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KNOWLEDGE ENGINEERING APPROACH FOR POWER TRANSFORMER ASSET MANAGEMENT

SACHIN S. BHANDARI*, NOPASIT CHAKPITAK,
KOMSAK MEKSAMOOT, TIRAPOT CHANDARASUPSANG

College of Arts, Media and Technology, Chiang Mai University, Chiang Mai, Thailand
*Corresponding Author: Sachin_camt@hotmail.com

Abstract

The main objective of the utility company is to maximize the utilization of its existing assets during their life cycle meeting both engineering and financial requirements. However, the knowledge available in the utility is unstructured and often in tacit form. This paper presents a knowledge based system for the utility companies in order to make an optimal decision on power transformer with their utilization. CommonKADS methodology, a structured development for knowledge and expertise representation, is utilized for designing and developing knowledge based system. A case study of One MVA power transformer of Nepal Electricity Authority is presented. The results show that the reusable knowledge can be categorized, modelled and utilized within the utility company using the proposed methodologies. Moreover, the results depict that utility company can achieve both engineering and financial benefits from its utilization.

Keywords: CommonKADS, Knowledge engineering, Asset management,
Power transformer.

1. Introduction

Asset management is the systematic and coordinated activities and practices to optimally manage their assets, and their associated performance, risks and expenditures over their life cycle attaining their organizational strategic plan [1], [2]. However, utility's portfolio comprises of a very large and diversified group of assets resulting in difficulty to manage their assets systematically. Therefore, effective asset management is inevitable to the utility from both financial and technical aspects.

Abbreviations

CC	Commissioning cost
CML	Corrective maintenance learning
EC	Engineering cost
IC	Installation cost
OC	Operational and maintenance cost
OMSC	Operational maintenance set up cost
PC	Planning cost
PML	Preventive maintenance learning
PT	Power transformer
TC	Transportation cost
TrC	Training cost
VIL	Visual inspection learning

The management and decision making activities of the power transformer operating in a power system are based on the normal load growth with some certain degree of reserved capacity. However, in reality the actual load profile does not always follow this designed load due to unexpected penetration. Then, the load violation will occur at some points during the life cycle of power transformer under which the utility is required to make strategic decision. In addition, they do not have knowledge about the status of each asset in the portfolio in terms of its technical and financial values. Thus, the decisions were mainly focused on the cheapest price of any assets available in the market without any consideration to investment budget limitation thinking only of the technical aspects rather than financial aspects [3-5]. Consequently, the decision becomes infeasible from the financial perspective. In this context, utility must make optimal decision on power transformer considering both financial and technical constraints.

The engineering and financial requirements can be fulfilled with the utilization of reusable knowledge embedded within power transformer over its life cycle. However, the available knowledge is unstructured and often in tacit form to be utilized. Hence, this paper is aimed to offer Knowledge Engineering and Management framework to develop knowledge based system for an effective life cycle assessment of power transformer in order to maximize its utilization during its life cycle.

2. Knowledge Engineering

Knowledge Engineering (KE) is not simply a means of extracting the knowledge from the expert. It now includes methods and techniques for knowledge acquisition, modelling, representation and utilizing [6]. The development of knowledge based system considers the knowledge modelling as a main activity.

2.1. Knowledge engineering methodologies

CommonKADS [6], SPEDE [7], MIKE [8], MOKA [9] and others are widely used KE methodologies and they are based on SE modeling notations. Models are used to capture the important features of a real system parts in order to understand and manage them easily. They are important to understand the working procedures within a knowledge based system [10].The conceptual models of knowledge intensive tasks are constructed using modeling process. The knowledge modeling is important in knowledge management. Understanding the source of knowledge, the inputs and outputs, the flow of knowledge and the dependents are necessary to model the knowledge [11]. CommonKADS is the most suitable technique that can be considered a knowledge engineering methodology because of having the following features such as object oriented approach, platform independent, hybrid approach and documentation and CommonKADS has been widely been applied in different domain such as medical, legal, engineering, business and social sciences [12].

2.2. CommonKADS

It is the de facto standard for knowledge modeling [6]. It support structured knowledge engineering techniques. The methodology explains principles, techniques, methods and document structure to support the construction of knowledge based system in three stages; context level, concept level and artefact level.

The knowledge model specifies the knowledge and reasoning requirements of the perspective system. It is a tool to clarify the structure of a knowledge- intensive information- processing task. It provides a specification of the data and knowledge structures needed for the application. The construction of a knowledge model consists of three knowledge categories; task knowledge, inference knowledge and domain knowledge. Each knowledge category has its own components to construct model. The details of CommonKADS can be found in [6].

3. Hidden Knowledge of Power Transformer

The hidden knowledge is the tacit knowledge possessed in knowledge workers or engineers who have been operating on the power transformers. It can also be available within the documents of power transformer. Life cycle phases of asset comprise of acquisition, utilization and disposal phase [13]. The life cycle phases of power transformer are shown in Fig. 1. There are different major events or activities occurred in the life cycle of power transformer which evaluates its life cycle cost.

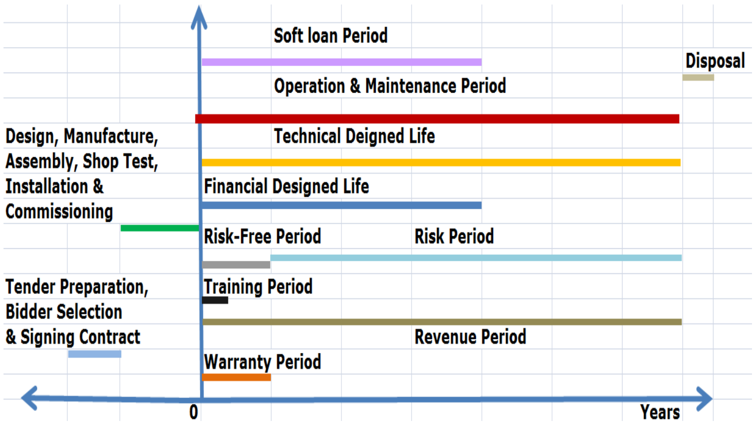

Fig. 1. Life Cycle Phases of Power Transformer [14].

The hidden knowledge is identified with the construction of life cycle of power transformer. The cost associated with the hidden knowledge is determined with interviewing the senior engineers of contractor and is verified with the experts from the manufacturer of power transformer.

Engineering Knowledge: This is the knowledge required for understanding the detail design specifications of power transformer during manufacturing process including drawings, testing reports, etc. It is utilized in the existing power transformer or new transformer during relocation or procurement, and to determine designed safety margin in order to operate further beyond its financial designed life. This is located on the head of manufacturer's experts and on the documents.

EC = function (Design drawings, General lay out drawings, Testing reports) (1)

Transportation Knowledge: It contains dispatch, receiving on site and handling knowledge. This knowledge is needed before installing the existing or new power transformer on the network. It is on the supervisor's head and inside the instruction manual.

TC = function (Freight Charges, Custom Clearance, Crain Charge, Supervisor cost per day, etc.) (2)

Installation Knowledge: Knowledge of location and mounting, site arrangement, erection, testing, oil filling, etc. are required for installation. The supervisor is needed for the proper supervision of installation process. This knowledge can be achieved through the supervisor and installation manual provided by the contractor.

IC = function (Supervisor cost/day × Installation Duration, Erection Cost, Labor Cost, Testing equipments, etc.) (3)

Commissioning Knowledge: This knowledge includes the concept of energizing, measurements and observations, etc; It is embedded within the supervisor and instruction document.

CC=function (Supervisor cost/day × Commissioning duration, Testing equipments, Labor Cost, Accessories, etc.) (4)

Operation and Maintenance Setup: It provides the complete guidelines, procedures and methods to do proper operations and maintenance of power transformer as well as safety precautions in the written form.

Corrective Maintenance Learning: This is the knowledge required for the operation and maintenance workers to diagnose and investigate the failure of power transformer during operation. It is learnt with the help of operation and maintenance expert during acquisition phase.

Preventive Maintenance Learning: It includes the learning of regular inspection, testing and reconditioning of power transformer ensuring correct operation. The operation and maintenance workers can learn from the operation and maintenance expert.

Visual Inspection Learning: This learning provides the knowledge about internal and physical inspections of power transformer periodically to the operation and maintenance workers. They can learn from the operation and maintenance expert of the contractor.

Planning Knowledge: This knowledge includes the concept of design specifications, tender preparation and bidding selection. It is needed at the time of procurement of power transformer. This knowledge can be gained through the expert's of planning and operation department of substation.

Training Knowledge: This knowledge is required to train operation and maintenance workers to become familiarize with the operating and maintenance, safety and protection aspects of power transformer in every five years. This can be achieved from supervisor/or trainer of contractor.

$$TrC = \text{Supervisor cost per day} \times \text{Training duration} \quad (5)$$

The total cost incurred at the year of power transformer acquisition is given below when the hidden knowledge is not utilized:

$$TC = PC + EC + TC + IC + CC + TrC + OMSC + VIL + PML + CML \quad (6)$$

Similarly, the total operating cost of power transformer is determined by the following equation in case of no utilization of hidden knowledge during operating and maintenance stage:

$$TC = TrC + OC + VIL + PML + CML \quad (7)$$

The knowledge embedded within the documents and experts such as drawings, testing reports, supervisors, etc. can be reused. In addition, it can provide technical knowledge of the power transformer for maintaining its engineering requirements. Hence, the above mentioned knowledge can be utilized within the power utility by constructing the knowledge based system.

4. Knowledge Based System Construction

The knowledge engineering is used to capture, model and utilize the knowledge systematically. CommonKADS (Common Knowledge Acquisition and Design System) is adopted because it supports structured knowledge engineering techniques. Besides, it offers some inference useful templates to create knowledge framework and these templates provide useful guidelines for interviewing, analyzing, modeling and utilizing knowledge [6, 12].The construction of knowledge based system is divided into three levels; organization model (context level), knowledge model and key ontology (concept level) and support tacit knowledge (artefact level). Firstly, the overall tasks associated with the life cycle cost of power transformer, referred to hidden knowledge, are presented in the organization model. Secondly, knowledge model and key ontology diagram are used for conceptualizing on the particular task. Finally, support tacit knowledge diagram explains the problem solving structure of all existing tasks. The knowledge elicitation processes is completed with the use of available knowledge templates shown in Tables 1 to 3 and organization model worksheets. It is represented with knowledge map (K-Map).

In addition, the hidden knowledge presented in the knowledge based system will become obsolete due to the advancement of technologies and practices. Hence, an expert is hired to update and maintain the knowledge based system in every five years in order to practice of obsolescence rate.

4.1. The context level

It includes CommonKADS Organization Model to discover problems and opportunities for knowledge based system. It can be constructed using organization model worksheets. This level provides the scope and crystal view of power transformer hidden knowledge implementation.

4.2. The concept level

This level conceptualizes the hidden knowledge of power transformer. CommonKADS Knowledge Model provides the types and structures of the knowledge used in performing a task in detail.

Table 1. CommonKADS Model Suite.

Model	Composition of Model
Knowledge Model	Task Knowledge (Goal and Sub Goal) Inference Knowledge (Reasoning) Domain Knowledge (Specification)

The key ontology template [15] also describes various sources from which the knowledge is elicited and formalized in terms of ontology.

Table 2. Key Ontology Template.

	Composition of Model
Who	Experts Knowledge Workers Community of Practice Knowledge Portfolio
Document	Manual Book Standards Working Procedures Drawings Control/Protection/Information System Checked Sheets Measuring Point List Cases Updated Information
Information	Link to Database
Abstract	The Short Description of Work

4.3. The artifact level

This last level contains support tacit model. The algorithms and tools required for implementation are included in this level. It describes the structure of the software system needed to implement the knowledge and communication models. The Table 3 [15] depicts the details of support tacit knowledge.

Table 3. Support Tacit Knowledge.

Model	Composition of Model
Support Tacit Knowledge	Precautions/Cautions Advantages/Disadvantages/Alternatives Methods/Strategy to Solve the Problem/Control /Maximize/Minimize/Optimize Condition/Criteria Guideline Techniques/Recommendation /Ensure Requirements/Objectives/Needs Limitations Assumptions Examples

5. Results and Discussion

Nepal Electricity Authority is used for a case study to confirm the applicability and benefits of using the hidden knowledge embedded within one MVA power transformer in the organizational wide context with the use of CommonKADS methodology. The following parameters are used to evaluate the net operating and maintenance cost of power transformer in each year during its life cycle:

Asset price = 200,000 USD;
Operation & Maintenance Cost /year= 2% of Asset Price;
Operation & maintenance expert cost Man-day =3000 USD;
Supervisor cost Man-day = 1000 USD;
Installation duration = 5 days;
Training Duration = 2 days and
Commissioning duration = 2 days

The knowledge elicitation is done by using structured interview with senior operation and maintenance engineers from Grid Operation Department of NEA, Manufacturer and Supplier of power transformer. Moreover, the knowledge is captured from the documents related to the life cycle cost of power transformer. Hence, the knowledge both in tacit and explicit forms are gathered and made more explicit within the power utility. The results are categorized into two subsections: construction and utilization.

5.1. Construction

This section presents the results obtained from the construction of knowledge based model using the CommonKADS model suite. The results show that the hidden knowledge implementation of power transformer consists of organization model worksheets, conceptual level and artefact level diagrams.

Firstly, the context level of power transformer hidden knowledge is shown by constructing CommonKADS Organization Model. It is represented in Tables 4 to 6. Table 4 provides the necessities of hidden knowledge implementation for the organizational context using worksheet OM-1 template. Adopting worksheet OM-2 template, involvement of employees, existing resource and required knowledge for power transformer life cycle management are identified and presented in Table 5.

Table 4. Identifying Knowledge Oriented Problems and Opportunities.

Organization Model	Problems and Opportunities Worksheet OM-1
Problems and Opportunities	• Not fully utilization of PT without the utilization of hidden knowledge. • Unstructured and in tacit form
Organizational Context	• Enable people to utilize the hidden knowledge possessed within the experts. • Provide both technical and financial values from the utilization of hidden knowledge
Solution	• Implement Knowledge Management System to disseminate and fully utilize the hidden knowledge within the organizational context

Table 5. Description of Organizational Aspects Affecting BY KMS.

Organization Model	Variant Aspects Worksheet OM-2
People	• Senior Planning Engineers • Operation & Maintenance Engineers • Technicians
Resource	Power Transformer Data Inventory System
Knowledge	• Planning Knowledge • Engineering Knowledge • Transportation Knowledge • Installation Knowledge • Commissioning Knowledge • Operational and Maintenance Setup • Corrective Maintenance Learning • Preventive Maintenance Learning • Visual Inspection Learning • Training Knowledge

The different tasks or activities involved in each phase of life cycle of power transformer are categorized on the followings aspects using the worksheet OM-3 and OM-4 template shown in Table 6.

- Who perform the tasks?
- Where is the task performed?

- What is the knowledge required to perform the tasks?
- What is the contribution of each task in terms of financial?
- Where is this required knowledge used in?

Table 6. Description of Tasks and Knowledge Components.

Organization Model			Process Breakdown and Knowledge Assets Worksheets OM-3 & OM-4		
Task	Performed By	Where	Knowledge Asset	Significance	Used In
Bidding Preparation	Senior Planning Engineer	Acquisition Stage	Planning Knowledge	0.25% of Asset Price	Relocation of PT & Procuring
Detail Design Drawings	Engineers of Manufacturer	Acquisition Stage	Engineering Knowledge	3.0% of Asset Price	Relocation of PT; Procuring and at the end of FDL
Dispatch & Receiving	Supervisor of Contractor	Acquisition Stage	Transportation Knowledge	10.0% of Asset Price	Relocation of PT & Procuring
Installation & Energizing	Supervisor of Contractor	Acquisition Stage	Installation & Commissioning	5% & 3% of Asset Price	Relocation of PT & Procuring
Operation & Maintenance	O&M Expert	O&M Stage	CML; PML; VIL and O&M SetUp	O&M Expert One-Man day/year for learning and 10 Man-Day for Set Up	Operating the PT
Training of Employee	Trainer of Contractor	O&M Stage	Training Knowledge	About 2% of Asset Price	O&M Stage in every 5 year

Secondly, the concept level diagrams are shown in Figs. 2 to 5. CommonKADS Knowledge model is represented in Figs 2 to 4 providing the relationships among task knowledge, inference knowledge and domain knowledge. Similarly, Fig. 5 shows the key ontology diagram of ratio test of power transformer. Thirdly, Fig. 6 presents the artefact level diagram of ratio test.

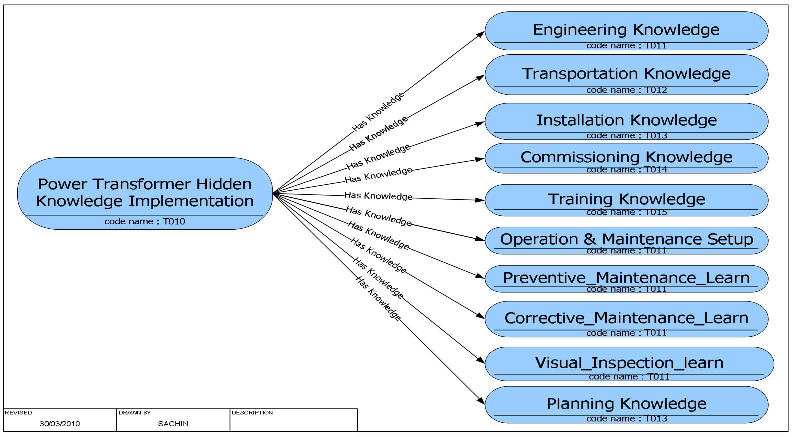

Fig. 2. Task Knowledge Diagram.

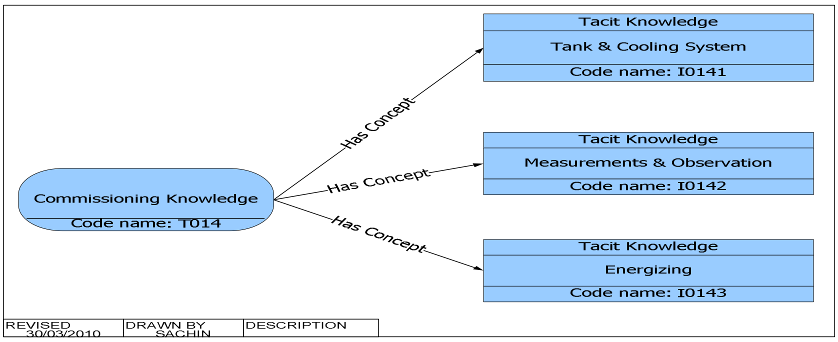

Fig. 3. Inference Knowledge Diagram.

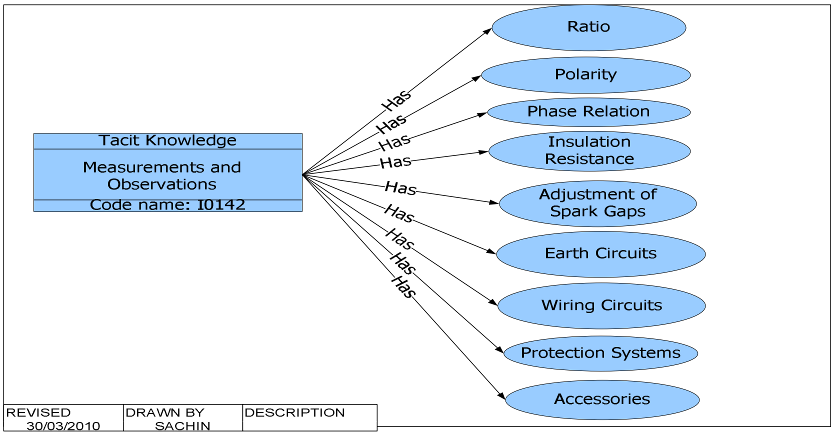

Fig. 4. Domain Knowledge Diagram.

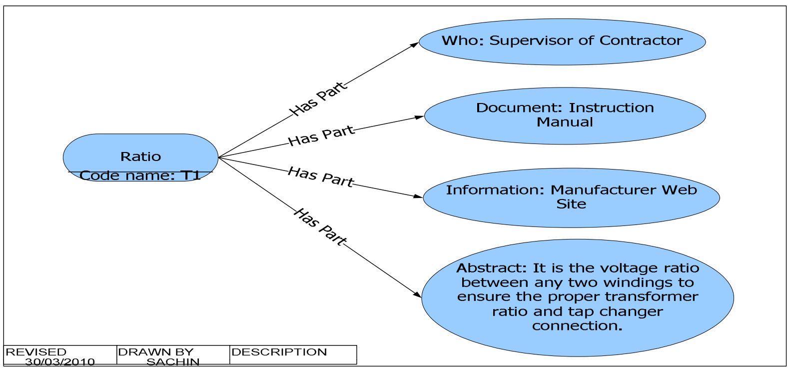

Fig. 5. Key Ontology Diagram.

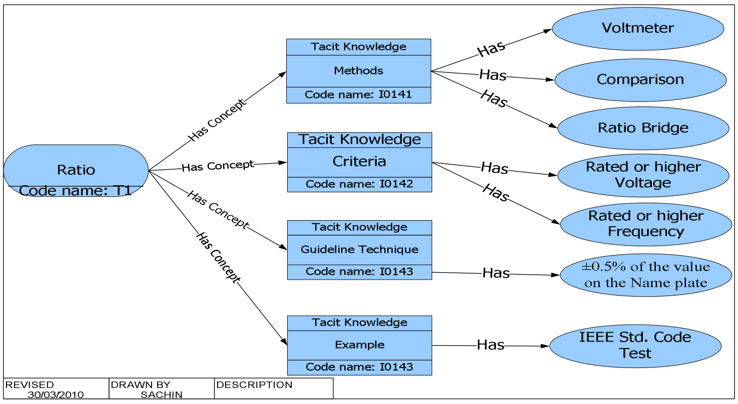

Fig. 6. Support Tacit Knowledge Diagram.

To make utilize of the knowledge framework by constructing the knowledge management system, the captured knowledge models are implemented using Microsoft Share Point [16]. It is selected because it enables people to make better-informed decisions and also connects people information and expertise. The example of hidden knowledge implementation using Microsoft Share Point is shown in Fig. 7. The embedded knowledge is updated and maintained in every five years through hiring an expert for one day.

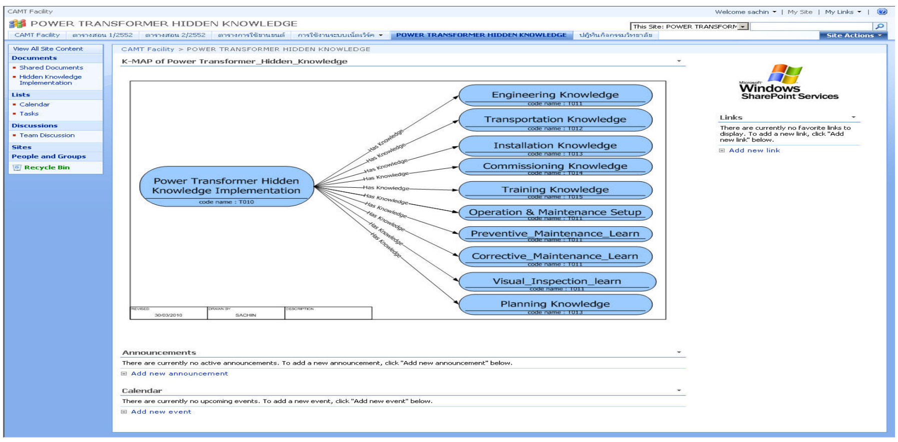

Fig. 7. Implementation in Microsoft Share Point.

The results are verified with the help of expertise of Nepal Electricity Authority and Nepal EKARAT Engineering Co. Pvt. Ltd. The knowledge becomes well structured and more manageable.

5.2. Utilization

The importance of hidden knowledge in terms of financial values is given in this section. Table 7 compares the cost of hidden knowledge in both cases: before and after utilization. In the previous section of Table 6, the contribution of hidden knowledge in its asset price is formulated and is applied to estimate their individual cost in case of its no utilization. When power transformer is reinstalled in another location, the hidden knowledge can be utilized and its individual cost is presented in Table 7. In this case, the transportation cost is about 2 % of its asset price due to the savings in custom charges and freight charges and is achieved from the experience of planning engineers of power utility. With the reuse of design drawings, general layout drawings and testing reports, the total engineering cost can be saved. Similarly, OM set up cost is zero because operation and maintenance set up documents can be reused. The installation, commissioning and training costs can be determined through deducting the total supervisor cost in Eqs. (3) to (5) respectively. During the installation, commissioning and training of power transformer, the total supervisor costs are \$5000, \$2000 and \$2000 respectively. Visual inspection learning, corrective maintenance learning and preventive maintenance learning include only the hiring cost of operation and maintenance expert. So, these learning costs become zero. Finally, the planning cost is also zero due to the savings in the preparation of tender cost.

Table 7. Hidden Knowledge Cost.

S.N.	Hidden Knowledge	Before Utilizing	After Utilizing
1.	Transportation Cost	\$20,000	\$4,000
2.	Engineering Cost	\$6,000	\$0
3.	Installation Cost	\$10,000	\$5000
4.	Commissioning Cost	\$4,000	\$2,000
5.	OM Set up Cost	\$30,000	\$0
6.	Visual Inspection Learning	\$3,000	\$0
7.	Corrective Maintenance Learning	\$3,000	\$0
8.	Preventive Maintenance Learning	\$3,000	\$0
9.	Training	\$2,000	\$0
10.	Planning	\$500	\$0
Total Hidden Knowledge Cost		\$81,500	\$11,000
Net Reusable Hidden Knowledge		\$70,500	
Updating & Maintaining Knowledge Cost		\$15,000	
Net Reusable with Practice Obsolescence Rate		\$55,500	

Moreover, Table 7 shows the importance of utilizing the whole hidden knowledge in terms of financial value (net savings) which is about 35.25% of its asset price. To update and maintain knowledge of power transformer in knowledge based model, it costs about \$15000 since it is required to hire an operation and maintenance expert for five times over its life cycle. Hence with the practice of obsolescence rate, the net reusable hidden knowledge is about 27.75% of its asset price.

Figure 8 illustrates the importance of utilizing the hidden knowledge during its life cycle. The graph is plotted over its financial designed life through the calculation of the total cost during acquisition and operation and maintenance periods with the help of Eqs. (6) and (7) respectively. At the installation year, there is a drastic difference between two cases because the complete hidden knowledge is utilized. Then, the difference is constant throughout the life cycle except in year 18 because utility need to provide training to operation and maintenance personnel in every five years after installation. During operation and maintenance period, the cost difference is not so huge since it can save only visual inspection learning, corrective maintenance learning, preventive maintenance learning and training cost. Thus the net acquisition cost can be sharply decreased by 85.92% with its utilization. It means that the cost of hiring the experts can be saved and other costs do remain the same.

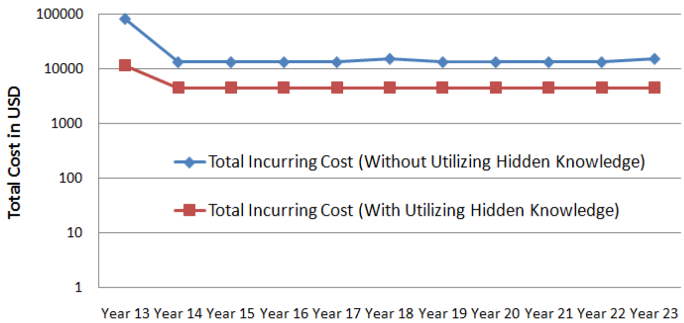

Fig. 8. Utilization of Hidden Knowledge over its Life Cycle in Case of Relocation.

The results are verified with the help of expertise of Nepal Electricity Authority and Nepal EKARAT Engineering Co. Pvt. Ltd. Finally, it is validated with the expertise of Metropolitan Electricity Authority of Thailand. The knowledge becomes well structured and more manageable. The results show that the CommonKADS methodology provides a structure to identify, capture, model and utilize the knowledge involved during the life cycle of power transformer systematically. However, CommonKADS methodology does not provide any confidence level measure metrics during knowledge elicitation process. So, it is quite difficult to justify the accuracy of their estimates. Nevertheless, the estimation is based on their knowledge gained through experience. Moreover, the visual inspection, corrective maintenance, preventive maintenance and engineering knowledge facilitate engineers/or technicians to do better operation of transformer maintaining the technical requirements. Some portion of financial savings can be achieved with the utilization of hidden knowledge in each year and can be used to meet technical requirements.

6. Conclusions

The aim of the knowledge based system is to support utility companies for managing the knowledge they currently possess, and to focus their operations towards knowledge reuse. Knowledge engineering is one approach in the development of knowledge based system. By using the CommonKADS Model Suite, hidden knowledge embedded within power transformer is characterized, modelled, and utilized within the power utility and consequently implemented for sharing and dissemination.

This paper shows that the hidden knowledge of power transformer can be categorized into two stages and each hidden knowledge is explained into three different levels using Knowledge Engineering and Management methodologies. Hence, utility can fully utilize the hidden knowledge, achieving both financial and technical values, to be used during the life cycle decision on power transformer in order to maximize the utilization of power transformer on the network.

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Appendix A

Questionnaire

Organization Name……………………………………………………

Name of the Interviewee………………………………………………

Designation…………………………Years of Experience………………

Part 1: Acquisition Phase

For: Planning Engineers of Power Utility

1. List all the major activities that are performed to acquire new power transformer.

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2. List all the services provided by the supplier that you have included in the bidding documents.

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3. What are the documents and drawings of power transformer that you have received from the supplier during procurement?

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For: Manufacturer/Supplier of Power Transformer

4. What are the factors associated with the total cost of power transformer?

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5. List all the activities that you have done during the acquisition phase of power transformer.

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6. What is the contribution of each factor *(in percentage)* to the total cost of power transformer?

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Part 2: Operation and Maintenance Phase

For: Operation & Maintenance Engineers/Technicians of Power Utility

7. How do you operate and maintain the power transformer on the network?

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8. List all the skills that are required for the operation and maintenance engineers/technicians.

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9. What are the necessary information/knowledge required about the power transformer for better operation and maintenance?

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