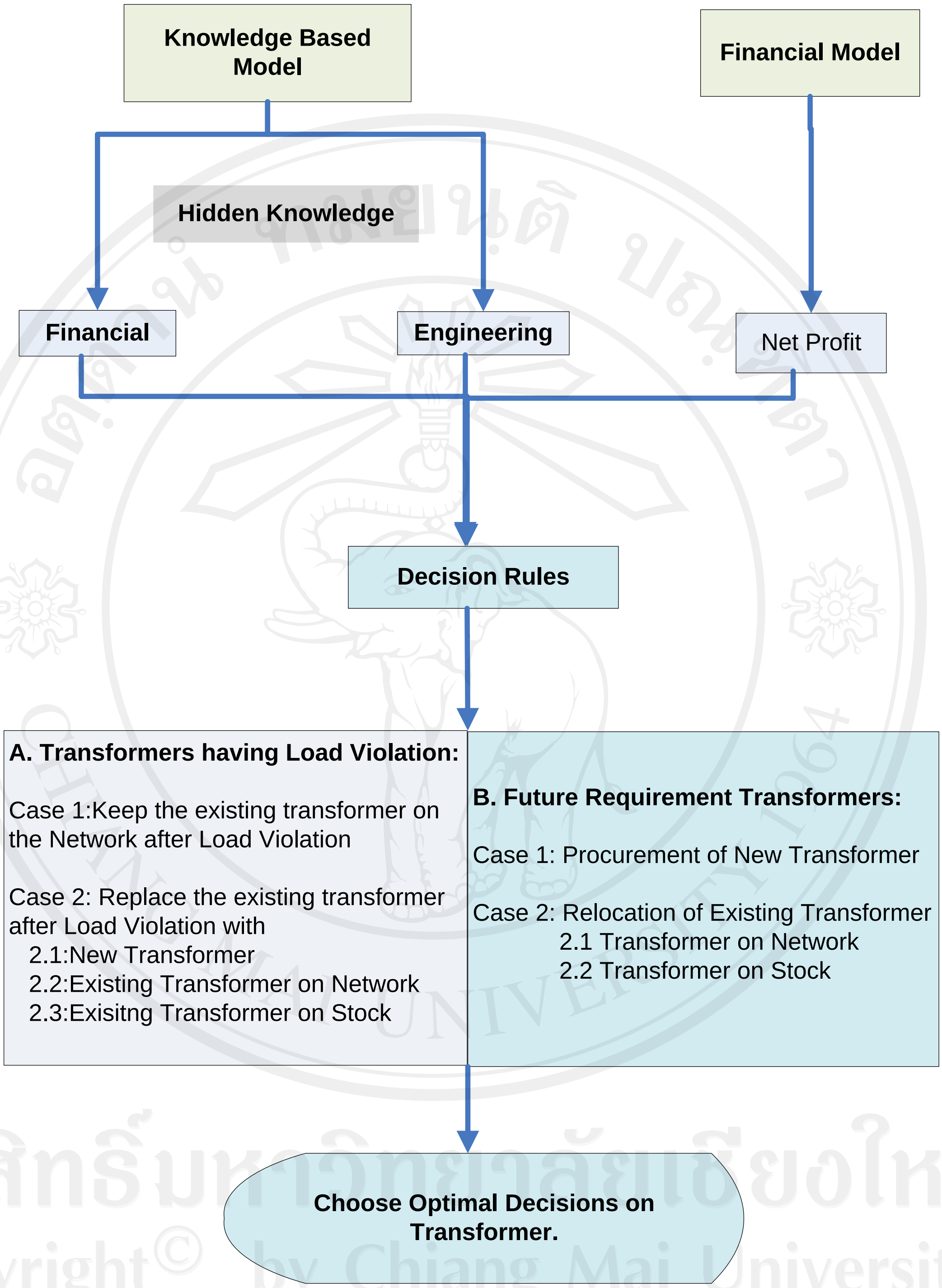

Figure 3.3 Proposed Decision Model of the Power Transformer Life Cycle Assessment.

3.5.2 Working Mechanism

Firstly, the short term planning horizon has been selected due to the instability of financial resources. During this planning horizon, the number of power transformers for procurement has been identified based on ageing assets. At the same time, the requirement of power transformers especially in rural regions will be determined where new connections will be established in the future due to the construction of new power houses, known as future requirement transformers. The load violation of each power transformer is determined from the actual load profile curve. The power transformers are characterized based on load violation. The power transformers having load violation before the end of their financial designed life have been selected in this research and are referred to as network transformers.

Secondly, the hidden knowledge cost associated with each power transformer has been estimated using knowledge based model. The hidden knowledge is the knowledge possessed within documents and humans from different activities or tasks involved in each phase of the life cycle of the power transformer. It can provide both financial and technical values to the utility. With the utilization of hidden knowledge, some portion of the cost can be saved in each year of its life cycle. The payback period, mortgage cost and net profit of each power transformer is determined using financial model. The hidden knowledge cost is utilized with the financial model in order to positively shift net profit value. The net profit of a power transformer is computed using Economic Valued Added (EVA) modeling to facilitate decision making. The details of the knowledge based model and financial model are explained in chapter 4.

Thirdly, the decision rules are established based on the different life cycle options on power transformers. They are mainly composed of two parameters; net profit and mortgage cost. During load violation, there are two possible options for the power transformer either keeping it on the network or replacing it after load violation is taken into consideration. The opportunity cost of not supplying energy to the consumers after load violation has also been considered.

Finally, the scheduling algorithm has been proposed to choose optimal decision on power transformers due to the complexity of network. It is formulated with the objective of maximizing the profit and minimizing the cost of keeping the power transformer on stock. The stock keeping cost is the mortgage cost associated within the power transformer when it is on stock. The decision rules and scheduling algorithm are described in chapter 5.

3.5.3 Suitability and Limitations of the Proposed Model

The proposed model is suitable due to the following reasons:

❖ The decisions are based on the net profit of a power transformer. The decisions become financially feasible with the utilization of hidden knowledge as it adds some financial value to the net profit. The financial model can provide a clear financial picture of each power transformer over its life cycle.

❖ The knowledge based model can provide the technical knowledge to the personnel working with the power transformer for better operation and maintenance of the power transformer such as corrective maintenance, preventive maintenance, visual inspection and engineering knowledge. Some portions of financial savings can be achieved with the utilization of hidden knowledge each year and can be used to meet technical requirements.

❖ This model has considered the type of utility where financial resources are the primary concern in decision making. The power transformers have been fully utilized during their financial deigned life. Finally, this model has balanced both the technical and financial values of the power transformer.

However, this model has some limitations. It has not incorporated environmental and social aspects, and the value of lost load because they have minor influence on the decision making process in this context. This model can work effectively only when the life of power transformers are within their financial designed life.

3.6 Robustness

The proposed model has been verified and tested case by case. The small number of power transformers have been selected to verify the model because it is quite complex to test a large number of power transformers case by case. In this research, four different cases have been studied to test the proposed model and are explained in chapter 5.

The model needs to be validated to determine the correctness of the proposed model from the utility aspects. It is validated from the judgment of planning experts of a power utility because they have had practical experience in this area for several years.

3.7 Implementation

The simulation software has been developed to demonstrate the operability of model in a systematic way. The proposed scheduling algorithm is coded in PHP (Hypertext Preprocessor) language in server side and MySQL as a database after it has been tested for correctness. The implementation procedures are described in chapter 5. However, it becomes difficult to test the large number of power transformers case by case. This simulation software facilitates executives or planning engineers of a power utility to select the optimal decision on power transformers and finally, they can enhance their contingency plans for power transformers.

3.8 Chapter Summary

In this chapter the alternative life cycle assessment model of the power transformer is proposed and presented. It consists mainly of knowledge based model, financial model and decision rules. These three components are tested in the later sections of this thesis. This alternative model is aimed at maximizing the utilization of the power transformer during its life cycle and minimizing the cost of keeping it on stock. Furthermore, the simulation software is developed to test the proposed model and is also explained later in this thesis.