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Consideration and Implementation of EHV substation in Metropolitan Area

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SUMMARY

The major consumption of electric power resides in the city center whereas the generation plants situated outside usually closed to the fuel sources. The utility responsible for supplying electricity to urban area thus needs to have an efficient means to deliver such high electric power to the consumers in the area. In order to accommodate such high demand, the extra high voltage (EHV) system is chosen. This is to ensure the stability and higher reliability for the power supply. Moreover, the EHV system can allow the bulk electric power delivery while keeping the power losses to minimum. However, the EHV system requires greater distance in air to insulate the live conductors from the adjacent parts which in turns needs larger land area to accommodate both the transmission lines and substations. It is not possible to acquire such a large plot of land inside the city. So the design and construction of EHV substations in city center require a thorough and systematic consideration in order that the constraints, the utilization of land plot in particular, as well as the criteria governed by the stakeholders can be effectively and efficiently managed.

This paper intends to demonstrate the application of knowledge management (KM) methodology to collect, analyze, identify, archive, and retrieve the knowledge employed in EHV substation design and implementation on one hand. On the other hand, it aims to share experiences of the Metropolitan Electricity Authority (MEA) Thailand in using the KM approach to support the decision making process on the selection of EHV substation design options that best suit the governing criteria. The aspects discussed in the paper comprise: (1) configuration of transmission lines, busbars and transformers, (2) equipment type and specification, (3) equipment layout and cabling route, (4) interface between different equipment, (5) control and protection system, (6) on-site test and diagnostics, (7) transportation and access, (8) construction and installation, (9) noise and visual pollution, (10) safety for utility staff and public walks, (11) fire prevention and extinguishing, (12) electromagnetic interference, and (13) regulatory compliance. The technique of CommonKADS is used to capture the knowledge required for implementing the EHV substation in metropolitan area whilst the multiple criteria decision making technique of analytic hierarchy processes employed for evaluating and selecting the most suitable design choices. The 230kV substation will be used as a reference case for managing knowledge applied for implementing EHV substation in Metropolitan area. Moreover, the techniques will be also applied to support the decision making process for the new 230 kV and 500 kV substation implementation in MEA power system in the future.

KEYWORDS

Extra high voltage, knowledge management, metropolitan area, substation, transmission line

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1. INTRODUCTION

The major consumption of electric power resides in the city center whereas the generation plants situated outside usually closed to the fuel sources. The utility responsible for supplying electricity to urban area thus needs to have an efficient means to deliver such high electric power to the consumers in the area. Previously, the power delivery through the high voltage (HV) transmission lines has been employed successfully without much constraint. However, since the city grows and the demand for electricity constantly increases, the tradition HV system may not be so efficient anymore to serve the purpose. The extra high voltage (EHV) lines are then introduced. This is to ensure the stability and higher reliability for the power supply. Moreover, the EHV system can allow the bulk electric power delivery while keeping the power losses to minimum. However, the EHV system requires greater distance in air to insulate the live conductors from the adjacent parts which in turns needs larger land area to accommodate both the transmission lines and substations. It is not possible to acquire such a large plot of land inside the city. So the design and construction of EHV substations in city center require a thorough and systematic consideration in order that the constraints, the utilization of land plot in particular, as well as the criteria governed by the stakeholders can be effectively and efficiently managed.

Planning and designing substations require engineering expertise and hand-on field experiences to perform the jobs. Such requirements may be difficult to obtain in current utility business conditions. This is due to staff reduction, aging and retiring workforce, overwhelmed workload on existing workforce as well as changes in stakeholder requirement. Substation implementation is a knowledge intensive task. It requires an understanding of both technical matters and regulatory requirements. As the scarcity of skilful and experienced hands exist, the knowledge management (KM) is thus a perfect combination and absolutely critical for implementing the substation, particularly in the urban area where many constraints are involved. KM is used to collect, analyze, identify, archive, and retrieve the knowledge employed in the knowledge intensive tasks. It can ensure effective management of knowledge asset, reuse past experiences, enhance knowledge creation and innovation, as well as support problem solving. KM facilitates employees or utility staff in obtaining the required information they need and at the required time, and thus make them perform their duties effectively.

In the paper, the techniques of KM are introduced. Then the options and criteria for EHV substation implementation are developed using those techniques. The designated options and criteria must be in line with the utility's requirement. Finally, the implementation case of 230 kV substation in Bangkok city center is shown to demonstrate the application of the techniques.

2. KNOWLEDGE MANAGEMENT

Knowledge is the whole body of data and information that people bring to bear to practical use in action, in order to carry out tasks and create new information [1]. It can be categorized as theoretical (concept) and practical (process) knowledge or as verbalized (explicit) and "embedded in head" (tacit) knowledge. Business success depends primarily on how well the organization can utilize these knowledge on real jobs. Although the knowledge already exist in the organization, the elicitation of such knowledge, however, is not a kind of "mining from the expert's head", it requires the systematic approach instead.

KM is a strategy, framework or system designed to help organisations create, capture, analyse, apply, and reuse knowledge to achieve competitive advantage [2]. It is absolutely critical for utility industry to ensure effective management of knowledge asset, reuse past experiences and enhance knowledge creation and innovation. KM in utility company aims to capture and organize knowledge and experience systematically gained from staff and business partners to make the knowledge readily accessible to users and encourage knowledge generation and learning and at last to achieve the organization objectives [3].

Substation design is a kind of synthetic task. It creates artefacts (implementation options) from a set of requirement, e.g. converts specification into equipment and installation layout. In order to develop the implementation options for substation, the KM technique can be employed to gather the ideas, collect the implementation choices from past experiences, formulate the criteria for each choice, analyse and prioritise the implementation choices against the governing criteria, and finally pick up the most preferable choices for implementation.

2.1 CommonKADS Template Knowledge Model [1]

CommonKADS (Knowledge Acquisition Data System) is a complete methodological framework for the development of a knowledge based system (KBS). It supports most aspects of a KBS development project, such as project management, organisational analysis, knowledge acquisition, knowledge analysis and modelling, capture of user requirements, analysis of system integration issues, and knowledge system design. It now becomes the European de facto standard for knowledge analysis and knowledge-intensive system development. CommonKADS provides many useful techniques for analysis and synthesis the knowledge applied for a knowledge intensive task. It facilitates the reuse organisation knowledge by preparing a collection of predefined sets of model elements. Utility engineers are offered with ready-made building blocks and thus prevent them from "reinventing the wheel" each time a new system has to be built. These which comprises (i) the analytical task for dealing with a system that already exists and (ii) the synthetic task which synthesizes a new system.

Design is a synthetic task in which the system to be constructed is some physical artefact. An example design task would be the design of substation. Design tasks convert the requirements into components and subsystems. These may include, for example, single line diagram, main power equipment, and control system. In order for system construction to be feasible, it is generally assumed that all components of the artefacts are predefined. This means they already exist and can be chosen to meet the requirements. CommonKADS already provides the synthetic building block as shown in Figure 1. This building block can help design engineers to obtain the most preferable design choice.

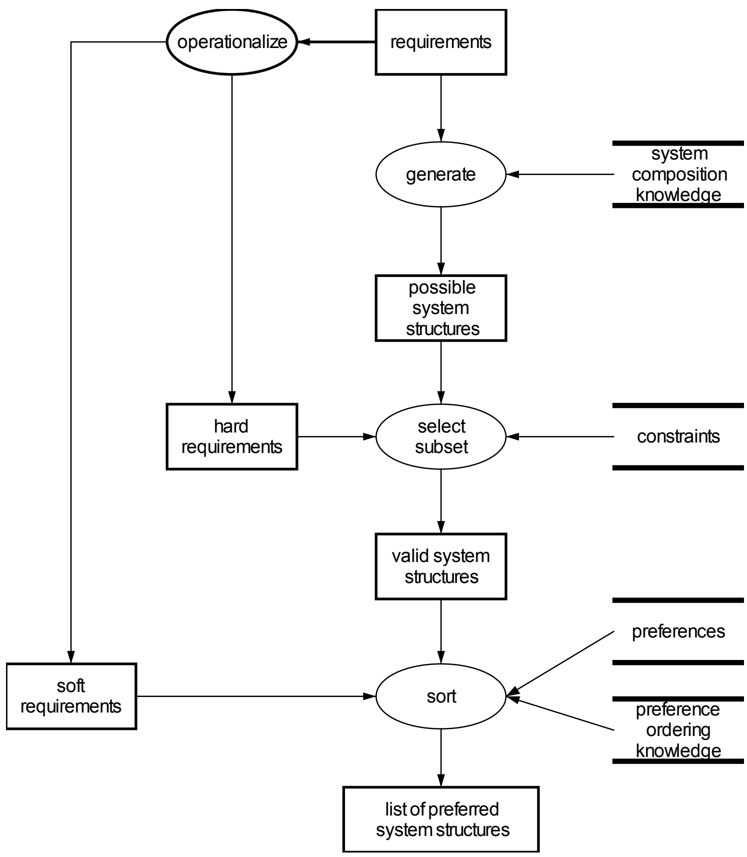

Figure 1. Inference structure of the ideal method for synthetic tasks [1]

Figure 1 above shows the specification of the idealized method for synthetic tasks which consists of 4 steps:

1. *Operationalize requirements*: Analyses and transforms the requirement into an operational representation which comprise “hard” and “soft” requirements as well as governing criteria.
2. *Generate possible system structures*: Generates a set of possible design choices based on the prior knowledge or past experiences whilst they must also satisfy the requirement.
3. *Select valid system structures*: Analyses if those choices are feasible and select the valid for implementing.
4. *Sort systems in preference order*: Sort the choice that complies the preferable criteria most.

2.2 Analytic Hierarchy Process (AHP)

AHP is an approach to decision making that involves structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives [4]. The output is a ranking which is prioritized indicating the overall preference for each of the alternatives. The AHP may be implemented in three simple consecutive steps [5]: computing the vector of objective weights, computing the matrix of option scores, and ranking the options. In addition, during formulating the matrix, the consistency check needs to be performed in order to guarantee that the comparison between each pair is made in a consistent manner.

The prime idea of AHP is to convert the qualitative nature of the degree of importance into the quantitative measurement. This can be obtained by firstly performing the pairwise comparison between two alternatives for each criterion. Then, performing the pairwise comparison between two criteria for all of them. After that, calculating the overall priority for each alternative by summing together the products of the criterion priority times the priority of its decision alternative. Finally, ranking of the alternatives according to the numerical scale. Table 1 below shows the numerical ratings recommended for verbal preferences expressed by decision maker.

Table 1: The pairwise combination scale [4]

Numerical Scale	Verbal Importance	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Slightly favour one over another
5	Essential or strong importance	Strongly favour one over another
7	Demonstrated importance	Dominance of the demonstrated in practice
9	Extreme importance	Evidence favouring one over another of highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

2.3 Knowledge Elicitation

There are a numbers of techniques that can be employed for capturing knowledge from experts and modelled for later uses. But the interview and after action review are two main techniques involved with MEA EHV substation implementation task. The techniques can be explained as follows.

2.3.1 After Action Review (AAR)

AAR is a structured review or debrief process for analysing what happened, why it happened, and how it can be done better by the participants and those responsible for the project or event [6]. The technique is really useful to capture lessons learned from past successes and failures, aiming to improve the future performance of the organization. It is conducted during or immediately after each event. For example, after a main transformer failure due to the through fault, experts from related departments are invited to participate in the discussion. At the meeting, after summarizing the events (what happened), the discussion then carrying on to identify the key issues (why it happened), determining the strengths and weaknesses, and suggesting the means to make them better (how to improve). Report that collects those critical elements is finally produced and archived for lesson learned and necessary actions.

2.3.2 Interview

The interview is the most commonly used technique employed for knowledge acquisition. It can ranges from informal, to semi-structured, and to formally planned, structured interview. Interview can be conveniently conducted any time anywhere, during job planning and review at office, job execution at site, or even in the car struck in the traffic during rush hour. However, if the focus is not clear of what to capture, or the expert is not so well in verbalizing of what he has had experienced or currently possesses, the interview may lead to inefficiency. The technique that can be applied to avoid those obstacles, for the knowledge engineers, is to prepare a set of questions suitable to extract all necessary information. A set of probing questions suggested by [1] as shown in Table 2 also offers a good tactical means to work out with the jointers.

Table 2: Probes to elicit further information in interviews

Question Template	Effect
Why would you do that?	Converts an assertion into a rule
How would you do that?	Generates lower-order rules
When would you do that? Is <the rule> always the case?	Reveals the generality of the rule and may generate other rules
What alternatives to <the prescribed action/ decision> are there?	Generates more rules
What if it were not the case that <currently true condition>?	Generates rules for when current condition does not apply
Can you tell me more about <any subject already mentioned>?	Used to generate further dialogue if expert dries up

3. FALICITATING THE CONSIDERATION AND IMPLEMENTATION OF EHV SUBSTATION IN METROPOLITAN AREA USING KM

The requirements for implementing the EHV substation in the metropolitan area primarily emphasize on the system reliability, people safety, harmony to local environment and easy access to all substation components. MEA then employed the knowledge elicitation techniques in conjunction with the CommonKADS and the AHP to digest the requirements; capture the governing criteria; develop the implementation options and finally assign the preferences. Below illustrates the critical criteria and the preferable options that MEA nurture for EHV substation implementation.

3.1 Configuration of transmission lines, busbars and transformers

Criteria:	Options:
– N-1 for transmission lines and transformers – Minimum fault current – Minimum cost – Fast automatic transfer between lines and transformers	– Single busbar – Double busbar (single breaker) – Double busbar (double breakers) – One-and-a-half breaker

3.2 Equipment type and specification

Criteria:	Options:
– Indoor installation – Minimal space required – Low maintenance	– Gas insulated switchgear – Hybrid gas insulated switchgear – Oil immersed transformer – Gas insulated transformer

3.3 Equipment layout and cabling route

Criteria:	**Options:**
– Easy access – Minimal floor loading – Minimum length of cables	– Multi-storey installations – High underground cables

3.4 Interface between different equipment

Criteria:	**Options:**
– Cable connections between switchgears and transformers	– Air bushing and cable terminator for GIS – Air bushing for transformers

3.5 Control and protection system

Criteria:	**Options:**
– Numerical protection – Interoperability	– IEC 61850 substation automation – Computerised substation control system

3.6 On-site test and diagnostics

Criteria:	**Options:**
– Commissioning test – Online condition monitoring	– High voltage withstand test – Diagnostic tests – Gas/oil quality

3.7 Transportation and access

Criteria:	**Options:**
– Easy access – Minimum loading area and lifting capacity	– Overhead crane in loading shaft

3.8 Construction and installation

Criteria:	**Options:**
– Total quality control – Pass all required tests	– Qualified contractors – Stringent test methods

3.9 Noise and visual pollution

Criteria:	**Options:**
– Low noise – Environmental friendly	– Indoor completely seal building – Building design in harmony with surrounding

3.10 Safety for utility staff and public walks

Criteria:	**Options:**
– Free from electrical and fire hazards	– Minimum oil-filled equipment – High reliability equipment – Safe step and touch voltage grounding system

3.11 Fire prevention and extinguishing

Criteria:	Options:
– Fire confinement – Automatic fire extinguishing	– Fire barrier and flame retardant – Water and CO_2 extinguisher

3.12 Electromagnetic interference (EMI)

Criteria:	Options:
– No EMI impact to either inside and adjacent electronic devices	– Room and building shielded

3.13 Regulatory compliance

Criteria:	Options:
– Compliance to all local and international codes	– Building constructed in accordance with local codes – Equipment specified in accordance with international standards

4. CASE STUDY

The Chidlom Terminal Station is located at the central business area of Bangkok, the capital city of Thailand. It is intended to ship bulk power from EHV transmission rings located at the outskirt of the city and then distribute those power to large business loads in the city center. There are 3 voltage levels employed in substation. They include 230 kV, 69 kV and 24 kV respectively. 230 kV is used to ship a large volume of power, whereas 69 kV is intended to convey those power to main distribution substation. 24 kV is applied for distributing medium voltage energy to the customer locations.

With the facilitation of the KM and multicriteria decision making techniques as discussed in the above sections, MEA then reaches the best possible solutions for implementing the EHV substation in metropolitan area. Below explain some highlighted characteristics of Chidlom Terminal.

4.1 Substation Configuration

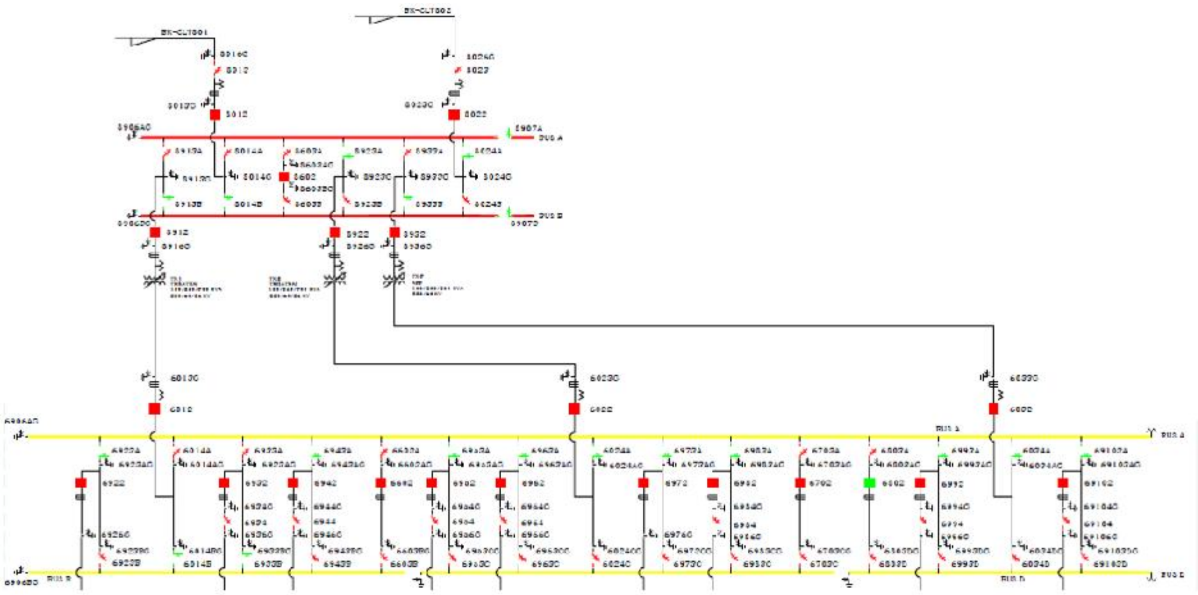

Figure 2 Single line diagram for 230 kV and 69 kV of Chidlom substation

MEA has designated the N-1 reliability criteria for configuring the transmission lines and power transformers in Chidlom Terminal. Automatic transfer function is also employed to perform a fast switch-over from the faulty part to the healthy section. The utilization of each line or transformer is kept under a certain level in order to maintain the reliability target. Single line diagram of Chidlom is shown in Figure 2.

It can be seen from the diagram that the lower bus of 69 kV was split into three sections. Each transformer will operate singly without units paralleling. This is to limit the fault level.

4.2 Main Equipment for Substation

In order to ease the power shipment, the 230 kV cables were installed to link from Bagnkapi Terminal Station which located at EHV transmission ring at the eastern area of Bangkok to Chidlom Terminal. Tunnel was built to accommodate two circuit of theses cables. The design was made with oil-filled type of cables due to its capability for self-healing against the certain degree of imperfections as well as the

The indoor type SF_6 GIS is selected to EHV switchgear. Although operated at 230 kV but the switchgear is specified at 245 kV rating. This is to ensure the maximum insulation level.

The transformers are oil-immersed type to obtain the minimum costs and simplicity of installation and maintenance. But they are installed in the fire confinement vault. Furthermore, the fire detection and automatic fire extinguishing system are well provided.

4.3 Control and Protection System

Chidlom Terminal was the first substation in the region that employed the IEC 61850 protocol for substation control and protection. This not only allows MEA to obtain the benefit of component interoperability, cable reduction, programmable control, etc., but also provide MEA with wide range of opportunity to select the IED products in case of system expansion, upgrade or even replacement. However, the protocol is applied on station bus only. MEA still hesitates to use this protocol for process level due to the technology for that level still requires firm evidences on its application.

4.4 Other Highlighted Aspects

Figure 3 below depicts the arrangement and connections between main equipment in substation. Mostly, the connections are made via the high voltage power cables. Only the connection between 230 kV GIS and transformers is made via bare conductor. This bare conductor is simply jumped across air bushings of GIS and transformer. This design will ease the replacement of failed transformer with new one can be easily made. No specific skill or special design is required to make a connection.

Every room is designed to confine fire in its place within two hours. Fire barrier are placed at openings between rooms. The doors of each equipment room are of fire-proof and can hold fire for 2 hours. In addition, the linked cables, either power or control cables, are designed as flame retardant. This can confine the fire that breaks out within one particular room; prevent them from spreading to the adjacent rooms.

Ground mesh is formed on every floor where the discharge of fault current to the earth can lead to the dangerous step voltage. Substation fence, gate and any metallic body that exposed to external contacts are completely grounded.

Every power system component, e.g. switchgears, transformers, cables, etc. is installed and completely concealed inside the substation building. The building also serves as an office building for the power system control department. So its appearance looks like a modern office building. It very well harmonizes into the surroundings. All the connections to the outside are made via underground cables. People who live nearby never realize there is a very large power station situated

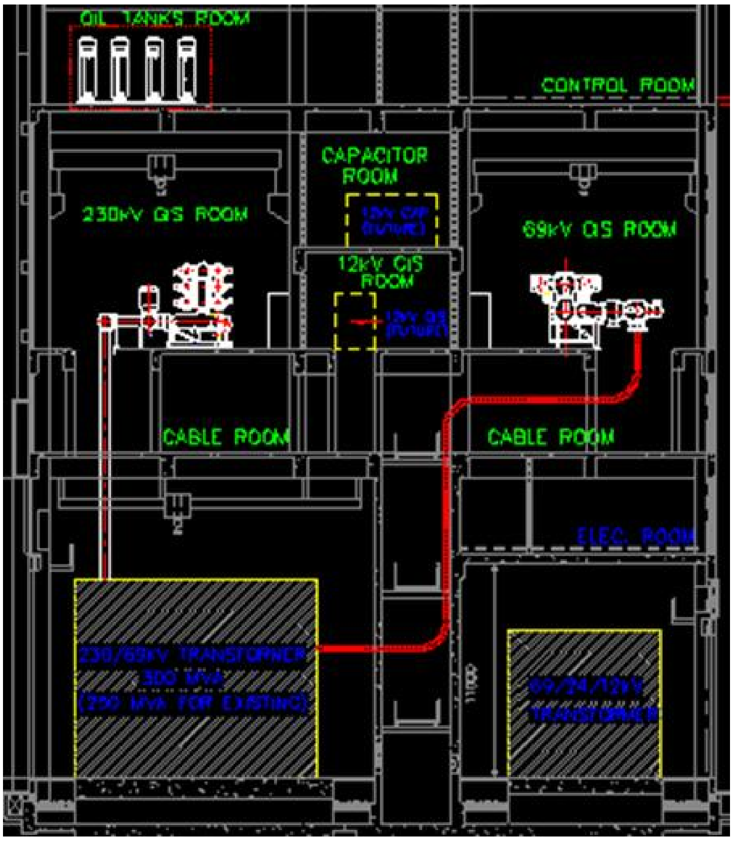

Figure 3. Arrangement of main equipment and connections between them

5. CONCLUSION

The implementation of EHV substation in the metropolitan area requires a comprehensive consideration and judgement. The impact of its implementation is very high. Not only has the impact posed on the power system reliability, but also the wellbeing of the neighbours. Lessons learned from previous operations are certainly of high values to the new project. KM hence becomes a powerful methodology to collect those lessons and later apply to the new job. This paper has demonstrated the applicability of KM for EHV substation consideration and implementation. The techniques and lessons learned can be applied to support the decision making process for implementing the new 230 kV and 500 kV substation implementation in MEA power system in the future.

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