CHAPTER 1
INTRODUCTION

1.1 Chapter Overview

In this introduction chapter, a general structure of the power distribution system is presented along with an initial description of the research problems. Furthermore, the current asset management approaches used by NEA (Nepal Electricity Authority) as well as the difficulties faced by the utility under the complex structure of assets and budget limitations are discussed. In the latter section, a solution including a proposed framework with its research outcomes are depicted. The novelties and list of publications are presented in the following sections.

1.2 Research Problems

An asset management is used in power utilities to improve performance, manage risk and reduce long term asset costs. Asset management is also concerned with life cycle management. The main objective of life cycle management is either to get the most out of an asset ensuring the longest possible service life, or to minimize the life time operating costs, whichever is the most appropriate [CIGRE, 2002]. However, it is difficult to establish a utility wide set of rules or standards to manage the life cycle of assets due to the list of variables and individual utility circumstances [W.H. Bartley, 2002]. In order to effectively assess the life cycle of assets, it is essential to have both technical and financial knowledge. It is not an easy task to monitor and assess the technical condition of asset. With investment in condition monitoring technologies, the technical deterioration characteristics of an asset can be determined. These measures are required to analyze and understanding the working behavior of an asset, but, due to the lack of expertise and sufficient knowledge in the power utility, it is challenging to implement [D.M. Allan, 2005]. Therefore, there is a requirement to capture knowledge about the asset in each phase of the life cycle, and share and disseminate this knowledge between the personnel involved in the various phases of the life cycle. On the other hand, power utilities have a very large and diversified group of assets resulting in difficulty obtaining the financial knowledge of each individual asset in the network. Financial knowledge means understanding when each asset will return back its investment after it has been put into operation. In addition, another major problem is the self-financing weakness of power utility companies in developing countries towards the planning of their assets [J. P. Delhaise, 1993]. They rely on soft loan from the international agencies and foreign countries to undergo expansion and rehabilitation of their infrastructure [M.R. Kafle, 2007].

In this research, the power transformer is selected as an asset since it is regarded as one of the most critical and expensive assets in the distribution system. It has the single highest value of assets within substations, comprising about 60% of the total investment [A. Naderian, 2008]. Due to increased load demand, the substations of power utilities become overloaded. Hence, the existing substations require reinforcement with the addition of new power transformers to meet the demand. Normally, power utilities have planned their power transformer based on the normal load growth with a certain degree of reserve capacity. However, the actual load profile does not always follow the designed load demand due to unexpected penetration. It causes the power transformer to experience load violation in the early period of its life cycle. The load violation is the point in the load demand curve when the load of the power transformer exceeds its rated capacity. In this situation, power utilities must make a strategic decision on the power transformer either for its continued use until failure, relocation or replacement. It is challenging for the power utility to make effective decision on power transformer satisfying both technical and financial requirements. Thus, the power utility must adopt asset management practices to maximum utilization by managing its power transformer, and its associated performances, risks and expenditures over its life cycle and within the available financial resources. However, most existing models or practices have considered aging assets that have almost reached to the end of their life. The management of assets in stock has been overlooked. The decisions were made on the basis of cheapest market price of the assets available in the market considering only the technical performance of the assets [J.J. Smith, 2006] [M. Shahidehpour, 2005].

By using the life cycle management techniques proposed, this thesis presents an alternative model for an effective life cycle assessment of the power transformer with the aim of its maximizing utilization over its life cycle satisfying both financial and engineering requirements through the utilization of hidden knowledge. The hidden knowledge is the tacit knowledge possessed in knowledge workers or engineers who have been operating the power transformers. It can also be available within the relevant documents of power transformer. The alternative model comprises of a knowledge based model, a financial model and decision algorithm. A case study of Nepal Electricity Authority is conducted in this research.

1.3 Power Distribution System

Electrical power distribution is the power delivery infrastructure that takes the electricity from the highly meshed, high voltage transmission circuits and delivers it to customers. In a distribution substation, a transformer takes the incoming transmission level voltage and steps it down to several primary distribution circuits. A distribution transformer takes the primary distribution voltage and steps it down to a low voltage secondary circuit (400/230 V). From the distribution transformer, the end users are connected to the secondary distribution circuits. The distribution infrastructure is expensive [T.A Short, 2006]. The importance of transformers application in power utilities is illustrated in figure 1.1. Then, a schematic diagram of distribution network is shown in figure 1.2.

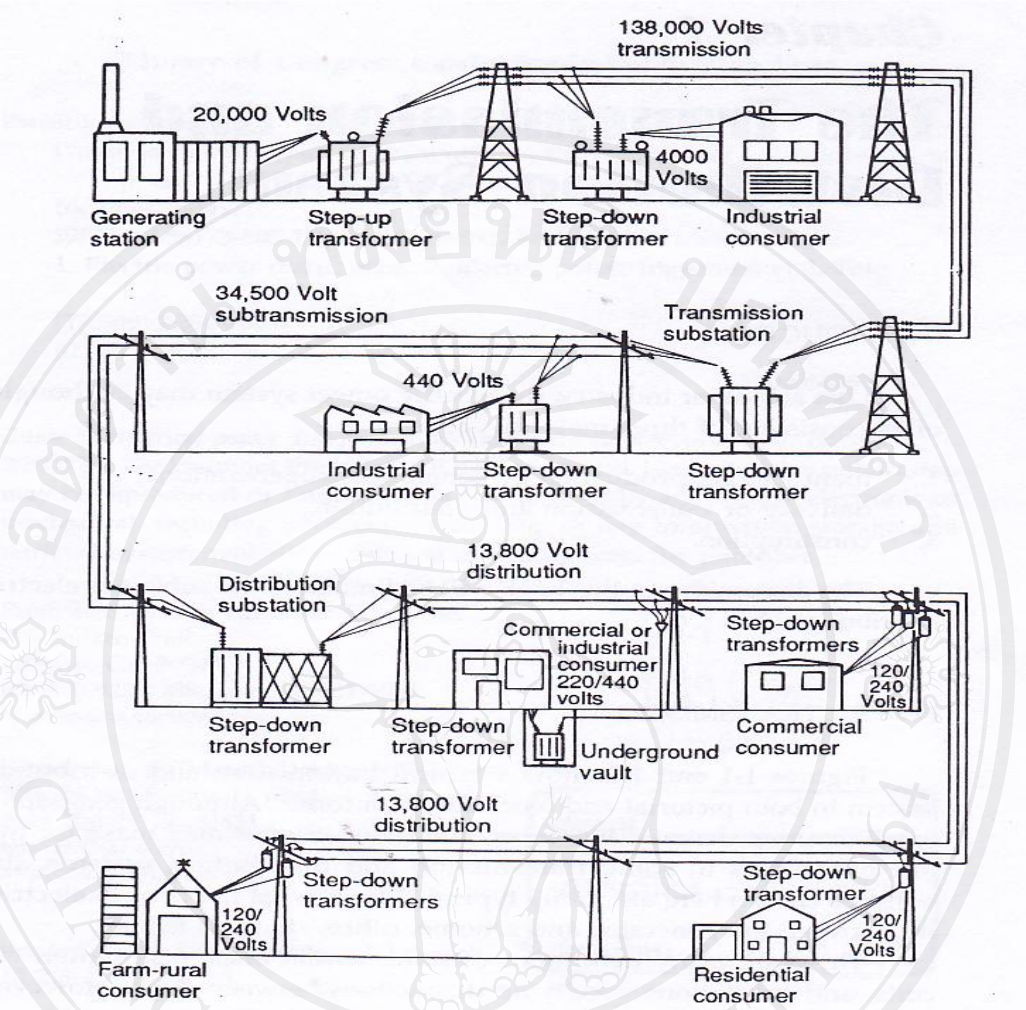

Figure 1.1 Transformer Application in Typical Electrical Supply

[A. J. Pansini, 2005].

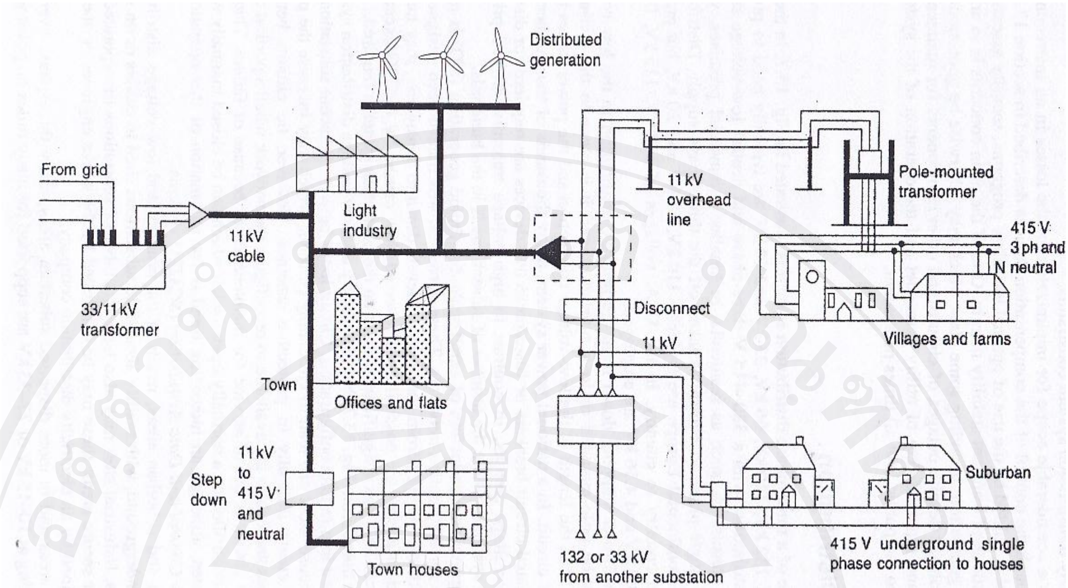

Figure 1.2 Distribution Network of Power Utility [D. F. Warne, 2005].

The distribution system comprises of many components as shown in figure 1.3. It has switching station, transformers, feeder lines, etc.

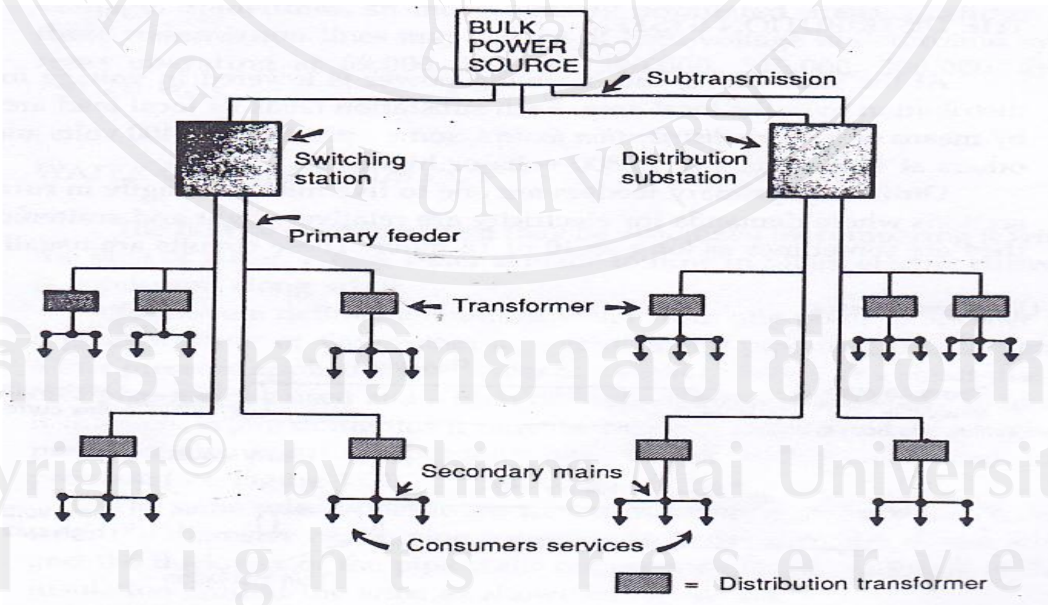

Figure 1.3 Distribution System Showing Components [A. J. Pansini, 2005].

The power distribution system in Nepal has operated in a monopolistic manner. The distribution and retailing activities are the responsibility of the transmission and system and distribution and consumer Services business groups under the jurisdiction of Nepal Electricity Authority [NEA, 2009]. With this system, the majority of nationwide consumers have to rely on its services. The transmission and system business Group is responsible for design, construction, operation and maintenance of the transmission system at voltage levels of 66 kV and above. Within this business group, there are Transmission line/substation construction, grid operation and system operation departments. Transmission line/ substation construction department is responsible for constructing new transmission lines and substations of 66 kV and higher voltage level. Similarly, the grid operation department is responsible for the operation and maintenance of the transmission system of the Integrated Nepal Power System. Furthermore, it is responsible for the upgrading, reinforcing and rehabilitation of transmission system. The system operation department supervises and controls the Integrated Nepal Power System using SCADA system. Finally, the distribution and consumer services business group is responsible for the overall management of the electricity distribution network of the NEA including operation, maintenance, rehabilitation and expansion of the network up to 33 kV voltage level [NEA, 2009]. Table 1.1 shows the different voltage levels used in NEA.

Table 1.1 Different Voltage Levels of NEA [NEA, 2009].

S.N.	**Voltage Level (kV)**
1.	132/11
2.	132/33
3.	132/66
4.	66/11
5.	66/33

1.4 Challenges and Asset Management Practices of NEA

Nepal is facing an ironic situation where about 60% of the population has no access to electricity, although the country has economically exploitable hydropower potential of 44,000 MW which remains untapped [NEA, 2008]. The total installed capacity in Nepal Electricity Authority (NEA) is 705.566 MW [NEA, 2011]. With an energy shortage situation in Nepal, the NEA has been implementing load shedding of a maximum fourteen hours per day [NEA, 2011]. To meet the continued growth in power and energy demand, the NEA has planned to undertake the construction of medium and large scale Hydropower. In the meantime, the NEA is at advanced stage of action in creating additional cross border trading with India to import and export power [NEA, 2008]. Effective development is hindered by the lack of financial resources, scarcity of local expertise and the presence of difficult geology. The major hindrance to the power utilities in developing countries is financial resources [B.B. Malla, 2001][J.P. Delhaise, 1993]. With the construction of new power houses and the extension of cross border trade, the NEA is required to build the required infrastructure such as construction of new substations.

The NEA is currently administrating certain tasks in operating power transformer during their life cycle. However, the certain methods that they are using are considered quite primitive. Power transformer decisions are based only on data of the historical load status of substations. In addition, the NEA has overlooked the remaining life and financial values of power transformer. This is conceptualized in figure 1.4.

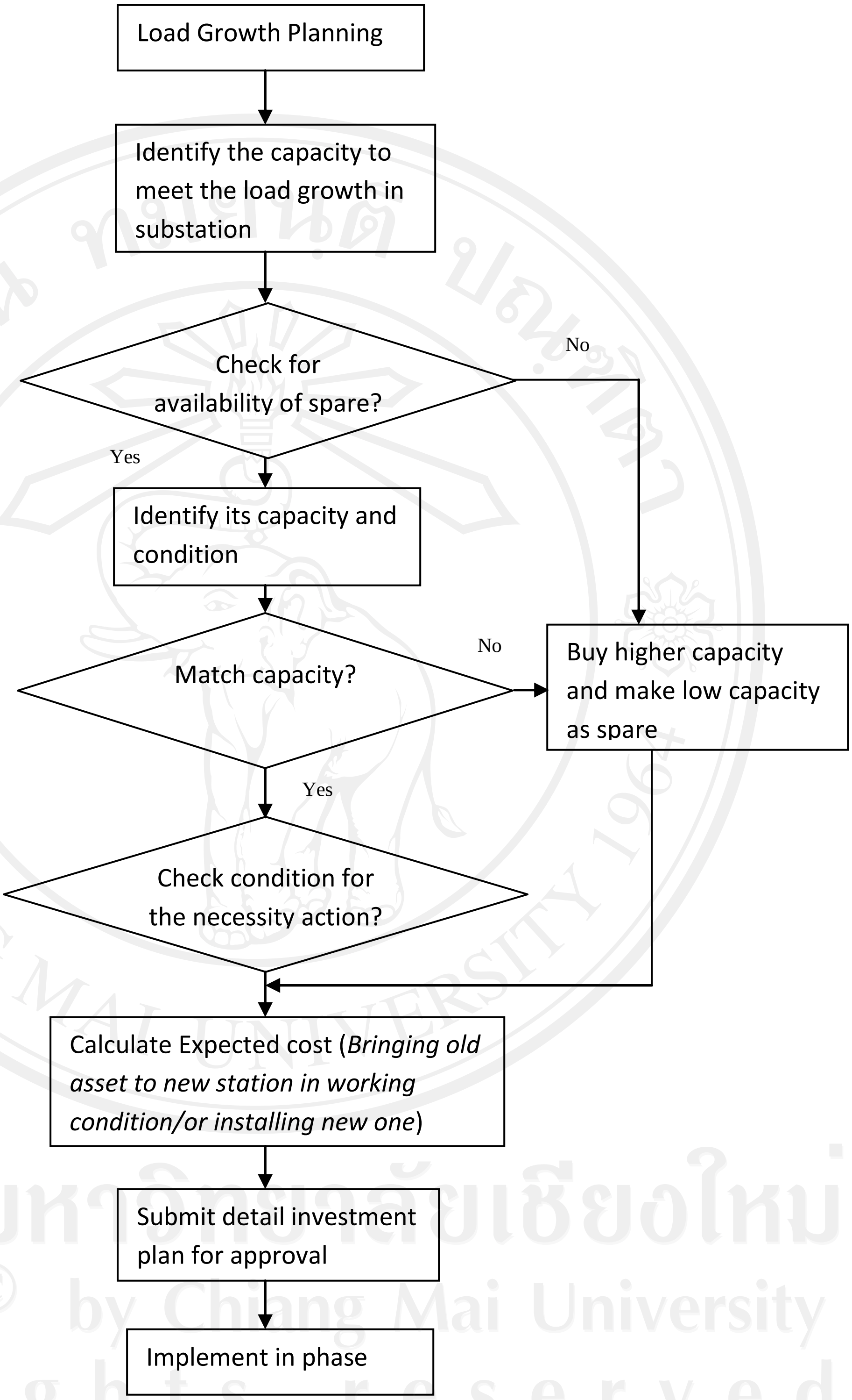

Figure 1.4 Asset Investment Planning Process of NEA [Grid Operation Department, 2008].

The load is forecast based on the availability of previous data from the grid operation department in order to plan for power transformers. The department identifies the capacity required to meet the load demand in substation. Then, they will identify spare one to meet that demand based only on its capacity and condition. The condition is checked based on whether to do major or minor repair on the power transformer. The expected cost is estimated based on the price of a new power transformer which considers all costs whereas in spare one, only its repair, installation and transportation costs are included. Finally, the detail investment plan is submitted for approval. In this way, NEA is managing its power transformers over their life cycle. So, the decision is mainly focused on the availability of spare transformer only and capacity with limited financial calculations. As a result, power transformers are not fully utilized over their life cycle.

1.5 Research Justification

The power distribution system is considered as one of the key elements of the entire electrical power system. The continuity of supply is the prime concern of both utility and customers. In the distribution system, the power transformer is regarded as one of the most critical and expensive assets. This is because sudden failures may cause disruption in power supply resulting in higher costs, revenue loss as well as environmental and collateral damage. This leads to significant investment each year [D. J. Woodcock, 2000] [M. Arshad, 2004b][Summary Report, 2006]. In addition, the life cycle management of power transformer becomes more important due to technical and economic aspects [J.Q. Feng, 2005]. Based on this, the power transformer is selected as the focus of research in this thesis.

In developing countries, the construction of new business/or industrial areas, migration of population or sudden changes in economic conditions can cause unexpected load growth in some regions. However, the power utility has planned the power transformer based on a normal load growth. In this case, utility has to meet the demand either from a new or stock power transformer. As a result, the cost of keeping power transformer in stock increases. In addition, the power transformer is not fully utilized over its life cycle. Eventually, the decision becomes unwise economically.

Therefore, this thesis attempts to address these problems and propose an alternative solution to make optimal life cycle decisions on power transformer when the loads exceed its rated capacity of a power transformer.

1.6 Research Theme

1.6.1 Research Methodology and Proposed Framework

The research is conducted in the following sequences:

Literature Review: The technical papers, reports, standards, proposals, fact sheets, catalogues and books related to this research are reviewed. The main focus is on different techniques of life cycle assessment and management of assets specifically power transformers, and knowledge engineering methodologies.

Data Collection and Analysis: The main sources of data reside at Nepal Electricity Authority in Kathmandu. Document exploration, expert interview and observation have been undertaken to collect the data. Experienced engineers/technicians in substations of the NEA and experts from the manufacturer were interviewed and observed to capture their knowledge regarding the life cycle management of power transformer. In addition, experienced designers and planners in the grid operation department of NEA were interviewed to elicit the knowledge of planning and designing substations activities. The documents such as transformer historical records, financial documents, asset investment plan, load forecasting documents and organization annual report were collected to determine their current practices of asset management.

The collected data were analyzed to capture the key concepts of power transformer life cycle management. This was done through constructing the life cycle of the power transformer and then classification of each activity at each phase.

Selection of Suitable Knowledge Engineering Methodologies and Decision Model: The main objective of this thesis is to propose an alternative life cycle assessment model for power transformers satisfying both technical and financial requirements. Different models have been reviewed to meet the objectives. The CommonKADS suite model has been selected to construct a knowledge based model. Economic value added (EVA) is selected and modeled to make decision on power transformer based on the proposed decision criteria.

Proposed Decision Model: An alternative decision model has been proposed to effectively assess the life cycle of the power transformer. The main objective of this model is to minimize the cost of keeping the power transformer on stock and maximize its utilization during its financially designed life. The financial values are used to make decision with the inclusion of technical values. The main components of this model are the knowledge based model, financial model and decision rules. The decision rules are made based on three scenarios: use up, replacement and relocation of the power transformer. Figure 1.5 depicts the decision framework for the power transformer asset management proposed in this thesis.

Simulation and Testing: The proposed decision model is tested for its robustness. To verify the model, a small number of power transformers were selected and tested case by case. In this research, four different cases were performed. The simulation software is developed to demonstrate the operability of the model in an efficient way. Experts verified the obtained results.

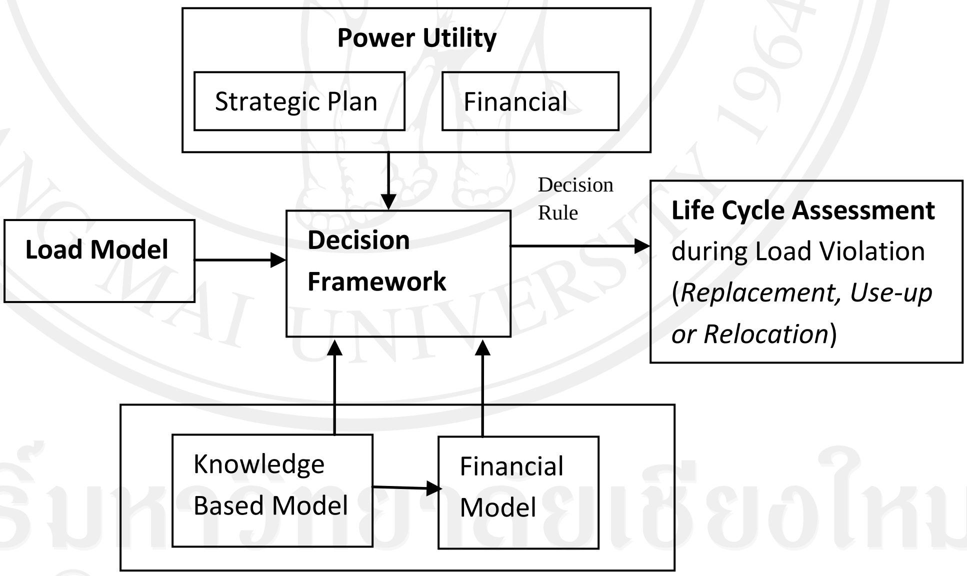

Figure 1.5 Proposed Decision Framework for Power Transformer Asset Management.

1.6.2 Research Questions

The following research questions are used to undertake this research:

RQ1: What kind of technical and financial knowledge should engineers/ executives require for life cycle decision of power transformer?

RQ2: What sort of hidden knowledge embedded within power transformer can be applied during life cycle decision of power transformer?

RQ3: How can we determine the hidden knowledge cost?

RQ4: How can we model and formulate the net profit and decision criteria of power transformer for each case during load violation under different scenarios?

RQ5: How can we utilize the hidden knowledge of power transformer over its life cycle?

1.6.3 Research Objectives

This research is aimed to provide alternative methodology to facilitate engineers/executives in the power utility in terms of how, when and where to make effective decisions on a power transformer during load violation over its life cycle. The main objectives of this research are outlined below:

- To maximize the utilization of the power transformer over its whole life cycle.
- To come up with a mathematical decision model that balances costs, performances and risk of a power transformer in the network.
- To investigate the life cycle cost of a power transformer in the network.
- To make use of embedded knowledge within the existing power transformer to satisfy the decision both in terms of engineering and financial aspects.
- To minimize the investment cost on power transformer by providing financial benefits as well as addressing some of the technical constraints through the utilization of more knowledge and expertise.

1.6.4 Research Outcomes

The key outcomes of this research are as follows:

- A decision support methodology to assist executives/engineers of power utility to make effective decisions on the power transformers during load violation under budget limitation.
- Financial model to determine the net profit of each power transformer over its life cycle.
- Fulfillment of engineering and financial requirements of the power transformer with the utilization of hidden knowledge.

• Produce an enhanced contingency plan for power transformers during procurement, relocation and replacement.

• Simulation software to effectively and efficiently assess the life cycle of power transformers.

1.6.5 Novelties

The following aspects are the key novel contribution of the research:

• In the Knowledge Management context: The Common KADS model suite is used to construct knowledge based model to implement reusable knowledge embedded within a power transformer over its life cycle. It provides both financial and technical values to the utility to enhance their utilization.

• In the Financial Model Context: It computes opportunity cost and stock keeping cost of power transformer while not supplying energy to the consumers with the modeling of EVA. It provides net profit of each power transformer.

• In the decision making context: the decision framework uses the actual load profile in order to determine the decision point during the life cycle. The framework has considered the financial designed life of each power transformer and used a financial model with the inclusion of hidden knowledge to make decisions.

• In the asset planning context: the software is developed to assist enhance decisions making on power transformers during load violation while meeting both financial and engineering constraints.

1.7 Related Publications

The publications resulting from the research are listed below:

• S.S. Bhandari, T. Chandarasupsang, "Alternative Life Cycle Assessment of Power Transformer", 3rd International Conference on SKIMA-09, Fes, Morocco, 21-23 October, 2009.

• S.S. Bhandari, N. Chakpitak, T. Chandarasupsang, "Decision Model for Life Cycle Assessment of Power Transformer During Load Violation", International Journal of Engineering Science and Technology, Vol. 2(5), pp. 1147-1154, 2010.

- S.S. Bhandari, N. Chakpitak, K. Meksamoot, T. Chandarasupsang, "Knowledge Based Model for Power Transformer Life Cycle Management using Knowledge Engineering", International Conference on Information and Knowledge Engineering, Singapore, 25-27 August, 2010.
- S.S. Bhandari, N. Chakpitak, K. Meksamoot, T. Chandarasupsang, "Knowledge Engineering Approach for Power Transformer Asset Management", Journal of Engineering Science and Technology, Accepted for Publication in 2012.

1.8 Thesis Overview

Chapter 2 provides a review of the existing theories and practices of life cycle assessment and management under the concept of asset management. In this chapter, life cycle phases, life cycle costing and life cycle decisions of assets are presented. Furthermore, a health index of assets is also discussed followed by loading characteristics of power transformer.

Chapter 3 reviews the existing life cycle assessment models of assets and proposes an alternative life cycle assessment model of power transformer with general description.

Chapter 4 deals with two components of the proposed model, financial model and knowledge based model. It reviews the existing financial measures in decision making, and principles and methodologies of knowledge management and engineering. Finally, the results are presented in two sections, illustrating the suitability of the financial model and knowledge based model.

Chapter 5 presents the decision algorithm used in the proposed model. The algorithm is explained thoroughly using a flowchart for single and multiple power transformers. Then, four case studies are conducted to test the robustness of the proposed system. The discussion and analysis on its performance are also presented during analysis of results. In addition, the development procedures of the simulation software are briefly described.

Chapter 6 presents the conclusion and future work.