2013 UKSim 15th International Conference on Computer Modelling and Simulation

A Malaysian Case Study on the Transmission Expansion/Investment Using Value-Based Approach

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***Abstract*—The introduction of Incentive Based Regulation as the tariff framework in Malaysia's Electricity Supply Industry calls for efficiency in the creation of a new asset while meeting the required reliability. In line with the new regulatory framework, Tenaga Nasional Berhad took the opportunity to enhance its planning methods and approaches by adopting value-based approach to achieve optimum total cost of ownership. This paper presents an actual case study of detailed analysis on the connection schemes and substation configuration for a newly proposed 275/132kV substation. The outcome of the study results in a significant cost saving as compared to traditional approach.**

Keywords*—*asset management; incentive based regulation; life cycle cost; value-based approach; reliability

I. INTRODUCTION

System Planning Department of Tenaga Nasional Berhad (TNB), through its 20-Years Transmission Development Plan has identified the need for a new injection in Terengganu by year 2017. Terengganu is one of the states in the Peninsula Malaysia's northeast. The existing 132kV network, which is made up of predominantly low capacity conductor, will become a constraint by year 2017.

A feasibility study conducted earlier has identified the best long term reinforcement option. The study has recommended the best site to build a 275/132kV substation and its associated transmission route. The feasibility study served as an input to this case study. In broad, this case study explores possible connection schemes and substation configuration and recommends the best configuration for implementation by adopting value-based approach to achieve optimum total cost of ownership.

II. OBJECTIVE

The intent of this case study is to identify plausible system connection schemes and configuration for Kuala Terengganu substation (KTGU) in 2017. The study would assess and identify all possible options for system connection from the 275kV grid system to KTGU. The study would also look at various busbar configurations for KTGU and recommend the most optimal solution for the substation design. The performance and compliance of each transmission development options are benchmarked against the Malaysian Grid Code (MGC)[1] and the Transmission System Reliability Standard (TSRS)[2].

III. MOTIVATION FOR CHANGE

Traditionally, utilities have employed a single-contingency (N-1) deterministic criterion to plan their transmission system augmentation[3]. Invariably, the transmission network was planned and built with enough spare capacity to withstand sudden failure of any component during system peak conditions without voltage violations or thermal overloads. However, the basic flaw of deterministic criterion, nevertheless, is that it does not react to the probabilistic nature of the power system behavior such as failures of a system component and load changes[4].

One of the major challenges to electric utilities is to provide competitive rates for customers through operation, maintenance, and construction costs optimization whilst increasing the market value of the services they provide with the right amount of reliability[5]. One of the common set of objectives in regulatory oversight is that, in order to meet future demands at the lowest reasonable cost, utilities should make efficient "investments in innovation"[6]. Given this regulatory environment and these demands, it is imperative for utilities to find means to reduce costs whilst still provide its customers the required reliability.

TNB's Physical Asset Management Policy and Strategy ensures the asset management activities and practices are conducted in a systematic and transparent manner by effectively managing the assets performance, whilst balancing their associated risks and life cycle cost, as well as taking into account stakeholders' requirements[7]. Malaysian Electricity Supply Industry's (MESI) business landscape is also changing with the introduction of Incentive Based Regulation (IBR), and an increased customers' expectation for safe, secure and reliable electricity. Central to the idea of IBR is to establish the appropriate rate of return for a utility company such as TNB, as these companies are not meant to make excessive profits[8].

For any power system supplying a specific mix of customers, however, there is an optimum value of reliability that would result in the lowest combined costs. Thus, in line with the new regulatory framework, Tenaga Nasional Berhad took the opportunity to enhance its planning methods and approaches by adopting value-based approach in order to achieve optimum total cost of ownership.

978-0-7695-4994-1/13 $26.00 © 2013 IEEE
DOI 10.1109/UKSim.2013.45

IV. APPROACH & METHODOLOGY

A. General Approach

When discussing total cost of ownership, the Publicly Available Specification of the British Standards Institution BSI PAS 55-2:2008, defines the Total Cost of Ownership as "the lowest combination of life cycle cost, risk, performance or service losses and other negative effects on business goals (such as damage to reputation or sustainability)"[9]. This virtue is also in harmony with one of the key objectives in Khazanah Nasional's Government Link Companies (GLC) Transformation Program 2005/6 Initiative 6 Guidelines (The Red Book), which is to "minimize Total Cost of Ownership"[10]. Khazanah Nasional Berhad is the Malaysia's state owned strategic investment fund.

As one of the key fundamentals of TNB's Physical Asset Management Policy and Strategy, the value-based planning process attempts to establish a balance between the costs of improving service reliability for various types of customers, and the benefits or value that these improvements bring to these customers[3]. The balance is achieved by trying to minimize the total cost, as in

$$\text{Total Cost} = \text{Utility Costs} + \text{Customer Outage Cost} \quad (1)$$

Utility costs consist of capital cost, operation and maintenance (O&M), losses, etc., whilst customer outage costs represent the costs due to unreliability.

B. Methodology

The study was divided into four parts – Qualitative, Deterministic, Probabilistic and Economic. Each part is summarized in these four major steps:

1) Part I: Part I employs Qualitative Analysis in selecting the sites for substation KTGU and the associated transmission line route. The study specifically looks into factors such as space requirements, site and way leave availability, environmental and societal impacts and project implementation risks.

2) Part II: Deterministic Analysis is a study on system connection scheme which utilizes PSS/E software. The analyses include steady state analysis, calculation of system losses, 3-phase short circuit assessment and transient stability analysis. Only the options that pass all these four criteria will be considered in the subsequent part and be used in generating options for the substation configurations.

3) Part III: Part III employs Probabilistic Assessment to analyze the options in terms of the reliability of the connection scheme coupled with different busbar arrangement. The reliability of a power system can be studied in depth using probability and statistical analyses with digital computer programs. General Reliability's software, namely TRANSREL and SUBREL modules, is employed to analyze the options in terms of the reliability of the connection scheme coupled with different busbar arrangement. A reliability index is the probability that equipment will function without failure over a specified period of time. This probability is significantly influenced by equipment failure rates and maintenance requirements[11]. The reliability indices will be factored in the calculation of Life Cycle Cost (LCC) in the subsequent analysis.

4) Part IV: Finally, Part IV looks into the economic aspect of the project or the LCC. The LCC of each option is calculated. A sensitivity analysis, a useful technique in selecting a robust option, is performed to study the impact of certain parameters on the Present Value (PV) of each option. The options are then ranked based on the least incremental cost of the PV incurred.

V. PART II – DETERMINISTIC ANALYSIS

Part I, selection of site and line routing for substation KTGU which employs Qualitative Assessment was conducted in a separate feasibility study.

In Part II, the system study first assessed the basic steady state requirement of the TSRS which are thermal and voltage limits. The system under each connection scheme should not violate these limits under normal and contingency condition. Next, the transmission losses incurred, in terms of MW and MVAr, are calculated and factored in the life-cycle cost.

The next step is the fault level analysis of each substation in the area under study. As per TSRS, the fault level at any substation should not exceed the three-phase short circuit rating of the circuit breaker. The fault level is calculated using IEC standard[12].

In the final step of the system study, each connection scheme is assessed in terms of its performance in Transient Stability. In this section, the system is subjected to the faults as described in Category B (3-phase fault with normal clearing), Category D (3-Phase Fault with Delayed Clearing e.g. Stuck Breaker or Protection System Failure) and beyond Category C and D (Delayed Clearing up to 1000 milliseconds on Backup Zone 3 Distance Relay) of the TSRS.

A. Grid Connection Schemes Options

Six options were considered for the grid connection scheme. These options are:

- Option A: Single Circuit Loop In-Loop Out (LILO) on circuit no. 1
- Option B: Single Circuit LILO on circuit no. 2
- Option C: Double Circuit LILO
- Option D: Double Tee-Off Connection
- Option E1: Connection via a Compact Switching Station.
- Option E2: Connection via a Conventional Switching Station.

The general layout of a compact switching station as per Option E1 is shown in Fig. 1. This ingeniously designed compact switching substation, is simple yet offers a comparable reliability level with the typical standard double busbar scheme. It is envisaged that this new design requires smaller foot-print, thus smaller land area, and may be accommodated within the transmission line reserve.

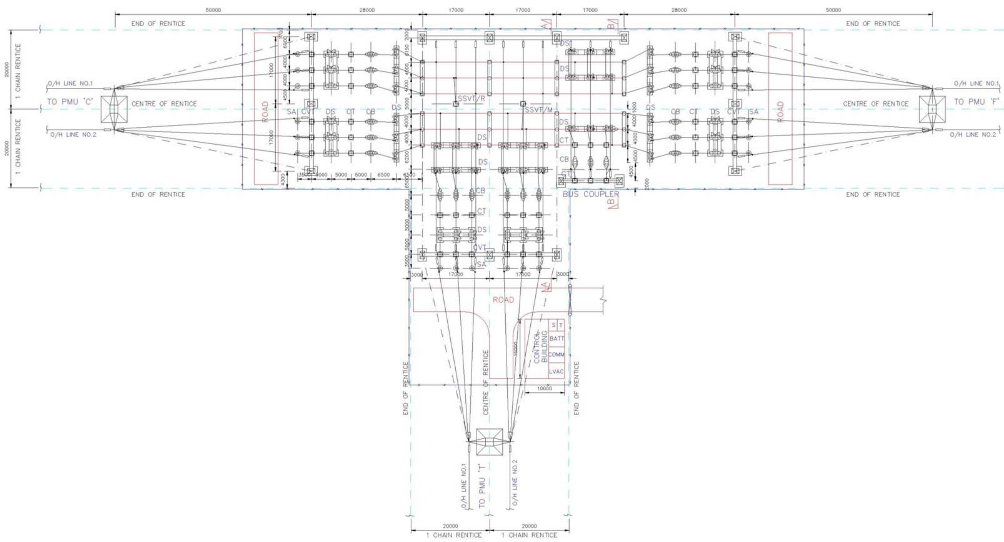

Fig. 1. General Layout of a Compact Switching Station

B. Results and Discussion

Under steady state (N-1) contingency criteria, all schemes show no violation. Under (N-2) all schemes record some voltage violations and thermal overload. The Planning Criteria however do not require (N-2) contingencies to be met and only serves as comparisons between options. The fault level for all is within the allowable limits. In terms of system losses, all schemes indicate a positive incremental saving. Therefore, in conclusion, all schemes pass the steady state requirement.

Assessment of Transient Stability indicates that all schemes are stable when subject to faults under Category B, D and beyond category C and D. The damping ratio for option Double LILO and Double Tee are slightly below the allowable limit; nevertheless, system remains stable throughout the simulation period.

Based on the result, the Switching Station scheme offers the most robust system performance while Double Tee is the least robust scheme. All schemes pass the transient stability requirement and will be evaluated in the next assessment.

VI. PART III – PROBABILISTIC ANALYSIS

In a bulk power system, reliability is defined as the "degree to which the performance of the elements of that system results in power being delivered to consumers within accepted standards and in the amount desired"[13]. The degree of reliability may be measured by the frequency, duration and magnitude of adverse effects on consumer service[14].

Part III of this study focuses on the reliability of the substation designs coupled with different connection scheme for substation KTGU. In this section, four substation designs, namely single busbar, double busbar, one and a half breaker and ring arrangement, were considered. For the switching station, an additional of Transformer Feeder Scheme is also studied. These designs are permutated with various connection options to produce the most reliable scheme for KTGU and its associated transmission connection. The reliability software SUBREL and TRANSREL are used to compute the reliability indices.

A. Approach and Methodology

The first step in reliability analysis is to create a detailed modeling of the substation in SUBREL, whereby the busbar, bus sections, breakers and switches are explicitly modeled instead of a single node representation. Each of these components has its own statistical data such as failure rate, repair time, maintenance rate, isolation time and stuck probability. The SUBREL file would be called in TRANSREL to study the impact of station related outages on system reliability.

TRANSREL would calculate the reliability indices for an electric utility transmission and station switchyard using contingency enumeration approach. This approach involves classification of each contingency according to specified failure criteria, selection and evaluation of contingencies, and computation of reliability indices[15]. This reliability indices include frequency, duration and severity. Failure events include overloads, voltage violations, load and energy curtailments. Both system and bus indices are calculated.

The information obtained from TRANSREL will help in identifying high probability/impact scenarios, equipment that causes critical situations and facilities that are most violated.

B. Dimensioning Criteria

The reliability performance of each scheme is measured in terms of System Disturbance Severity Index and the Expected Energy Not Served (EENS). The EENS expressed in kWhr/year is calculated based on the following formula:

$$EENS = (LA - CR) * PF * CPI * CD * PDF * 1000 \quad (2)$$

Where LA is the transmission line loading under contingencies, in MVA; CR is the transmission line capacity, in MVA; PF is the power factor to convert MVA to MW. Value of 0.9 is assumed to be the PF; CPI, Contingency Probability Index is the number of times the contingency occurs in one year at a load level; CD, Contingency Duration is the number of hours the contingency occurs at a load level; and PDF is the Probability Distribution Function.

The indices are calculated for each load flow scenario. Each run calculates indices at a specified load level, given by a load PDF, and are valid only for that particular sampled load level. In this case, the load level used throughout the analysis is the peak load.

Another index calculated in this analysis is the System Disturbance Severity, also known by System Minutes (SM) index. SM is the ratio of EENS index (MWh x 60 minutes), and the annual system peak (MW)[16].

$$SM = (EENS*60) / \text{System Peak} \quad (3)$$

The following contingencies were applied to calculate the amount of overload on the line and transformers:

- (N-1) and (N-2) for 275kV & 132kV network, and
- (N-1-1-stuck) for busbar elements

C. Main Assumptions

As a prerequisite to computing reliability indices, two sets of statistical data are required, namely the substation component data and the transmission line outage data. The forced outage data is extracted from the Centralized Tripping Information System (CTIS) database while the maintenance data is obtained from the Integrated Commissioning and Outage Management System (iCOMS) database, both from the TNB's Transmission Division.

For substation component reliability data, TNB has yet to have a statistically sufficient database and currently in the process of compilation. In the absence of TNB's own data, data from an accessible source were used.

One of the most widely used reliability data was published by CIGRE. CIGRE Working Group 13.06 had conducted two worldwide reliability surveys of the reliability of high-voltage circuit breakers 63kV and above[16]. In addition to this, CIGRE Working Group 12.05 (WG12.05) published a report summarizing the results of their analysis of transformers up to 20 years of age that failed in the period 1968 to 1978[17]. The report on WG12.05's analysis, in which 13 countries from 3 different continents participated, was published in 1983. CIGRE has recently commissioned another round of survey but has yet to publish results. Not withstanding that, the 1983 survey is still regarded as the sole accessible international survey on transformer reliability.

D. Options Considered

There are twenty six (26) substation configurations analyzed in SUBREL. The options are listed in Table I.

TABLE I. OPTIONS FOR SUBSTATION CONFIGURATIONS

System Connectivity		Substation Configuration
Option A Single Circuit Looping In/Out from Line 1		Ai : Single Busbar with Bus-Section
		Aii : Double Busbar with Bus-Coupler
		Aiii:One-and-Half Breaker Scheme
		Aiv:Ring Bus
Option B Single Circuit Looping In/Out from Line 2		Bi : Single Busbar with Bus-Section
		Bii : Double Busbar with Bus-Coupler
		Biii: One-and-Half Breaker Scheme
		Biv: Ring Bus
Option C Double Circuit Looping In/Out		Ci :Single Busbar with Bus-Section
		Cii :Double Busbar with Bus-Coupler
		Ciii:One-and-Half Breaker Scheme
		Civ:Ring Bus
Option D Double Tee-Off Connection		Di:Single Busbar with Bus-Section
		Dii:Double Busbar with Bus-Coupler
		Diii:One-and-Half Breaker Scheme
		Div:Ring Bus
Option E Switching Station	Option E1 Compact Substation Configuration	E1iTx:Transformer Feeder Scheme
		E1i:Single Busbar with Bus-Section
		E1ii: Double Busbar with Bus-Coupler
		E1iii:One-and-Half Breaker Scheme
		E1iv:Ring Bus
	Option E2 Double Busbar with Bus-Coupler	E2iTx: Transformer Feeder Scheme
		E2i:Single Busbar with Bus-Section
		E2ii:Double Busbar with Bus-Coupler
		E2iii:One-and-Half Breaker Scheme
		E2iv: Ring Bus

For substation configuration under Option E, the transformer feeder scheme offers a cheaper alternative in comparisons with conventional fully switched outdoor and indoor arrangement. The scheme consists of 275/132kV transformers and transformer breakers. The cost saving is resulted from less equipments, less initial civil works and reduced maintenance and spares holding requirement. The reliability level of this scheme is comparable to those of single busbar with bus section scheme[18]. The transformer feeder scheme can be designed to offer future expandability. The scheme can later be converted to a fully switched substation provided that sufficient clearances and land have been allocated in the initial design stage.

E. Results & Discussion

The results of the calculated SM and the EENS in kWh/year and the incremental of each index are tabulated in Table II.

Compared to the base-case or do-nothing option, at PDF of 0.0999316, Option A, B, E1 and E2 indicate a negative incremental System Minutes and EENS, which means reduction in the expected energy loss. This implies that these options result in an increased reliability as compared to the do-nothing option.

TABLE II. RELIABILITY ANALYSIS RESULTS

Option	System Disturbance Severity Index or System Minutes		Expected Energy Not Served (EENS)	
	Minutes	ΔMinutes	kWh	ΔkWh
Base Case	5.17	N/A	1620049	N/A
Opt Ai -Aiv	4.96	-0.21	1,552,917	-67,132
Opt Bi -Biv	4.97	-0.20	1,556,218	-63,830
Opt Ci -Civ	5.34	0.17	1,673,391	53,342
Opt Di -Div	8.55	3.38	2,677,302	1,057,253
Opt E1i- E1iv	4.66	-0.52	1,458,118	-161,930
Opt E1i Tx	4.66	-0.52	1,458,781	-161,268
Opt E2i- E2iv	4.66	-0.52	1,458,010	-162,039
Opt E2i Tx	4.66	-0.52	1,458,781	-161,268

On the contrary, Option C and D record a higher System Minutes and EENS than the do-nothing option. This means that these options will result in a less reliable system if implemented. The result is somewhat expected because Option C is a Double LILO configuration. The longer line length means higher exposure to line failure. As for Option D, the Double Tee configuration requires the whole stretch to be out of service during forced or maintenance outage and therefore decreases the reliability level of the configuration.

F. Summary

The impact on SM and EENS were significant in determining the best recommended option for substation KTGU project. The PV of each option will vary significantly at different value of PDF, thus changing the ranking of the options. In a later section, as a sensitivity analysis, the value of PDF will be varied to study the impact of this parameter on the overall project cost.

VII. PART IV – ECONOMIC ANALYSIS

Life Cycle Cost (LCC) Analysis refers to total cost of ownership over the life of an asset. The cost considered includes the capital cost, operation and maintenance (O&M), cost due to losses and outage cost. The options were ranked using Present Value (PV) of the total costs.

Initially, the value of PV of each option is calculated based on certain assumptions of some important parameters. A sensitivity analysis of these parameters is done to study their impact on the overall cost of each proposed scheme. These two parameters are Value of Loss of Load (VoLL) and load Probability Distribution Function (PDF).

The Economic Analysis result is listed in Table III. The result is categorized into three selection criteria, namely, based on capital cost (CAPEX) only, LCC with O&M, and the LCC with O&M and System and Station Reliability factored in. The options are ranked based on the lowest PV of each category.

A. Sensitivity Analysis

Life Cycle Cost of a project can vary significantly with the VoLL. The VoLL is the aggregated or average value of outage costs across the whole array of customers in a given power system. The VoLL is an important indicator for risk assessment in power system operation or for utilities to make the right decision when it embarks on any form of asset expansion. A research done by TNB Research Sendirian Berhad (TNBR) and Universiti Tenaga Nasional's Power Engineering Centre (UNITEN PEC) in September 2008 concluded that the VoLL for the MESI is RM10.47/kWh interrupted[19]. For sensitivity study, the VoLL is varied from RM0.3354/kWh to RM10.47/kWh.

The load PDF indicates the amount of time the peak load occurs in a day. A load PDF of 0.0999316 implies that the peak load is only occurring about 2.4 hours per day. A higher PDF implies longer exposure time to peak load. The demand is projected to increase every year. Therefore, each year should have its own load duration curve with its associated PDF. Thus, sensitivity analysis should be conducted to study the impact of the growing load on the chosen scheme. By varying the load PDF from the base value of 0.3354 to 0.5, one can emulate the impact of the annual load demand increase on the connection scheme.

1) PV vs. Load PDF: A sensitivity of PV vs. load PDF indicates that except for Option D, the PV of each option is insensitive to the increasing PDF. The ranking of the lowest PV does not change much. The cheapest option is Option Ai – LILO A with Single Busbar with Bus Section scheme. This sensitivity is done at VoLL equals to RM0.3354/kWh.

2) PV vs. VoLL: By varying the VoLL from RM0.3354/kWh to RM10.47/kWh with PDF fixed at 0.5, the value of PV changes significantly. In the beginning, Option Ai – LILO A with Single Busbar with Bus Section scheme is the cheapest option. However, at VoLL approximately greater that RM3.5/kWh, Option E1iTx becomes the cheapest option, and the most attractive.

3) PV vs. VoLL and Load PDF: In the preceding section, the value of VoLL and PDF were varied independently against the PV. For more accurate result, here both VoLL and PDF were varied simultaneously using a 3-dimensional analysis. Based on the sensitivity analyses, two options with the lowest PV were chosen, i.e. Option Ai and Option E1iTx. The simulation results are plotted in Fig. 2.

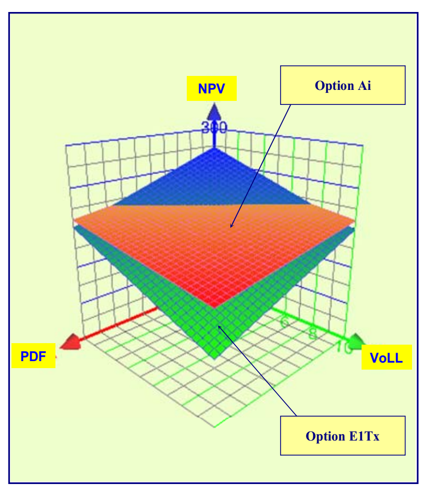

Fig. 2. Present Value (PV) vs. Load PDF and VoLL

The 3-dimensional plot above shows that initially, Option Ai emerges as the most attractive option. However, as PDF and VoLL increase simultaneously, Option E1iTx becomes a more attractive option. A close look at the plot shows that for VoLL greater than RM7.5/kWh or PDF greater than 0.75, Option E1iTx – Compact Switching Station with transformer feeder scheme emerges as the cheapest option.

B. Discussion & Summary

Economic analysis is the final, yet the most important factor in choosing the best option for a project. In this study, the LCC analysis was done to determine the lowest PV of the total cost of the options. The LCC analysis is a comprehensive approach as it encompass the capital cost, O&M cost, cost due to losses and resultant saving from the system and substation reliability of each option for the asset life of 30 years. The summary of results is tabulated in Table III.

TABLE III. ECONOMIC ANALYSIS RESULTS

Option	Ranking Based On			
	Capital Cost	LCC at Present Value (PV)		
		TNB's Cost Only	TNB's + Customer Outage Cost	Sensitivity @ VoLL= RM10.47, PDF=0.5
Opt Ai	2	3	1	7
Opt Aii	8	8	7	11
Opt Aiii	10	10	8	14
Opt Aiv	4	4	2	8
Opt Bi	1	5	5	12
Opt Bii	7	12	12	16
Opt Biii	9	13	13	18
Opt Biv	3	6	6	13
Opt Ci	23	23	23	19
Opt Cii	25	25	25	21
Opt Ciii	26	26	26	22
Opt Civ	24	24	24	20
Opt Di	5	1	3	23
Opt Dii	11	7	9	25
Opt Diii	12	9	11	26
Opt Div	6	2	4	24
Opt E1i	14	14	14	2
Opt E1ii	16	16	16	4
Opt E1iii	17	17	17	5
Opt E1iv	15	15	15	3
Opt E1i	13	11	10	1
Opt E2i	19	19	19	9
Opt E2ii	21	21	21	15
Opt E2iii	22	22	22	17
Opt E2iv	20	20	20	10
Opt E2v	18	18	18	6

Based on the capital cost alone, Option Bi – LILO B with Single Busbar Scheme is the cheapest option. However, based on the LCC, Option Ai – LILO A with Single Busbar Scheme is the most attractive option. On the contrary, sensitivity studies on PV reveal that by varying VoLL and load PDF, the PV of the option changes significantly, thus changing the ranking of the options. At VoLL greater than RM7.5/kWh and load PDF greater than 0.75, Option E1iTx – Compact Switching Station with transformer feeder scheme becomes the best option.

Thus, based on the result, it can be concluded that Option E1iTx – Compact Switching Station with transformer feeder scheme, is the best connection scheme and design for substation KTGU. The scheme meets all the reliability criteria and deliver the lowest PV in the long run, as well as robust against future demand increase and higher VoLL. Extendibility can be built-in for future system augmentation. In addition, the Compact Switching Station offers simple design, smaller foot-print but yet, offers comparable reliability level.

VIII. CONCLUSION

A total of twenty six (26) configurations were evaluated using deterministic, probabilistic and economic analysis to come up with the most cost effective and robust design overall. The best option is Option E1iTx – Compact Switching Station with transformer feeder scheme as it offers reliability, future expandability and ultimately the lowest PV in the long run. This approach managed to save TNB approximately twenty six percent (26%) of the project capital cost, with comparable reliability, as compared to if TNB were to employ TNB's traditional planning and standard engineering design methodology. It is shown that with an application of sound assessment principles, the investment is clearly justified in the sense that it focuses on the right asset at the right time.

It is a point to note that, however, the management opted for the second best option, Option E1i Single – Compact Switching Station with Single Busbar scheme, due to additional operational flexibility and maintainability. TNB, traditionally, has been using deterministic approach in its planning methodology. As such, the management was quite judicious in adopting the value or risk based approach due to incredulity on reliability analysis. In addition, the study team was having difficulty in getting reliability data owing to the statistically inadequate data.

ACKNOWLEDGMENT

The authors of this paper would like to sincerely express their gratitude and appreciation to Tenaga Nasional Berhad for giving consent to publish this paper. Sincere gratitude also go to Mr. Ibrahim Adham Salleh and Mr. Mohd Nordin Ab Wahab, Engineering Department of the Transmission Division, for their invaluable assistance.

The information presented and views expressed herein this paper are solely those of the authors and do not necessarily represent the views of TNB and/or the management and staffs of TNB.

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