Study on Effective Power Infrastructure Investment through Power Grid Interconnections in East Asia

edited by

Kazutaka Fukasawa

Ichiro Kutani

Yanfei Li

September 2015

ERIA Research Project FY2014 No. 30
Published September 2015

This report, prepared for the 'Study on Effective Power Infrastructure Investment Through Power Grid Interconnections in East Asia' under the Economic Research Institute for ASEAN and East Asia (ERIA) Energy Project utilises certain data and methodologies proposed by the Institute of Energy Economics, Japan (IEEJ) to assess the optimal power supply infrastructure for this study. These data and methodologies may differ from those normally used in each of the countries included in the study. Therefore, the calculated result here should not be viewed as official national analyses of the participating countries.

Furthermore, the economic analysis in this study is based on certain conditions. For instance, some parts of the assessment model are simplified to make simulation analysis more general and easier. Some assumptions were set to fill in missing data. Therefore, calculation results of this study should be dealt with care.

Preface

In East Asian Summit (EAS) countries where demand for electricity is rapidly increasing, generating more capacities is necessary. At the same time, cheaper electricity is required when considering impact on the general public and economy, and cleaner electricity when considering impact on pollution and climate issue.

On the other hand, potential resources to fuel power plants like coal, natural gas, and river remain untapped and/or underdeveloped in EAS countries. These resources can possibly supply sufficient and cheap electricity if the region can utilise them. Furthermore, the region's energy security can be enhanced by reducing dependence on imported energy supply.

A possible option to maximise the use of undeveloped resources in the region is regional grid interconnections where the region can optimise power-supply mix through cross-border power transactions.

Against this backdrop, the Economic Research Institute for ASEAN and East Asia (ERIA) organised a working group to carry out a study aimed at analysing a possible optimum power generation mix for the region and providing policy recommendations to improve the situation. Experts from EAS countries gathered and discussed their existing power development plans and possibilities for regional optimisation.

We hope that the outcomes from this study will serve as a reference for policymakers in East Asian countries and contribute to the improvement of energy security in the region as a whole.

Ichiro Kutani

Leader of the Working Group

June 2015

Acknowledgements

This report is a joint effort of the members of the working group from the EAS countries and the Institute of Energy Economics, Japan. We acknowledge the support by everyone involved.

Also, we acknowledge Mr Shaiful Bakhri Ibrahim, secretary in charge of the Heads of ASEAN Power Utilities/Authorities Council (HAPUA), for contributing insights on the studied issue.

Special mention and recognition are due Mr Katsuhiro Komura and Mr Noboru Sek of the Tokyo Electric Power Company who wrote some chapters of this report.

Mr Ichiro Kutani

Leader of the Working Group

June 2015

Contents

List of Tables

List of Figures

List of Abbreviations

ADB	Asia Development Bank
AERN	ASEAN Energy Regulators Network
AGTP	ASEAN Power Grid Generation and Transmission Systems Planning Institution
AIMS	ASEAN Interconnection Master Plan Study
APG	ASEAN Power Grid
ASEAN	Association of Southeast Asian Nations
ATSO	ASEAN Power Grid Transmission System Operators Institution
COD	commercial operation date
EAC	Electricity Authority of Cambodia
EAS	East Asia Summit
ECTF	Energy Cooperation Task Force
EDC	Electricité du Cambodge
EGAT	Electricity Generating Authority of Thailand
EMA	Energy Market Authority
ERIA	Economic Research Institute for ASEAN and East Asia
GMS	Greater Mekong Subregion
HAPUA	The Heads of ASEAN Power Utilities/Authorities
HVAC	high-voltage alternate current
HVDC	high-voltage direct current
IEEJ	The Institute for Energy Economics, Japan
IPP	independent power producer
LTMS PIP	Laos, Thailand, Malaysia and Singapore Power Integration Project
MOU	memorandum of understanding
NPTC	National Power Transmission Corporation
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
PDP	Power Development Plan
PPA	power purchase agreement
ROW	right of way
SOME	Senior Officials Meeting on Energy
TNB	Tenaga Nasional Berhad
TOR	terms of reference
TSO	transmission system operator
WG	working group

List of Project Members

Working Group Members

MR ICHIRO KUTANI (LEADER): Senior Economist, Manager, Global Energy Group 1, Assistant to Managing Director, Strategy Research Unit, The Institute of Energy Economics, Japan

MR SHIMPEI YAMAMOTO (ORGANISER): Managing Director for Research Affairs, Economic Research Institute for ASEAN and East Asia

MR SHIGERU KIMURA (ORGANISER): Special Advisor to Executive Director on Energy Affairs, Economic Research Institute for ASEAN and East Asia

DR ANBUMOZHI VENKATACHALAM (ORGANISER): Senior Energy Economist, Energy Unit, Research Department, Economic Research Institute for ASEAN and East Asia

DR HAN PHOUMIN (ORGANISER): Energy Economist, Energy Unit, Research Department, Economic Research Institute for ASEAN and East Asia

DR YANFEI LI (ORGANISER): Energy Economist, Energy Unit, Research Department, Economic Research Institute for ASEAN and East Asia

MR PISETH SOUEM: Officer, General Department of Energy, Ministry of Mines and Energy, Cambodia

MR AWDHESH KUMAR YADAV: Director, System Planning and Project Appraisal Power System, Central Electricity Authority, India

MR PRAMUDYA: Electricity Inspector, Directorate of Electricity Program Supervision, Directorate General of Electricity, Ministry of Energy and Mineral Resources, Indonesia

MR WATARU FUJISAKI: Senior Coordinator, Global Energy Group 1, Strategy Research Unit, The Institute of Energy Economics, Japan

MR YUHJI MATSUO: Senior Economist, Nuclear Energy Group, Strategy Research Unit, The Institute of Energy Economics, Japan

MR KAZUTAKA FUKASAWA: Senior Researcher, Global Energy Group 1, Strategy Research Unit, The Institute of Energy Economics, Japan

Mr Hironobu Masuda: Researcher, Global Energy Group 1, Strategy Research Unit, The Institute of Energy Economics, Japan

Mr Boungnong Bouttavong: Deputy Director, Technical Department, Electricite Du Laos, Lao PDR

Mr Joon bin Ibrahim: General Manager, Technical Advisory and Industry Development, Single Buyer Department, Tenaga Nasional Berhad, Malaysia

Dr Jiraporn Sirikum: Assistant Director, System Planning Division—Generation, Electricity Generating Authority of Thailand, Thailand

Mr Tang The Hung: Deputy Director, Planning Department, General Directorate of Energy, Ministry of Industry and Trade, Viet Nam

Executive Summary

Dense cross-border power grid connections can benefit the ASEAN region through maximum use of untapped resources for power generation and achieve power supply stability with low investment for power stations. This study aims to support existing initiatives, i.e. ASEAN Power Grid and GMS Power Master Plan, by quantitatively showing possible economic and environmental benefits of such power grid connections.

The study selected from candidate international connection lines extracted in the fiscal year 2013 study[1] specific routes for further examination. The study carried out the preliminary planning and cost estimation for the selected routes and cross-border line per kilowatt hour. The estimated results indicate that although cross-border connection lines are capital-intensive projects, attainable benefits seem large enough to rationalise investment.

Case		Gross benefit (A)		Cost (B)		Net benefit (C)=(A)-(B)		Benefit/Cost ratio (D)=(C)/(B)
		[Million US$]	[US¢/kWh]	[Million US$]	[US¢/kWh]	[Million US$]	[US¢/kWh]	[-]
B	THA—LAO	21,387	3.77	1,506	0.26	19,881	3.51	13.2
E	VNM—LAO—THA	24,707	3.68	2,097	0.32	22,610	3.36	10.8
G	LAO—THA—MYS—SGP	27,490	3.88	2,000	0.28	25,490	3.60	12.7

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Author.

To materialise these beneficial investments, we propose the following policy recommendations.

First, the region needs to establish a regulatory or coordination body to oversee the entire electricity market in the region. The body needs to harmonise rules for cross-border line connections and electricity transactions. Second, efficiency of investment for power stations and transmission lines need to be improved. At present,

[1] ERIA (2014), Investing in Power Grid Interconnection in East Asia, September.

the region does not coordinate country-based power development plans (PDPs). High costs in country-based PDPs can be avoided with more cross-border connections and electricity trade. Last, harmonisation of technical standards regarding cross-border interconnection is an indispensable precondition.

CHAPTER 1

Introduction

The demand for electricity is steadily increasing in East Asia Summit (EAS) countries due to population increase and economic growth. Improving electrification rate is an important policy task in many countries as demand for electricity is certain to increase in line with rise in living standards. Meanwhile, as income remains relatively low for most, it is necessary to supply electricity at the minimal cost possible. For EAS countries, large-scale power source development in a steady and economically efficient way is an urgent task. In addition, such development should lower emissions, waste water, and greenhouse gases.

A country basically develops power source on the premise of self-sufficiency. From the perspective of energy security, such approach is rational when a country has enough capability to develop the necessary number and desirable types of power stations with its resources. However, when demand growth outstrips the capacity to supply manufacturing, human, and financial resources or when it becomes difficult to develop economically efficient power stations due to constraints such as high costs of fuel transportation and power loss during transmission, importing electricity from neighbouring countries should be an option. In the light of the above, it may be possible to optimise or improve the efficiency of power infrastructure investments in terms of supply stability, economic efficiency, and reduction of environmental burden if we consider ways of developing power infrastructure on a pan-regional basis.

In the ASEAN region, the Heads of ASEAN Power Utilities/Authorities (HAPUA) and the Asian Development Bank (ADB) are initiating intra-regional power grid interconnections, while bilateral power imports–exports are ongoing. However, individual countries are still prioritising optimisation of investments at the domestic level. Besides, power imports and exports are not brisk enough to contribute to ‘power grid interconnections’, and moves toward pan-regional optimisation have been slow.

1. Rationale

The rationale of this study is derived from the 17th ECTF[1] meeting held in Phnom Penh, Cambodia, on 5 July 2012. During this meeting, the Economic Research Institute for ASEAN and East Asia (ERIA) explained and proposed new ideas and initiatives for energy cooperation, including strategic usage of coal, optimum electric power infrastructure, nuclear power safety management, and smart urban traffic.

The participants of the ECTF meeting exchanged views on the above proposals and agreed to endorse them.

As a result, ERIA formed the working group for the 'Study on Effective Power Infrastructure Investment Through Power Grid Interconnections in East Asia'. Members from EAS countries were represented in the working group, with the Institute of Energy Economics, Japan (IEEJ) as the secretariat.

2. Objective

This study will quantify the possibility and benefits of pan-regional optimisation of power infrastructure development in the EAS region. It is expected to provide clues for improving efficiency of investment for power stations and cross-border grid interconnections. It should be noted that since this study has been developed by referencing the Greater Mekong Subregion (GMS) program of ADB and the ASEAN Power Grid (APG) program of HAPUA, it is consistent with these existing initiatives.

3. Work Stream

3.1. Fiscal Year 2012– 2013

In the past two years of the study, the following work streams were conducted.

(A) Collection and compilation of information relating to power infrastructure;
(B) Identification of challenges and discussion points;
(C) Development of a broad-area power infrastructure simulation model and evaluation of the simulation results;
(D) Analysis and examination of optimal power infrastructure;

[1] Energy Cooperation Task Force under the Energy Ministers' Meeting of East Asia Summit (EAS) countries.

(E) Selection of possible interconnection lines and preliminary economical evaluation; and
(F) Drawing out policy recommendations.

The study first developed a simulation model that analysed the least-cost mix of power generation and grid interconnection. A second part of the study estimated the cost of possible interconnection lines based on the above-mentioned simulation analysis. By comparing these outcomes, i.e. cost and benefit of enhanced grid interconnection, the report selected priority projects that seem to provide greater benefits for the region and, at the same time, are perceived to be economically viable.

In the fiscal year 2013 (FY2013) study, costs and net economic benefits of possible interconnection lines—which imply feasibility and priority of the proposed new transmission capacities—are estimated.

Table 1-1. Case Setting for Power Generation Mix and Trade Flow Analysis*

Case	Additional capacity of international grid connection	Additional development of hydro power potential
0 (reference)	no	no
1	yes (certain limit exist)	no
2a	yes (certain limit exist)	yes
2b	yes (certain limit exist)	yes (export purpose only)
3	yes (no limit exist)	yes (export purpose only)

* For details, please refer to Economic Research Institute for ASEAN and East Asia (2014), 'Investing in Power Grid Interconnection in East Asia', September.
Source: Author.

A positive net economic benefit indicates economic feasibility of the project, and thus should be prioritised. Amongst the listed projects, a Viet Nam–Lao PDR–Thailand–Malaysia–Singapore interconnection route could be the most beneficial, and a Cambodia–Thailand linkage or a Malaysia–Indonesia linkage could be the second most beneficial interconnection.

Table 1-2. Possible Interconnection Lines and their Priority

Line	Possible cumulative net cost benefit range [Million USD]	Estimated cost of trasmission line [Million USD]	
A: THA—KHM	4,560—5,470	162—1,009	second priority
B: THA—LAO	19,282—20,604	728—1,957	first priority
C: THA—MYA	(4,607)—(2,766)	2,244—3,956	need careful assess.
D: MYA—THA—MYS—SGP	(1,118)—3,064	2,384—6,272	need careful assess.
E: VNM—LAO—THA	21,604—23,715	922—2,885	first priority
F: MYS—IDN	3,968—4,087	1,790—1,901	second priority
G: LAO—THA—MYS—SGP	23,217—26,557	868—4,273	first priority

IDN = Indonesia, KHM = Cambodia, LAO = Lao People's Democratic Republic, MYA = Myanmar, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
* Numbers in brackets are negative.
** For details, please refer to 'Study on Effective Investment of Power Infrastructure in East Asia Through Grid Interconnection', Economic Research Institute for ASEAN and East Asia, 2014.

Source: Author.

3.2. Fiscal Year 2014

Based on the above described achievements, the following work streams were conducted on the third year of the study.

(G) Selecting priority routes

From candidate international interconnection lines extracted in the FY2013 study, the working group selected specific routes for further examination.

(H) Preliminary planning and cost estimation

Based on the specific routes considered in (G) above, the working group carried out preliminary planning work and cost estimation for the selected interconnection routes. Then, it estimated unit power transmission costs based on projected transmission demand for the lines. In doing so, the following key elements are accounted in the model: connecting points to existing grids, preliminary route selection, basic design of transmission line, and cost estimation.

(I) Policy and institutional challenges

The working group analysed the institutional and policy challenges for realising the selected interconnection lines, especially the regulatory/coordination framework and the technical issues related to multi-regional power trade.

(J) Drawing policy recommendations

Based on analyses (G) to (I) above, the working group drew policy recommendations to accelerate interconnection build-up which benefits the entire ASEAN region.

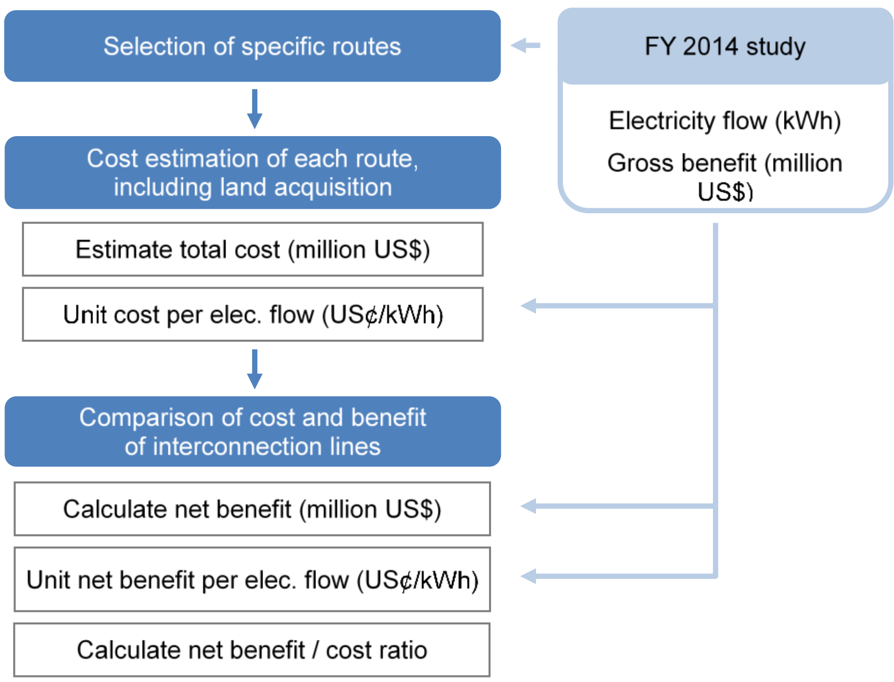
CHAPTER 2

Preliminary Feasibility Assessment of Selected Routes

1. Overview of Study

Regarding the three most economically beneficial routes from 2014 study, Chapter 2 covers the selection of specific cross-border interconnection routes and estimation of construction costs for transmission lines and land acquisition costs for each interconnection route.

Figure 2-1. Study Flow



Source: Author.

1.1. Top Three Economically Beneficial Routes

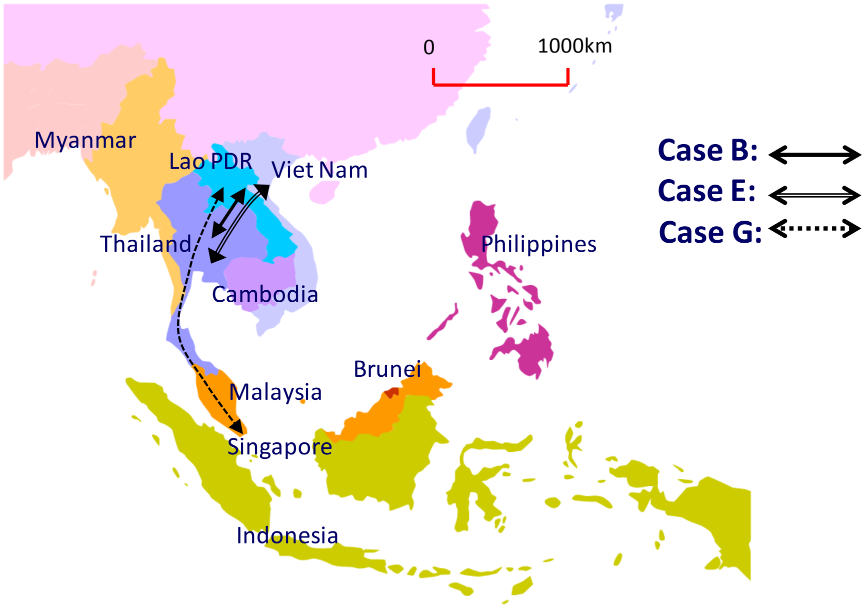
In last year's study, these routes are estimated to bring larger economic benefits from power grid interconnection:

Case B: Thailand–Lao PDR

Case E: Viet Nam–Lao PDR–Thailand

Case G: Lao PDR–Thailand–Malaysia–Singapore

Figure 2-2. Three Economically Beneficial Routes



km = kilometre, Lao PDR = Lao People's Democratic Republic.
Source: Prepared by the working group.

Sorting through the three most economically beneficial routes, cross-border interconnection sections can be summarised into four. From the east, these interconnection sections are 1) Viet Nam–Lao PDR, 2) Lao PDR–Thailand, 3) Thailand–Malaysia, and 4) Malaysia–Singapore.

1.2. Researching the Status of Cross-border Interconnections

To select the most promising interconnection route, the current state and future plans for the aforementioned four sections are investigated.

1.2.1. Viet Nam–Lao PDR

Table 2-1. Cross-border Interconnection (Lao PDR–Viet Nam)

No.	Project	System	Type	SCOD	MW
10	**Lao PDR -Vietnam**				
	Existing				
	• Xekaman 3 - Thanhmy	HVAC: kV	PP: La->Vn	2013	248
	•				
	Ongoing				
	• Xekaman 1- Ban Hat San - Pleiku	HVAC: kV	PP: La->Vn	2016	1000
	• Nam Mo - Ban Ve	HVAC: kV	PP: La->Vn	TBC	TBC
	• Luang Prabang - Nho Quan	HVAC: kV	PP: La->Vn	2020	1410
	•				
	Future				
	• Ban Hat San - Stung Treng - Tay Ninh	TBC	TBC	TBC	TBC
	•				

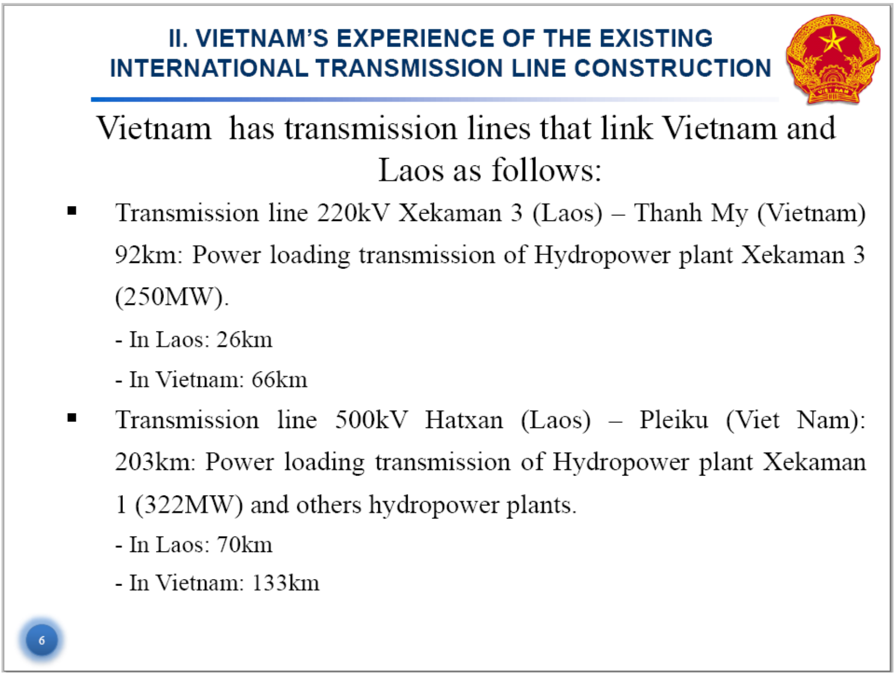
HVAC = high-voltage alternating current, kV = kilovolt, MW = megawatt, PP = power plant, SCOD = schedule commercial operation date, TBC = to be confirmed.
Source: Development of Cross-Border Trade between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

As shown in Table 2-1, a cross-border interconnection currently exists to export power from some hydropower plants in Lao PDR to Viet Nam (Xekaman 3–Thanhmy). Three cross-border interconnections are being constructed to export power from Laotian hydropower plants to Viet Nam, and one future connection (unclear whether from hydropower plants or between substations) is proposed.

Memorandums of agreements (MOUs) have been signed for ongoing work from the Nam Mo hydropower plant (Lao PDR) to Ban Ve (Viet Nam), and from the Luang Prabang hydropower plant (Lao PDR) to Nho Quan (Viet Nam), and deliberations are currently under way. However, according to the latest Electricite du Laos (EDL) plans (see Figure 2-10), the Luang Prabang P/P–Nho Quan plan is missing. This plan seems to have been terminated as its feasibility was not so high.

Figure 2-3 was presented by the Electricity Viet Nam in the first working group meeting on 11 November 2014. Two Viet Nam–Lao PDR interconnections exist: the Xekaman 3 (Lao PDR)–Thanh My (Viet Nam) line, which has been completed, and the Hatxan (Lao PDR)–Pleiku (Viet Nam) line, which should currently be under construction. These lines are consistent with data from Table 2-1.

Figure 2-3. Viet Nam's Experience on the Existing International Transmission Line Construction



km = kilometre, kV = kilovolt, MW = megawatt.
Source: FY2014 1st EIPI presentation material by the Electricity Viet Nam.

1.2.2. Thailand–Lao PDR

Table 2-2. Cross-border Interconnection (Thailand–Lao PDR)

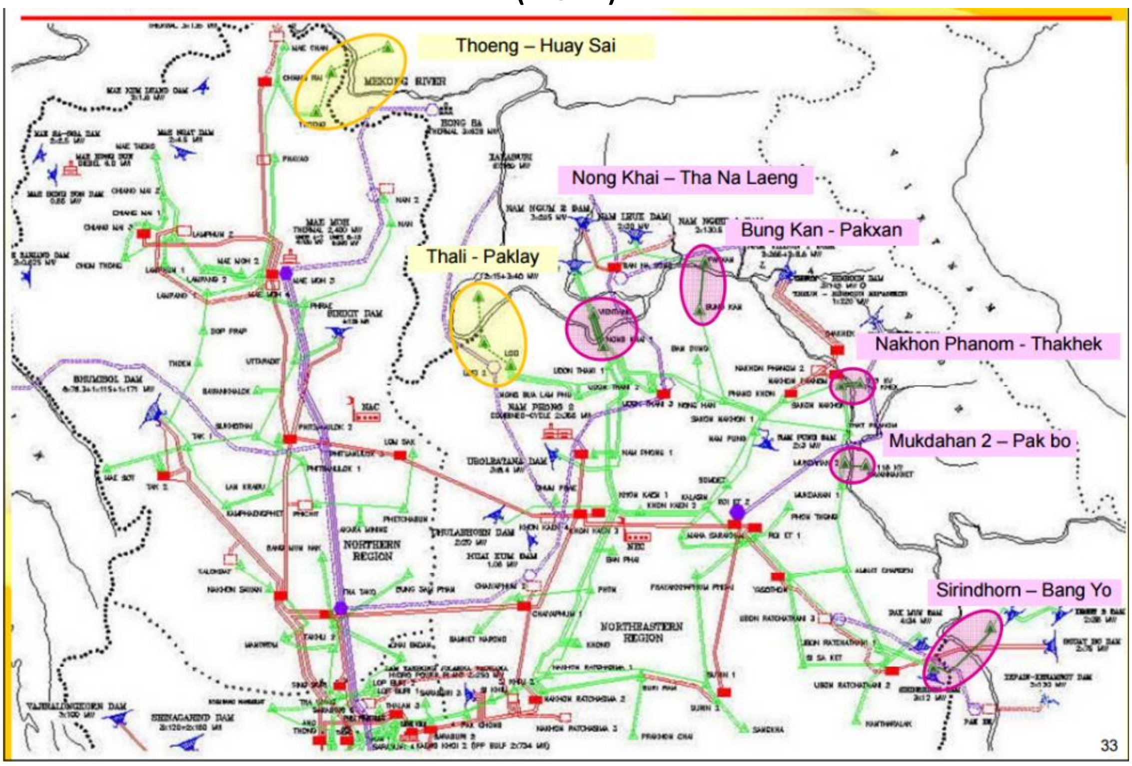
No.	Project	System	Type	SCOD	MW
9	**Thailand - Lao PDR**				
	Existing				
	• Nakhon Phanom - Thakhek - Theun Hinboun	HVAC: 230 kV	PP: La->Th	1998	220
	• Ubon Ratchathani 2 - Houay Ho	HVAC: 230 kV	PP: La->Th	1999	126
	• Roi Et 2 - Nam Theun 2	HVAC: 230 kV	PP: La->Th	2010	948
	• Udon Thani 3 - Na Bong - Nam Ngum 2	HVAC: 500 kV	PP: La->Th	2011	597
	• Nakhon Phanom 2 - Thakhek - Theun Hinboun (Expansion)	HVAC: 230 kV	PP: La->Th	2012	220
	•				
	Ongoing				
	• Mae Moh 3 - Nan 2 - Hong Sa	HVAC: 500 kV	PP: La->Th	2015	1473
	• Udon Thani 3 - Na Bong - Nam Ngiep 1	HVAC: 500 kV	PP: La->Th	2019	269
	• Ubon Ratchathani 3 - Pakse - Xe Pien Xe Namnoi	HVAC: 500 kV	PP: La->Th	2018	390
	• Khon Kaen 4 - Loei 2 - Xayaburi	HVAC: 500 kV	PP: La->Th	2019	1220
	•				
	Future				
	• Nong Khai – Khoksa-at (Selected by AIMS-II)				
	• Nakhon Phanom – Thakhek (Selected by AIMS-II)	HVAC: 230 kV	EE	2015	600
	• Thoeng – Bo Keo (Selected by AIMS-II)				
	• Udon Thani 3 - Na Bong - Future project	HVAC: 500 kV	PP: La->Th	2018	510
	• Ubon Ratchathani 3 - Pakse - Future project	HVAC: 500 kV	PP: La->Th	2019	315
	• Nan 2 - Tha Wang Pha - Nam Ou	HVAC: 500 kV	PP: La->Th	2023	1040
	•				

EE = substation, HVAC = high-voltage alternating current, kV = kilovolt, La = Lao PDR, MW = megawatt, PP = power plant, SCOD = schedule commercial operation date.
Source: Development of Cross-Border Trade Between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

As shown in Table 2-2, all interconnection lines will be from Laotian hydropower plants to Thailand, except the cross-border interconnections selected by the ASEAN Interconnection Master Plan Study (AIMS)-II listed under future connections. Given that the AIMS-II lines are scheduled with commercial operation date in 2015, it seems the plan is likely to be not progressing.

While not listed in Table 2-2, it appears that there are some cross-border interconnections between substations at 115 kV, as shown in Figure 2-3. An example is the 115-kV interconnection between Pak Bo (Thailand) and Mukdahan2 (Lao PDR).

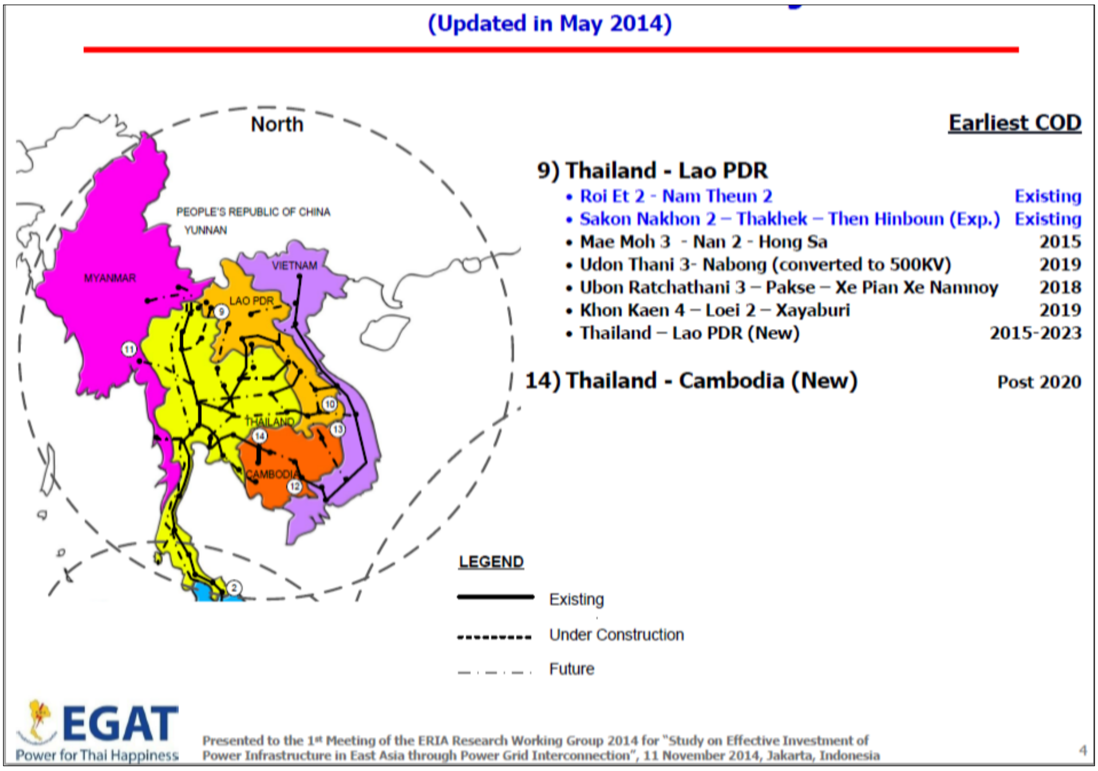
Figure 2-4. Interconnections Between Thailand and Lao PDR (115 kV)



Source: Electricity Generating Authority of Thailand (accessed 23 March 2015).

Figure 2-5 was presented by the Electricity Generating Authority of Thailand (EGAT) in the first working group meeting on 11 November 2014.

Figure 2-5. ASEAN Interconnection Projects (Thailand–Lao PDR)

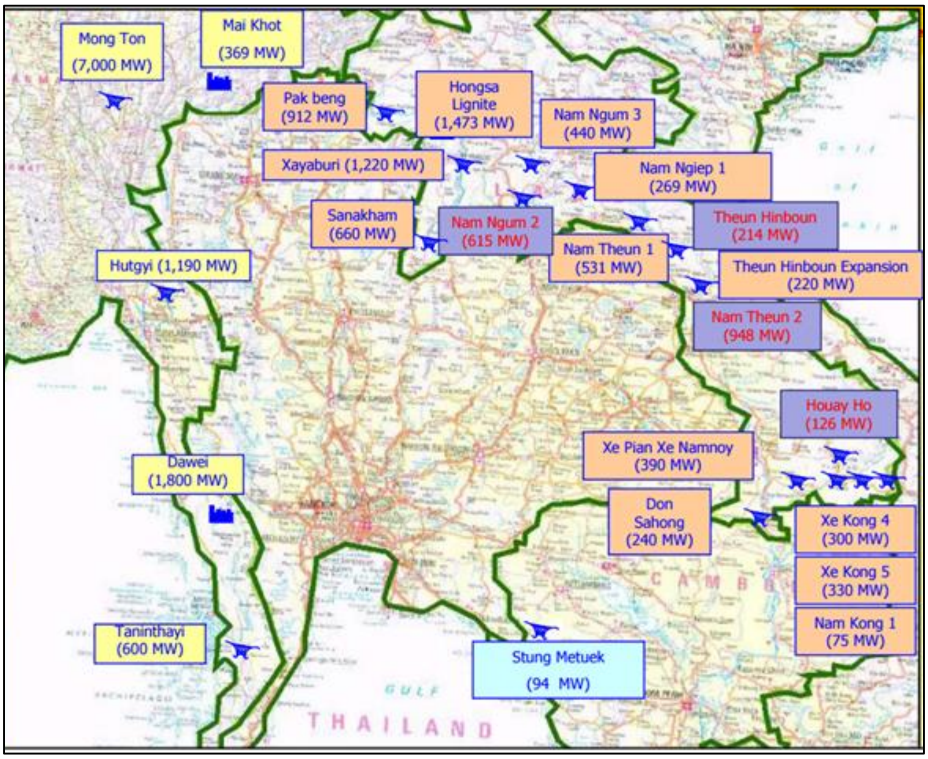


COD = commercial operation date

Source: FY2014 1st EIPI presentation material by the Electricity Generating Authority of Thailand.

Figure 2-6 shows potential power plants exporting to Thailand from its neighbouring countries. It is easy to understand the locations of the potential projects in Lao PDR.

Figure 2-6. Potential Power Projects in Thailand's Neighbouring Countries



Source: Electricity Generating Authority of Thailand, (Accessed 23 March 2015).

1.2.3. Thailand–Malaysia

Table 2-3. Cross-border Interconnection (Thailand–Malaysia)

No.	Project	System	Type	SCOD	MW
2	**Thailand - P.Malaysia**				
	Existing				
	• Sadao - Chuping	HVAC: 132/115 kV	EE	1980	80
	• Khlong Ngae - Gurun	HVDC: 300 kV	EE	2002	300
	Ongoing				
	• Su - ngai Kolok - Rantau Panjang	HVAC: 132/115 kV	EE	2015	100
	•				
	Future				
	• Khlong Ngae - Gurun (Addition)	HVDC: 300 kV	EE	2016	300
	•				

EE = substation, HVAC = high-voltage alternating current, HVDC = high-voltage direct current, MW = megawatt, MYS = Malaysia, SCOD = schedule commercial operation date, THA = Thailand.

Source: Development of Cross-Border Trade Between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

All THA–MYS cross-border interconnections are between substations, with both high-voltage alternating current (HVAC) and high-voltage direct current (HVDC) systems. Also, an increase in HVDC capacity is planned for 2016.

1.2.4. Malaysia–Singapore

Table 2-4. Cross-border Interconnection (Malaysia–Singapore)

No.	Project	System	Type	SCOD	MW
1	**P.Malaysia - Singapore**				
	Existing				
	• Plentong - Woodlands	HVAC: kV	EE	1985	450
	•				
	Ongoing				
	• -	-	-	-	-
	•				
	Future				
	• Selected by AIMS-II	HVDC: kV	PP: PM->Sg	2018	600
	•				

EE = substation, HVAC = high-voltage alternating current, HVDC = high-voltage direct current, kV = kilovolt, MW = megawatt, MYS = Malaysia, PM = Peninsula Malaysia, PP = power plant, SCOD = schedule commercial operation date, Sg = Singapore, SGP = Singapore.
Source: Development of Cross-Border Trade between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

There is an HVAC MYS–SGP cross-border interconnection between substations. HVDC lines are also planned to carry power to Singapore from a thermal power plant in the Malaysian peninsula.

1.3. Capacity of Cross-border Interconnection Facilities

From the grid interconnection materials of each country discussed, the interconnection capacity in each country can be summarised as follows:

Table 2-5. Existing and Future Plan of Interconnection Capacity

Unit: GW	VNM–LAO	LAO–THA	THA–MYS	MYS–SGP
Existing	0.2	2.1	0.4	0.5
Ongoing	2.4	3.4	0.1	0.0
Future	0.0	2.5	0.3	0.6
Total	**2.6**	**7.9**	**0.8**	**1.1**

GW = gigawatt, LAO = Lao PDR, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

In 2014 study, the totals (in gigawatt [GW]) in Table 2-5 were set as upper limits for interconnection capacity in Case 2b, which is described later.

1.4. Annual Power Trade Flows for Interconnection Lines

The estimated power trade flows in 2035 are shown in Table 2-6. A detail of these case settings (please refer to Table 1-1) and calculated numbers are described in ERIA's 2014's 'Study on Effective Investment of Power Infrastructure in East Asia Through Grid Interconnection'.

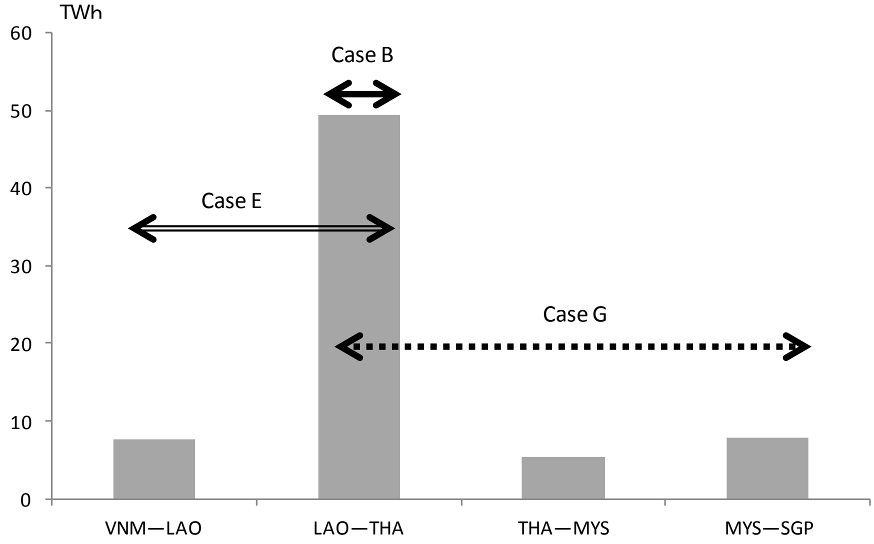
Table 2-6. Power Trade Flows in 2035

Unit: TWh	VNM-LAO	LAO-THA	THA-MYS	MYS-SGP
Case 2b	7.6	49.4	5.4	7.8
Case 3	0	54.7	136.6	35.8

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, TWh = tera watt hour, VNM = Viet Nam.
Herein with Case 2b and Case 3 are defined as follows:
Case 2b: Additional grid connections available, but additional hydro-potential for export purposes only.
Case 3: Same as Case 2b, with no upper limit for international grid connection capacity.
Source: Prepared by the working group.

Case 3 eliminates the upper limits on interconnection capacity in Case 2b, resulting in unrealistically large amounts of power trade flow. (For example, the 136.6 tera watt hour (TWh) between Thailand and Malaysia is equivalent to 36.7 percent of Malaysia's estimated 372 TWh power consumption in 2035, and the 35.8 TWh between Malaysia and Singapore is equivalent to 54.2 percent of Singapore's estimated 66 TWh power consumption in 2035. As such, 2014 study took Case 2b as a possible future scenario and estimated its economic benefits. Figure 2-7 depicts power trade flow for Case 2b.

Figure 2-7. Power Trade Flows in 2035 (Case 2b)



LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

Figure 2-7 shows that the LAO-THA power trade flow is much greater than that between other countries, making it the main component that can provide economic benefits.

1.5. Necessity for Increase in Interconnections

An estimated interconnection line and relevant facilities' capacity required to transmit electricity are shown in Table 2-7. The minimum capacity requirement is calculated at the premise that a constant amount of electricity is flowing 24 hours a day. It should be noted that actual electricity flow varies greatly between wet and dry seasons and between night-time and daytime. As such, the capacity for interconnection facilities will need to be larger than the estimated minimum capacity requirement.

The formula used for calculations is: Traded volume [TWh] * 1,000 / 24 / 365 = GW.

Table 2-7. Minimum Interconnection Capacity Requirement in 2035

Unit: GW	VNM–LAO	LAO–THA	THA–MYS	MYS–SGP
Case 2b	0.9	5.6	0.6	0.9
Case 3	0	6.2	15.6	4.1

GW = gigawatt, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

By comparing Tables 2-5 and 2-7, we can understand an investment gap for interconnection lines.

1.5.1. Viet Nam–Lao PDR

Table 2-8. Investment Gap of Interconnection Capacity (Viet Nam–Lao PDR)

VNM—LAO			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	0,2 / 0,9	2,6 / 0,9	2,6 / 0,9
Case 3	0,2 / 0	2,6 / 0	2,6 / 0

GW = gigawatt, LAO = Lao People's Democratic Republic, VNM = Viet Nam.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

In Case 2b, the minimum capacity requirement is 0.9 GW, while the planned interconnection capacity will reach 2.6 GW. Planned capacity addition seems sufficient as it is three times the minimum capacity. This shows that no additional new interconnection lines will be required if all future connection lines progress smoothly as planned. However, with the status of the plans for the Luang Prabang-Nho Quan line unclear as mentioned, it is uncertain whether any new interconnection lines will be required.

Meanwhile, minimum capacity requirement for Case 3 is 0 GW. No increase in interconnection would be required whatsoever. Following construction, cross-border interconnections would be for emergency use.

The reason for the relatively small trade flow of VNM–LAO is that a large amount of it will come from South China and Cambodia into Viet Nam.

1.5.2. Lao PDR–Thailand

Table 2-9. Investment Gap of Interconnection Capacity (Lao PDR–Thailand)

LAO—THA			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	2,1 / 5,6	5,5 / 5,6	7,9 / 5,6
Case 3	2,1 / 6,2	5,5 / 6,2	7,9 / 6,2

GW = gigawatt, LAO = Lao People's Democratic Republic, THA = Thailand.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

In Case 2b, the minimum capacity requirement is 5.6 GW, while the planned interconnection (including ongoing and future) capacity will reach 7.9 GW. It means that if future projects are implemented as planned, the interconnection line will have sufficient capacity to transmit estimated electricity flow. The same can be said in Case 3.

The minimum capacity requirement, however, does not account for seasonal and daily variations of electricity flow. Thus, the actual interconnection capacity will need to be several times higher than the minimum capacity requirement, necessitating additional new interconnection lines in this route.

1.5.3. Thailand–Malaysia

Table 2-10. Investment Gap of Interconnection Capacity (Thailand–Malaysia)

THA—MYS			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	0,4 / 0,6	0,5 / 0,6	0,8 / 0,6
Case 3	0,4 / 15,6	0,5 / 15,6	0,8 / 15,6

GW = gigawatt, MYS = Malaysia, THA = Thailand.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

The planned transmission capacity is 0.8 GW, which is almost the same as the 0.6 GW of minimum required capacity for Case 2b. A reason of this similarity in capacity is that the Case 2b simulation set a certain cap (upper limit) in the interconnection capacity. On the other hand, the result of Case 3, which is not set a cap in a calculation, shows very large requirement of capacity (15.6 GW) between the Thailand and Malaysia interconnection. These two facts indicate a large potential of electricity trade between the nations. Therefore, it is expected to increase interconnection capacity beyond existing plan as larger capacity may bring more economical benefit.

1.5.4. Malaysia–Singapore

Table 2-11. Investment Gap of Interconnection Capacity (Malaysia–Singapore)

MYS—SGP			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	0,5 / 0,9	0,5 / 0,9	1,1 / 0,9
Case 3	0,5 / 4,1	0,5 / 4,1	1,1 / 4,1

GW = gigawatt, MYS = Malaysia, SGP = Singapore.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

The planned interconnection capacity is 1.1 GW, almost the same as the 0.9 GW minimum required capacity in Case 2b. Results here show that planned capacity is not enough to transmit estimated electricity trade flow in 2035. It is the upper limit in interconnection capacity in Case 3 is removed, the estimated trade flow increases to 4.1 GW. As this route can potentially further increase electricity trade, which will also increase the economic benefits, it is recommended to expand an interconnection capacity to a level that will enable it.

1.6. Lao PDR, Thailand, Malaysia, and Singapore Power Integration Project

The Lao PDR, Thailand, Malaysia, Singapore Power Integration Project (LTMS PIP) is a joint statement of the relevant agencies of Lao PDR, Thailand, Malaysia and Singapore in September 2014. LTMS PIP is exactly the same as Case G from last year’s study (see Chapter 1 for reference), a project for Lao PDR to export power to Singapore via Thailand and

Malaysia. The joint statement is shown in Figure 2-7.

As a first step, the plan will trade up to 100 MW from Lao PDR to Singapore, and some media reveal that the final target of trade flow would be about 10 percent of demand in Singapore.

Figure 2-8. Joint Statement of the Lao PDR, Thailand, Malaysia, and Singapore Power Integration Project

23 September 2014
Vientiane, Lao PDR

1. The Ministry of Energy and Mines of the Lao People's Democratic Republic, Ministry of Energy of the Kingdom of Thailand, Ministry of Energy, Green Technology and Water of Malaysia, and Ministry of Trade and Industry of the Republic of Singapore agreed today on a pilot project entitled "Lao PDR, Thailand, Malaysia, Singapore (LTMS) Power Integration Project (PIP)" to study cross border power trade from Lao PDR to Singapore.

2. Launched during Lao PDR's chairmanship of the ASEAN energy track, this pilot project will serve as a pathfinder to complement existing efforts towards realizing the ASEAN Power Grid (APG) and the ASEAN Economic Community (AEC), by creating opportunities for electricity trading beyond neighboring borders. This initiative will contribute towards energy security by strengthening the power integration network and enhancing the economic prosperity of the region. The project is also expected to help identify and resolve issues affecting cross – border electricity trading in ASEAN.

3. As a first step, the four countries will set up the LTMS PIP Working Group to study the technical viability of cross border power trade of up to 100 MW from Lao PDR to Singapore through existing interconnections. The working group is also expected to examine policy, regulatory, legal and commercial issues relating to cross border electricity trading.

4. The completion of the pilot study is envisaged to illustrate the feasibility of cross border electricity trade among all four countries of Lao PDR, Thailand, Malaysia and Singapore.

Source: Singapore Ministry of Trade and Industry News Room (accessed 3 March 2015).

2. Method of Selecting New Line Routes

2.1. Overview of Power Grids in the Five Countries

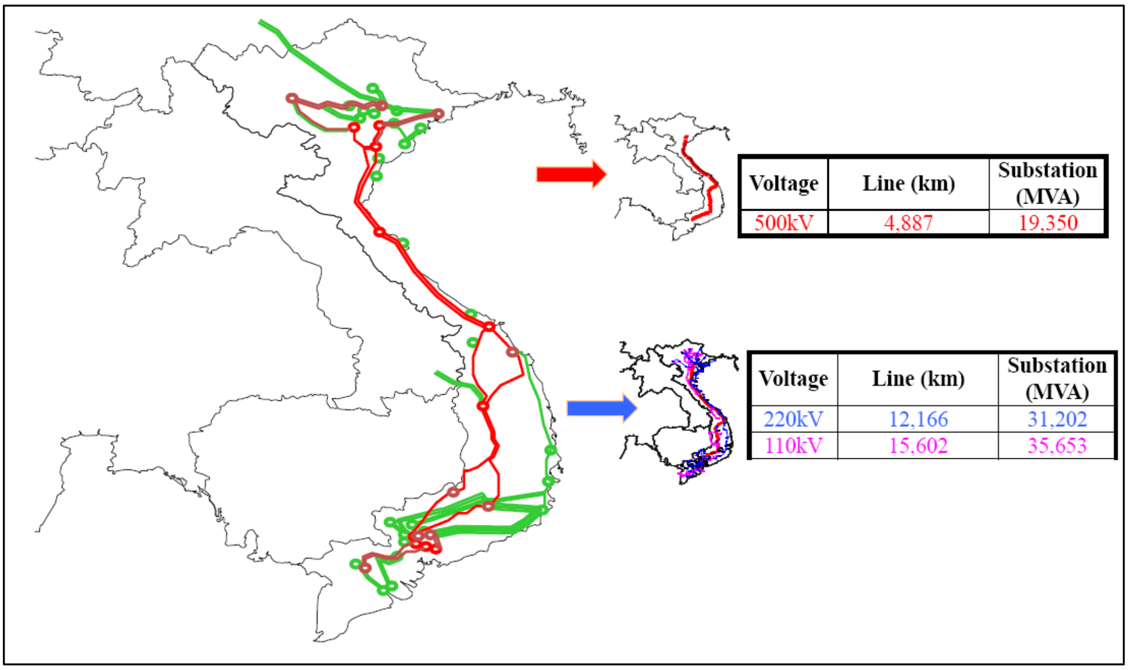
In deciding specific connection points (substations) along the interconnection routes, power transmission and demand for each country were examined.

Table 2-12. Transmission and Demand in Five Countries

	Transmission Voltage (kV)	Frequency (Hz)	Demands as of 2010 (TWh)
VNM	500/220/110	50	92.17
LAO	(500)/230/115*	50	8.45
THA	500/230/115	50	147.01
MYS	500/275/132	50	124.10
SGP	400/230	50	45.38

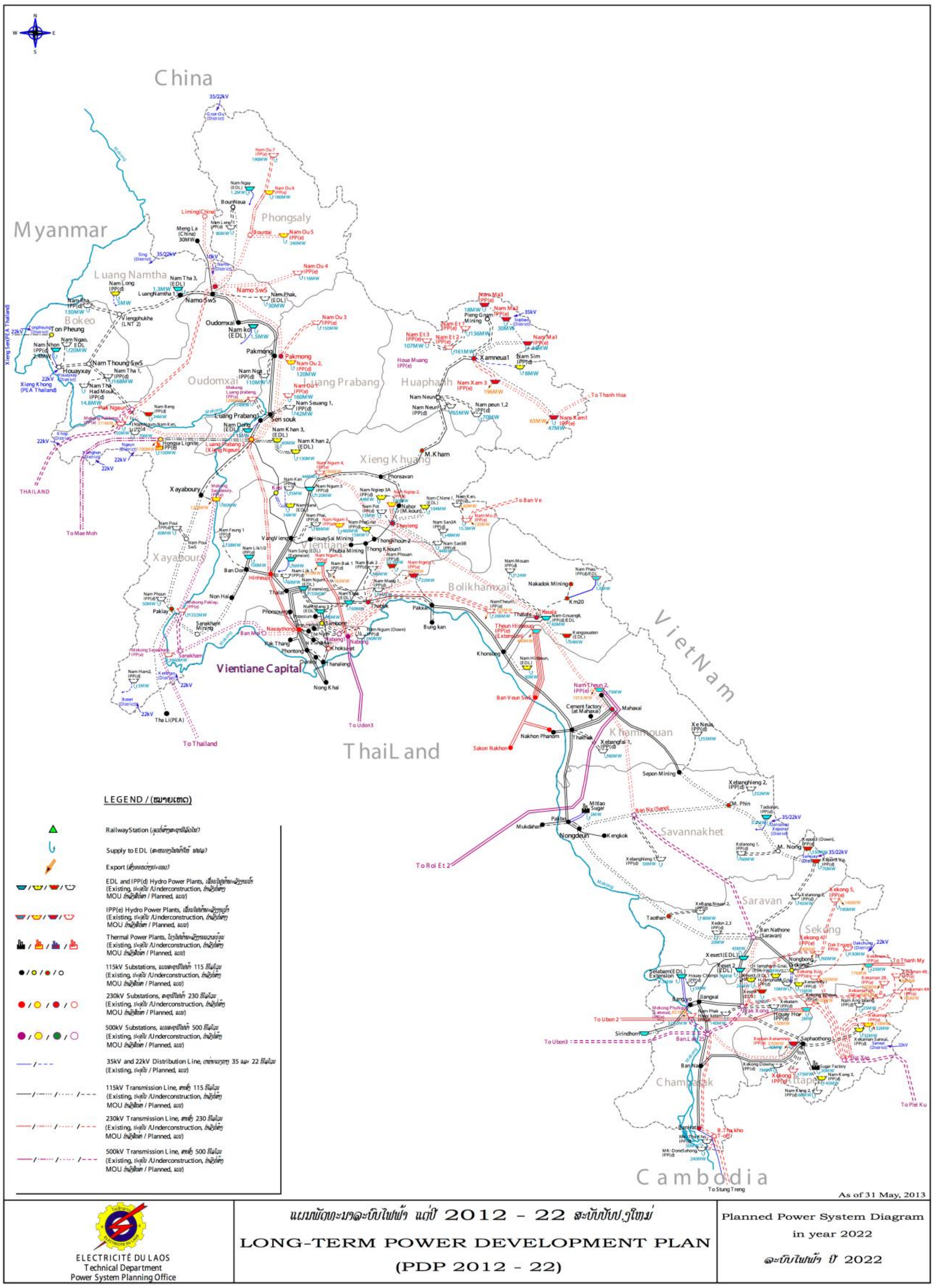
Hz = hertz, kV = kilovolt, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, TWh = tera watt hour, VNM = Viet Nam.
Note: 500 kV in Lao PDR is only for IPP grids to Thailand.
Source: Prepared by the working group.

Figure 2-9. Transmission Lines in Viet Nam



km = kilometre, kV = kilovolt, MVA = million volt ampere.
Source: Presentation material by the Electricity Viet Nam in the first meeting of ERIA on the 'Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection' in 2014.

Figure 2-10. Long-term Power Development Plan (2012–2022) in Lao PDR

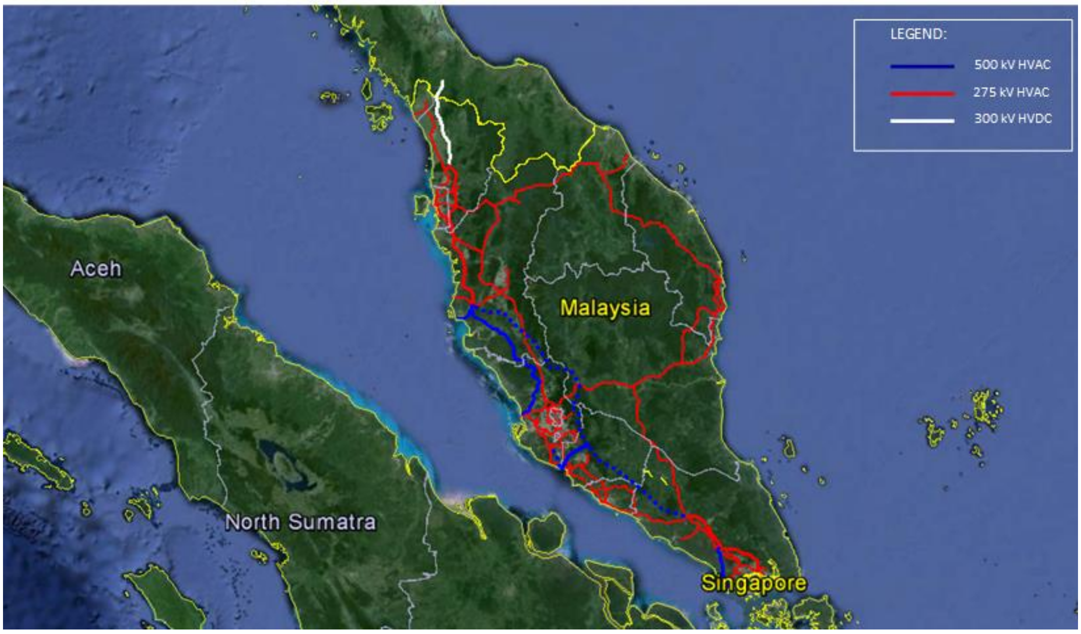


Source: Electricité du Laos (accessed 23 March 2015).

Figure 2-11. Transmission Lines in Thailand

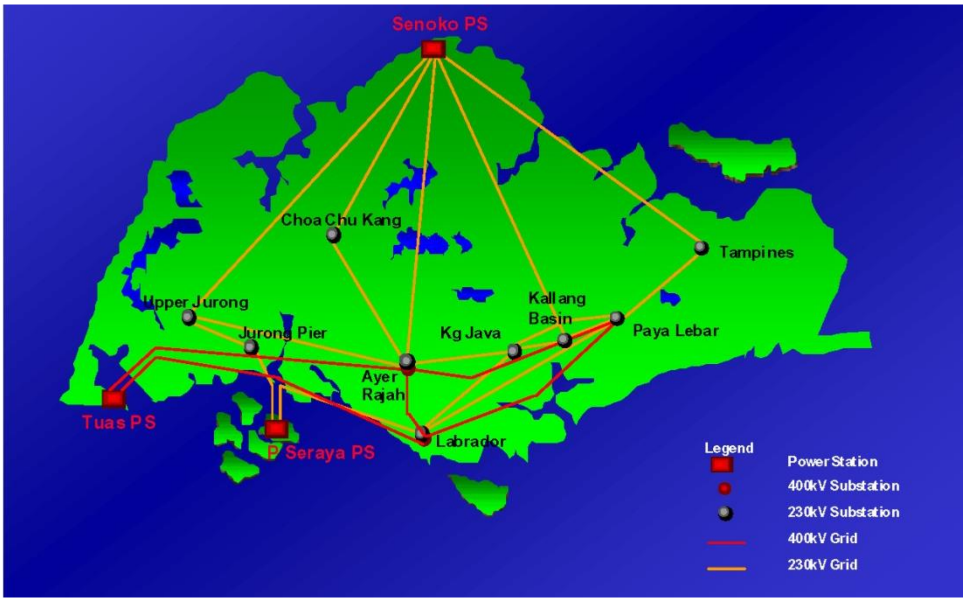
Source: Global Energy Network Institute (accessed 23 March 2015).

Figure 2-12. Transmission Lines in Malaysia



Source: Presentation material by the Tenaga Nasional Berhad in the first meeting of ERIA on the 'Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection', 2014.

Figure 2-13. Transmission Lines in Singapore



Source: Global Energy Network Institute (accessed 23 March 2015).

2.2. Route Selection Method

The following guidelines were used in deciding interconnection points (substations) along specific interconnection routes:

- Select from existing substations for interconnection points.
- Select from 500-kV substations or ultra-high voltage substations.

- Avoid selecting exclusive substations for certain IPP.
- Prioritise substations not discussed in the past.
- Select shorter linear distance route.
- Avoid crossing high mountains and wide rivers in the routes.
- Avoid crossing natural reserves or national parks in the routes.
- Consider future planned line routes or substations.

The following guidelines were used in deciding specific interconnection routes:

- In general, select the shortest linear distance route.
- Account for existing plans (urban planning, transmission line plans, etc.)
- Avoid crossing cities and communities. No residences within 50 metres of right of way.
- Avoid crossing natural parks (valuable natural resources), protected forests, valuable biological habitats, landing zones for migratory birds, etc.
- Avoid passing areas near airports.
- Avoid crossing wide rivers (one kilometre or greater), if possible.
- Consider crossing points with roads, rail, and other transmission lines.
- For workability in future construction work and convenience of maintenance work, select routes near roads.
- Select flatlands and avoid mountains.
- Select routes that pass close to planned hydropower plants, if any.

3. Selected Interconnection Routes

3.1. Viet Nam–Lao PDR

Between Viet Nam and Lao PDR, the Luang Prabang 2 (Lao PDR) and Nho Quan (Viet Nam) substations are selected for the following reasons:

- Connection location near Viet Nam's high-power consumption areas, i.e. Hanoi in the north or Ho Chi Minh City in the south.
- High concentration of natural parks in Viet Nam, southern Lao PDR, and north-eastern Cambodia, thus the route connecting northern Lao PDR and Viet Nam instead.

- The route between the Luang Prabang plant (IPP) and Nho Quan substation was discussed in the past but not implemented, thus the preference for this route.

Luang Prabang 2 (Lao PDR)	Luang Prabang 2 is a 230-kV substation scheduled for construction on the Mekong River in northern Lao PDR. It will be a large substation, collecting power from multiple hydropower plants in Nam Ou. Power is transmitted to the capital in Vientiane via Luang Prabang 2.
Nho Quan (Viet Nam)	Nho Quan is an existing 500-kV substation located about 100 km south of Hanoi.

The following guidelines were used in selecting the route: avoid national parks and mountains 1,500 m or higher in elevation.

3.2. Thailand–Lao PDR

Between Thailand and Lao PDR, the Luang Prabang 2 (Lao PDR) and Nan (Thailand) substations are selected for the following reasons:

- The Thailand side uses 500-kV transmission lines.
- There are three existing 500-kV circuits, and four planned circuits from Lampang in northern Thailand to Bangkok.
- The expansion of existing 500-kV lines will be minimal once the interconnection between northern Thailand and Lao PDR is realised.
- The Thailand substation is close to the Laotian border, with 500-kV transmission lines running from northern Thailand to Bangkok.
- On the Lao PDR side is a 230-kV substation near the Thai border.
- The route has the shortest linear distance between the Thai substation and the Laotian substation.

Nan (Thailand)	Nan is a new 500-kV substation located on transmission lines roughly halfway between the Hong Sa lignite thermal power station (IPP), currently under construction in Lao PDR, and the Lampang substation in Thailand.
Luang Prabang 2 (Lao PDR)	Refer to 3.1

The following guidelines were used in selecting the route:

- Avoid close national parks.
- Avoid close mountains 1,500 m or higher in elevation.
- Pass close to the planned Pakbeng hydropower plant.

3.3. Thailand–Malaysia

Currently, there is a 300-kV, 300-MW HVDC system between Thailand and Malaysia scheduled for expansion to a total of 600 MW in 2016. Thus, instead of exploring a new route, this line expansion is considered as the Thailand–Malaysia interconnection line.

The Thailand–Malaysia HVDC interconnection project establishes a new efficient interconnection between Khlong Ngae converter station in southern Thailand and Gurun converter station in northern Malaysia. Both converter stations are linked by a 300 kV DC overhead line of 110 km (approximately 24 km on the Thai side and 86 km on the Malaysian side). Initially, the converter stations were configured as a monopolar converter with a power transfer capacity of 300 MW. Provision has also been made for adding a second 300 MW pole to extend the system into a bipolar configuration with a total transfer capability of 600 MW.

Project implementation started in August 1997. A joint implementation committee was set up by EGAT and Tenaga Nasional Berhad (TNB) to oversee and ensure the consistent project implementation by both utility companies. Each utility is responsible for the HVDC station and the DC transmission line in each country. On Thailand’s side, the project involves the construction of a new DC transmission system and the reinforcement of the existing high-voltage AC transmission system.

Figure 2-14. Map of Thailand–Malaysia HVDC

HVDC = high-voltage direct current.
Source: Electricity Generating Authority of Thailand (accessed 3 March 2015).

Table 2-13. Specifications of Thailand–Malaysia HVDC

Smoothing reactor	100 mh,single core
Converter transformers	3 x 116 MVA, 1 phase – 3 winding 230/122.24/122.24 kv
Thyristor valves	T 1501 N75T-S34 12 group valves indoor air insulation suspension type No. of thyristor per valve : 48 Blocking voltage : 8 kv /1550 A
DC hybrid filters	Passive part filter (12/24 harmonics) Active part filter (6/15/21/24/27/33/36/42/48 harmonics)
Transmission line	DC, 110 km (24 km on Thailand's border and 86 km on Malaysia's boder) Pole conductor : 546 mm^2 (ASCR Cardinal) Neutral conductor :298 mm^2 (ASCR Hen)
Main contractor	Siemens AG ,Germany
Consultant	Teshmont Consultants Inc..,Canada

ASCR = aluminum conductor steel reinforced, DC = direct current, HVDC = high-voltage direct current, km = kilometre, kv = kilo volt, mh = milli henry, MVA = mega volt ampere
Source: Electricity Generating Authority of Thailand (accessed 3 March 2015).

3.4. Malaysia–Singapore

Currently, there is a 450-MW HVAC system between Malaysia and Singapore . Additionally, a 600 MW HVDC line is planned to connect from a thermal power plant on the Malaysian side. Thus, instead of exploring for a new route, this planned HVDC line is considered the Malaysia–Singapore interconnection line.

The TNB and the Singapore Power are interconnected from Plentong in the southern Malaysian Peninsula to the Senoko Power Station in Singapore via 2x250 MVA, 275 (TNB side)/230 (SP side) kV of AC overhead line (12 km) and submarine cables (4 km). The project was commissioned in 1985 to provide a source of power supply during extreme system emergencies for both interconnected power systems.

3.5. Thailand–Singapore (Direct Connection Line)

As part of the Lao PDR, Thailand, Malaysia, and Singapore power integration project, TNB proposed a transmission route across Malaysia, whose feasibility appears to be low due to high costs, although estimates have been made in this study for both HVAC and HVDC proposals. The dashed line in Figure 2-15 represents the proposed transmission line across Malaysia.

Figure 2-15. Thailand–Singapore Route through Malaysia

HVAC = high-voltage alternating current, HVDC = high-voltage direct current, kV = kilovolt.
Source: Tenaga Nasional Berhad.

4. Transmission Line Construction Costs

Conditions for cost estimation and calculated result are listed below:

Table 2-14. Conditions for Cost Estimation

No.	Items	Cost (Million US$)	Unit
1	**AC Transmission Lines 500 kV**		
	＊Capacity;:Maximum 1.8 GW/circuit		
	Overhead Transmission Lines	0.45	/km/circuit
	Submarine Cable Transmission Lines	5	/km/circuit
2	**DC Transmission Lines ±300 kV**		
	＊Capacity: Maximum 3.0 GW/circuit		
	Overhead Transmission Lines	0.3	/km/circuit
3	**Substations (every 160 km-line)**		
	Land, Civic, Buildings, Common Facilities	20	/location
	Equipment	10	/circuit
	Existing extensions	10	/circuit
4	**AC-DC Converters**	150	/GW/location

AC-DC = alternating current-direct current, GW = gigawatt, km = kilometre, kV = kilovolt.
Source: Prepared by the working group.

4.1. Viet Nam–Lao PDR

[Assumption]

- Type: HVAC 500 kV Overhead
- Number of circuits: Two (one circuit + one backup circuit)
- Number of routes: 0.9 GW/1.8 GW = 0.5, rounded up to one route
  *0.9 GW is minimum requirement capacity between Viet Nam and Lao PDR.
  *1.8 GW is typical AC circuit capacity.
- Transmission distance: 420 km
- Number of new substations: Two

[Cost]

Total: US$498 million

- Transmission: US$0.45M /km × 420 km × 2 circuits = US$378M
- Number of new substation: (US$20M + US$10M × 2 circuits) × 2 locations = US$80M
- Existing substation extension: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$378M + US$80M + US$40M) × 1 route = US$498M

4.2 Thailand–Lao PDR

[Assumption]

- Type: HVAC 500 kV Overhead
- Number of circuits: Two (one circuit + one backup circuit)
- Number of routes: 5.6 GW/1.8 GW = 3.11, rounded up to four routes

*5.6 GW is minimum requirement capacity between Thailand and Lao PDR.

*1.8 GW is typical AC circuit capacity.

- Transmission distance: 270 km
- Number of new substations: One

[Cost]

Total: US$1,292 million

- Transmission: US$0.45M /km × 270 km × 2 circuits = US$243M
- New substation: (US$20M + US$10M × 2 circuits) × 1 location = US$40M
- Existing substation extension: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$243M + US$40M + US$40M) × 4 routes = US$1,292M

4.3 Thailand–Malaysia

[Assumption]

- Type: HVDC ±300 kV Overhead
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.6 GW/3.0 GW = 0.2, rounded up to 1 route

  *0.6 GW is minimum requirement capacity between Thailand and Malaysia.

  *3.0 GW is typical DC circuit capacity.
- Transmission distance:110 km
- Number of AC-DC converters: Two
- Capacity of AC-DC converter: 0.6GW

[Cost]

Total: US$286 million

- Transmission: US$0.3M / km × 110 km × 2 circuits = US$66M
- AC-DC converter: US$150M/GW × 0.6 GW × 2 locations = US$180M
- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$66M +US$180M + US$40M) × 1 route = US$286M

4.4 Malaysia–Singapore

[Assumption]

- Type: HVAC 500 kV Overhead＋Submarine cable
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.9 GW/1.8 GW = 0.5, rounded up to 1 route

  *0.9 GW is minimum requirement capacity between Malaysia and Singapore.

  *1.8GW is typical AC circuit capacity.
- Transmission distance — Overhead: 12 km, Submarine cable: 4 km
- Number of new substations: zero

[Cost]

Total: US$91 million

- Transmission: US$0.45M/km × 12 km × 2 circuits + US$5M /km × 4 km × 2 circuits =

US$50.8M

- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (5US$0.8M + US$40M) × 1 route = US$90.8M

4.5 Thailand–Singapore

4.5.1 HVAC System

[Assumption]

- Type: HVAC 500 kV Overhead
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.9 GW/1.8 GW = 0.5, rounded up to 1 route
  *Grounds for capacity of 0.9 GW: As direct link between Thailand and Singapore is regarded as a dedicated line to meet import requirement of Singapore, necessary line capacity may be equivalent to that of export capacity from Malaysia to Singapore.
  *1.8 GW is typical AC circuit capacity.
- Transmission distance: 800 km
- Number of new substations: Five

[Cost]

Total: US$960 million

- Transmission: US$0.45M / km × 800 km × 2 circuits = US$720M
- Number of new substations: (US$20M + US$10M × 2 circuits) × 5 locations = US$200M
- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$720M + US$200M + US$40M) × 1 route = US$960M

4.5.2 HVDC System

[Assumption]

- Type: HVDC ±300 kV Overhead
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.9 GW/3.0 GW = 0.3, rounded up to 1 route
  *Grounds for capacity of 0.9 GW: As direct link between Thailand and Singapore is regarded as a dedicated line to meet the import requirements of Singapore, necessary line capacity may be equivalent to that of export capacity from Malaysia to Singapore.
  *3.0 GW is typical DC circuit capacity.
- Transmission distance: 800 km
- Number of AC-DC converters: Two
- Capacity of AC-DC converter: 0.9 GW

[Cost]

Total: US$790 million

- Transmission: US$0.3M/km × 800 km × 2 circuits = US$480M
- AC-DC converter: US$150M /GW × 0.9 GW × 2 locations = US$270M
- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$480M + US$270M + US$40M) × 1 route = US$790M

5. Land Acquisition Costs and Easement for Power Transmission

Because of the great difference in laws and costs, it is difficult to assume the accurate costs of land acquisition for transmission lines in each country covered in this study. Therefore, the following assumptions were made to come up with estimates. Note that estimates may vary greatly from actual costs.

- Interval of transmission tower: 400 m
- Foundation area of transmission towers: 200 m^2 (to be purchased)
- Right of way: 30 m (portion for easement to be acquired)
- Land acquisition costs: US$20/$m^2$ in rural areas; US$60/$m^2$ in urban areas
- Ratio of easement acquisitions: 10 percent usage rights in rural areas, 30 percent in urban areas

5.1. Viet Nam–Lao PDR

Of the total 420 km interconnection lines, 378 km (90 percent) are estimated to be in rural areas and 42 km (10 percent) in urban areas. Estimate results are shown in Table 2-15.

Table 2-15: Land Acquisition and Easement (Viet Nam–Lao PDR)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	378	42	420
Number of transmission towers	-	945	105	1050
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	3,780,000	1,260,000	5,040,000
Easement (under power lines)	US$	21,886,200	21,886,200	43,772,400
Total land acquisition cost (US$)				**48,812,400**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$49 million.

5.2. Thailand–Lao PDR

Of the total 270 km transmission interconnection lines, about 243 km (90 percent) are in rural areas and 27 km (10 percent) in urban areas. Estimates are shown in Table 2-16.

Table 2-16. Land Acquisition and Easement (Lao PDR–Thailand)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	243	27	270
Number of transmission towers	-	608	68	676
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	2,432,000	816,000	3,248,000
Easement (under power lines)	US$	14,069,280	14,065,920	28,135,200
Total land acquisition cost (US$)				**31,383,200**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$31 million for one route. As this location consists of four routes, grand total cost will be US$124 million.

5.3. Thailand–Malaysia

Of the total 110 km transmission interconnection lines, about 99 km (90 percent) are in rural areas and 11 km (10 percent) in urban areas. Estimates are shown in Table 2-17.

Table 2-17: Land Acquisition and Easement (Thailand–Malaysia)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	99	11	110
Number of transmission towers	-	248	28	276
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	992,000	336,000	1,328,000
Easement (under power lines)	US$	5,731,680	5,728,320	11,460,000
Total land acquisition cost (US$)				**12,788,000**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$13 million.

5.4. Malaysia–Singapore

It is assumed that no land acquisition and easements will be necessary for submarine portions of the transmission interconnection lines. All 12 km of the interconnection on land is estimated as urban line. Estimate results are shown in Table 2-18.

Table 2-18: Land Acquisition and Easement (Malaysia–Singapore)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km		12	12
Number of transmission towers	-	0	30	30
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	0	360,000	360,000
Easement (under power lines)	US$	0	6,253,200	6,253,200
Total land acquisition cost (US$)				**6,613,200**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$ 124 million.

5.5. Thailand–Singapore

Of the total 800 km transmission interconnection lines, about 720 km (90 percent) are estimated to be in rural areas and 80 km (10 percent) in urban areas. Estimates are shown in Table 2-19.

Table 2-19. Land Acquisition and Easement (Thailand–Singapore)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	720	80	800
Number of transmission towers	-	1800	200	2000
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	7,200,000	2,400,000	9,600,000
Easement (under power lines)	US$	41,688,000	41,688,000	83,376,000
Total land acquisition cost (US$)				**92,976,000**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$ 93 million.

6. Total Transmission Line Costs

6.1. Total Cross-border Transmission Line Costs

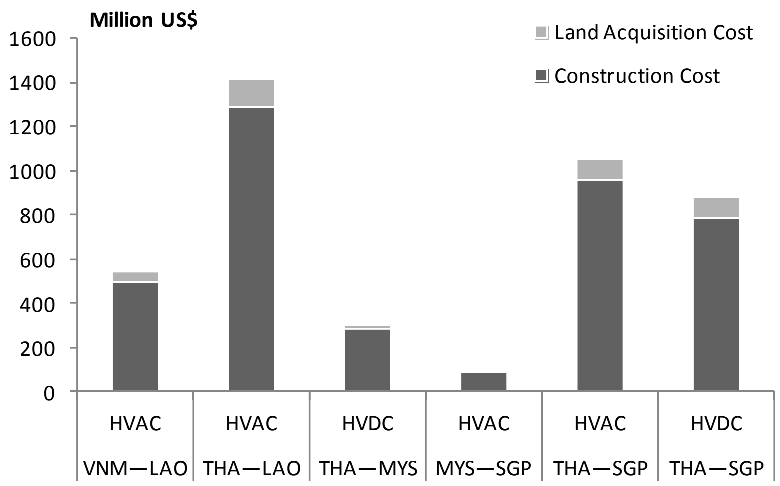
The costs of construction and land acquisition for each route are summarised in Table 2-20. With regard to direct connection between Thailand and Singapore, calculated results show that both HVAC and HVDC options are costly than an extension of existing interconnections in THA–MYS and MYS–SGP. Therefore, we are not going to discuss these expensive options.

Table 2-20. Costs of Interconnection and Land Acquisition

Interconnection Location	Type	Construction Cost	Land Acquisition Cost	Total Cost
VNM–LAO	HVAC	498	49	547
THA–LAO	HVAC	1,292	124	1,416
THA–MYS	HVDC	286	13	299
MYS–SGP	HVAC	91	7	98
THA–SGP	HVAC	960	93	1,053
	HVDC	790	93	883

HVAC = high-voltage alternating current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: US$ million.
Source: Prepared by the working group.

Figure 2-16. Line Construction and Land Acquisition Costs



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

6.2. Total Transmission Line Costs, by Case

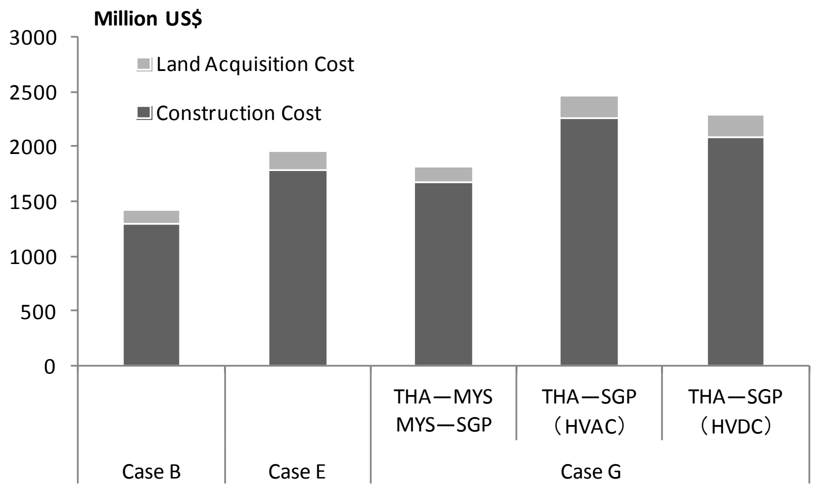
Table 2-21 summarises cost estimation for cases B, E, and G.

Table 2-21. Line Construction and Land Acquisition Costs, by Case

Case	Interconnection	Type	Construction Cost	Land Acquisition Cost	Total Cost
B	THA–LAO	—	1,292	124	1,416
E	VNM–LAO–THA	—	1,790	173	1,963
G	LAO–THA–MYS–SGP	THA–MYS MYS–SGP	1,669	144	1,813
		THA–SGP (HVAC)	2,252	217	2,469
		THA–SGP (HVDC)	2,082	217	2,299

HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: Million US$.
Source: Prepared by the working group.

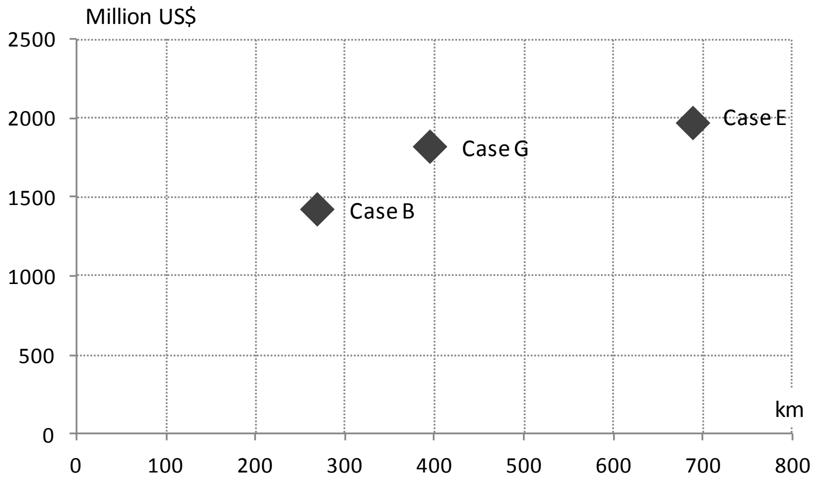
Figure 2-17. Interconnection Construction and Land Acquisition Costs, by Case



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, MYS = Malaysia, SGP = Singapore, THA = Thailand.
Source: Prepared by the working group.

Figure 2-18 describes a relationship between line distances and construction costs for each case.

Figure 2-18. Distances and Construction Costs, by Case



km = kilometre.
Source: Prepared by the working group.

From Figure 2-18, we can conclude the following:

- For Case E, the VNM–LAO–THA route has the longest distance (700 km) and the highest construction costs.
- As Case G spans Lao PDR, Thailand, Malaysia, and Singapore, the total distance seems to be the longest. However, as discussed before, direct connection between Thailand and Singapore is quite expensive; thus, extending the existing AC line is cheaper and realistic. Therefore, the combined distance will be roughly equivalent to the VNM–LAO segment at approximately 400 km.
- Case G is costly despite its distance as it uses HVDC lines for the THA–MYS section, and a submarine HVAC cable for MYS–SGP.

7. Transmission Line Construction Costs per Kilowatt-hour

7.1. Power Trade Flow and Equations

The transmission line construction cost per kWh, *CkWh,* excluding line maintenance costs and management fees, is calculated with the simple expression.

$$C_{kWh} = C_{US\$} / T / W_{2035}$$

Where,

C_{kWh} : Transmission line construction costs per kWh (US¢/kWh)

$C_{US\$}$: Transmission line construction costs for each route (Million US$)

T : Service life of new interconnection lines (years), assumed at 30 years

W_{2035} : Average annual power trade flow in 2035 of all cross-border interconnection lines (TWh)

7.2. Calculation

By using above-mentioned equation, we calculated cost per unit electricity flow for each cross-border line, and then summed up each unit cost by case.

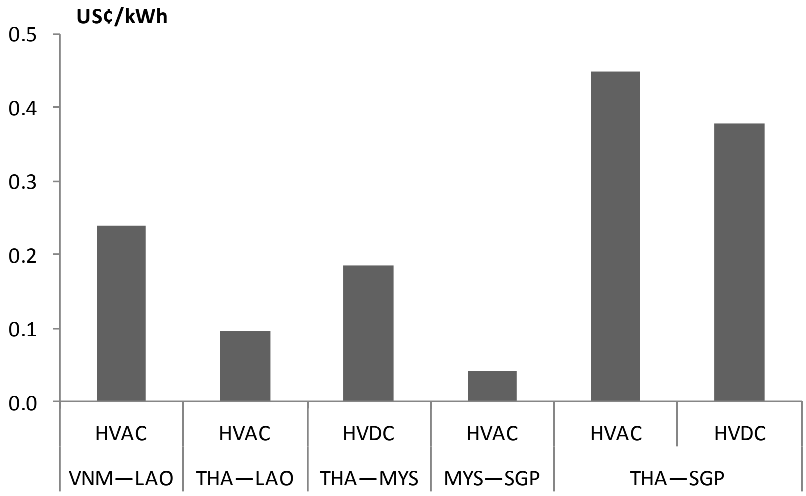
In terms of initial investment cost, the VNM-LAO route seems lower in feasibility due to its overall transmission line cost per kWh of over US¢ 0.2.

Table 2-22. Transmission Line Costs per Kilowatt-hour, by Route

Interconnection Location	Type	Total Flow (TWh)	Total Cost (Million US$)	Total Cost per kWh
VNM–LAO	HVAC	7.6	547	0.240
THA–LAO	HVAC	49.4	1,416	0.096
THA–MYS	HVDC	5.4	299	0.185
MYS–SGP	HVAC	7.8	98	0.042
THA–SGP	HVAC	7.8	1,053	0.450
	HVDC	7.8	883	0.377

kWh = kilowatt-hour, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, TWh = tera watt hour, VNM = Viet Nam.
Unit: US¢/kWh.
Grounds for total flow of THA–SGP (7.8 TWh): As direct link between Thailand and Singapore is regarded as a dedicated line to meet the import requirement of Singapore, necessary line capacity may be equivalent to that of export capacity from Malaysia to Singapore.
Source: Prepared by the working group.

Figure 2-19. Transmission Line Costs per Kilowatt-hour, by Route



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

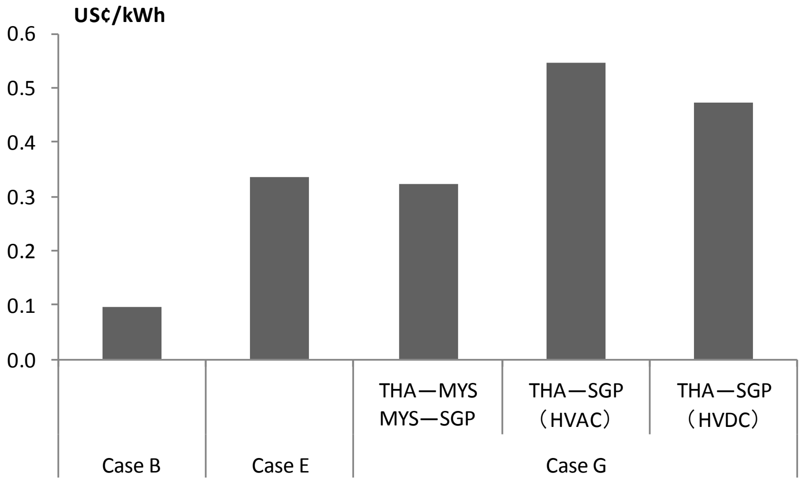
Feasibility is lower for Cases E and G, due to the high overall transmission line cost per kWh in terms of initial investment cost. If the project can strictly control and keep construction costs low, Case B is the lowest in necessary capital.

Table 2-23. Transmission Line Costs per Kilowatt-hour, by Case

Case	Interconnection	Type	Total Cost (Million US$)	Total Cost per kWh
B	THA–LAO	—	1,416	0.096
E	VNM–LAO–THA	—	1,963	0.335
G	LAO–THA–MYS–SGP	THA–MYS MYS–SGP	1,813	0.322
		THA–SGP (HVAC)	2,469	0.546
		THA–SGP (HVDC)	2,299	0.473

HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: US¢/kWh
Source: Prepared by the working group.

Figure 2-20. Transmission Line Costs per Kilowatt-hour, by Case



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, kWh = kilowatt-hour, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

8. Costs and Benefits of Interconnections

This section compares costs and benefits of each interconnection case.

8.1. Cost and Benefit Comparison from 2025 to 2035

The cost of the new interconnection lines was estimated in the following manner. This methodology is the same as that taken in the 2014 study.

- The transmission lines will be constructed in 2025, with the full cost added that year.
- The operation and maintenance (O&M) cost (0.3 percent of the construction cost) is added annually starting the following year, 2026.
- With a discount rate of 10 percent, the net present value in 2025 is calculated.

With regard to the benefit of having a new line, reduction of fuel cost and power plant investment cost, the study used the same number which was estimated in a 2014 study.

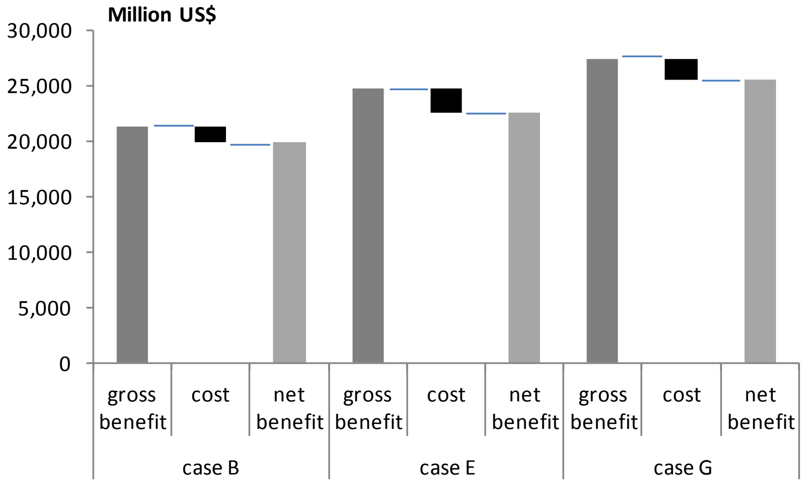
Table 2-24 shows the results of the above-mentioned calculations. The results indicate that net benefits seem high enough compared to line addition costs (capital expenditure + operating expenditure).

Table 2-24. Costs and Benefits of Interconnection Lines (2025–2035)

Case		Gross Benefit	Cost	Net Benefit
B	THA–LAO	21,387	(1,506)	**19,881**
E	VNM–LAO–THA	24,707	(2,097)	**22,610**
G	LAOTHAMYSSGP	27,490	(2,000)	**25,490**

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: Million US$.
* Plus value in the table means gain in benefit.
Source: Prepared by the working group.

Figure 2-21. Costs and Benefits of Interconnection Lines (2025–2035)



Source: Prepared by the working group.

8.2. Unit Cost and Benefit Comparison from 2025 to 2035

The trade flow from 2025 to 2035 under Case 2b is shown in Table 2-25.

Table 2-25. Trade Flow from 2025 to 2035, by Route

Route	Trade flow from 2025 to 2035
VNM–LAO	105
LAO–THA	567
THA–MYS	52
MYS–SGP	91

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: TWh
Source: Prepared by the working group.

Table 2-26. Trade Flow from 2025 to 2035, by Case

Case		Trade flow from 2025 to 2035
B	THA–LAO	567
E	VNM–LAO–THA	672
G	LAO–THA–MYS–SGP	709

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: TWh
Source: Prepared by the working group.

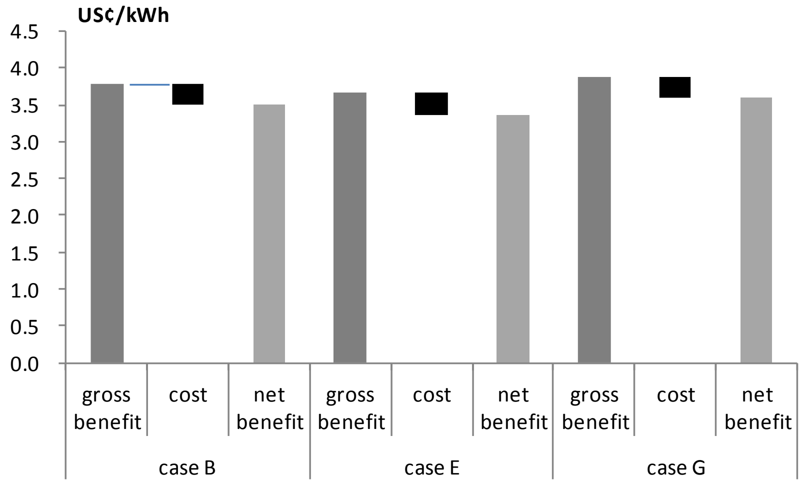
The cumulative benefit of transmissions per kilowatt-hour is shown in Table 2-27, and the formula of the calculation is simply: Benefit [M US$]/Flow[TWh].

Table 2-27. Unit Cost and Benefit of Interconnection Lines (2025–2035)

Case		Gross Benefit	Cost	Net Benefit
B	THA–LAO	3.77	0.26	**3.51**
E	VNM–LAO–THA	3.68	0.32	**3.36**
G	LAO–THA–MYS–SGP	3.88	0.28	**3.60**

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: US¢/kWh
Source: Prepared by the working group.

Figure 2-22. Unit Cost and Benefit of Interconnection Lines (2025–2035)



kWh = kilowatt-hour, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

8.3. Return on Investment

The return on investment on the interconnections is calculated with the formula:

Cumulative benefit from 2025 to 2035 [Million US$]

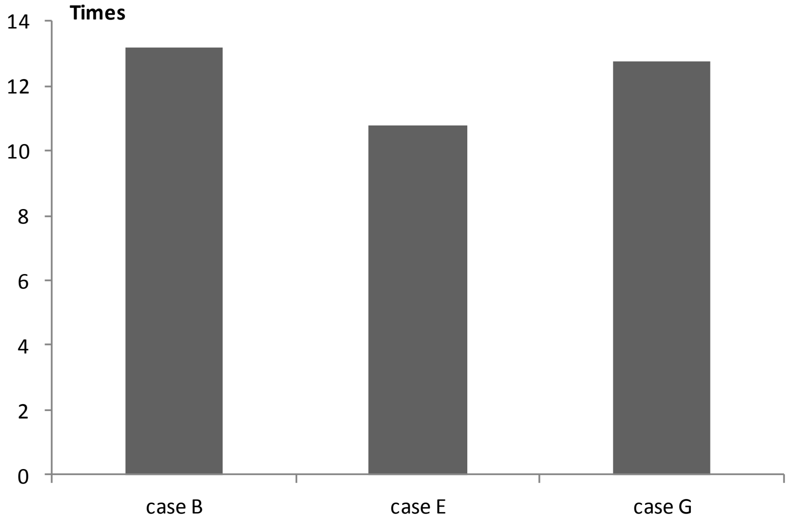
÷ Construction Cost with land [Million US$]

Table 2-28. Return on Investment (2025–2035)

Case		Net Benefit [Million US$]	Construction Cost ［Million US$］	Benefit/Cost ［-］
B	THA–LAO	19,881	1,506	13.2
E	VNM–LAO–THA	22,610	2,097	10.8
G	LAO–THA–MYS–SGP	25,490	2,000	12.7

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

Figure 2-23. Return on Investment (2025–2035)



LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore,
THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

8.4. Summary of Cost and Benefit Comparison

- Case G provides the largest net benefit.
- In terms of unit net benefit, Cases B and G are performing better than the others.
- In terms of return on investment, Case B is the most beneficial.

CHAPTER 3

Institutional and Regulatory Framework

In this chapter, the current power transmission interconnections in the ASEAN region are outlined based on the power business system, power infrastructure development plan, and technical standards. Also presented is an introduction to the Nordic Grid that has, from long ago, enabled electric power interchange across country borders and established an efficient power supply system. Finally, based on indications from precedents, the future direction and tasks are summarised to realise an area-wide interconnection network in ASEAN countries.

1. Power Grid Interconnection Situation in the ASEAN Region

The significance of international interconnection of transmission lines is implied by the availability of a power pool, i.e. power imports and exports, amongst power systems. The effects of international interconnection can be roughly divided into improvement of power supply reliability and economic benefits through reduction of power generation costs, i.e. fuel costs and the costs of avoided peak-power capacities.

The former becomes significant, for instance, when a country's power supply suddenly becomes insufficient due to a sudden increase in electricity demand or a serious accident at a generation facility, and the nation's demand cannot be met by power sources in the country. Power imports then become important to bridge the supply and demand gap. Also, for instance, when peak-hour demands for electricity differ between two adjacent countries, the powersupply capability of a neighbouring country can be utilised as the reserve supply capacity for another country. In this way, international interconnection secures the same level of power supply reliability with lower reserve supply capacity than what is otherwise considered necessary for a single power system maintaining a certain level of power supply reliability.

The latter signifies that interconnection of power transmission lines makes purchase of electricity from power systems of other countries cheaper than what is generated by a country's power system. In the ASEAN region, energy resources such as coal, natural gas, and hydropower vary depending on the country and region. A large part of potential resources exist in regions with relatively low demand, while supply capability and soaring generation costs due to lack of resources have become major tasks in regions with high energy demand. For instance, some ASEAN countries, especially Lao PDR, Cambodia, and Myanmar, have relatively high hydropower generation potentials. By comprehensively planning the development of power sources, utilising such potential resources, and establishing power transmission interconnection networks in the region, it may become possible to economically balance the power supply and demand across the region.

The ASEAN region is strengthening its international interconnection with 16 interconnectivity projects led by the Heads of ASEAN Power Utilities/Authorities (HAPUA). A steady rise in electricity demand in ASEAN is expected and a stable supply of electricity becomes increasingly important. There is no doubt that strengthening power transmission interconnections will further be promoted to gain economic benefits and ensure energy security in the region.

The power supply and demand situation, characteristics, background factors, and significance of international interconnection promotions are summarised below for the countries that participated in this study's working group. For details, readers can refer to the Appendix of this report.

Cambodia	● Power plants in the country are few and generation cost is high due to the energy mix centred on petroleum-fired thermal power. Power imports are advantageous in terms of stable supply and the economy. ● While development and diversification of power sources in the county are urgently needed, power import is necessary for the time being to fill the short- to medium-term supply-and-demand gap.
Indonesia	● Being an island country, there is constant shortage of power in regions where interconnection is difficult, and the country is forced to supply high-cost electricity generated by petroleum-fired power plants. ● Interconnection with neighbouring countries with different electricity demand peaks will enable efficient power supply and improvement of supply reliability.
Lao PDR	● By exporting electricity generated by hydropower resources that are relatively abundant compared to the country's power demand, it is possible to acquire foreign currency. ● Power import will supplement power shortage during dry season, a weakness of an energy mix focused on hydropower.
Malaysia	● The current interconnection lines are reserved supply mainly for emergency situations. ● Based on high-energy demand in Peninsular Malaysia, power transmission

	projects utilising the abundant indigenous resources in Sumatra (Indonesia) and large hydro-potential resources in Sarawak (Malaysia) are in progress.
Singapore	● Since the country has no domestic energy resources, enhancement of energy security is important. Importing electricity from neighbouring countries is one option. ● Because the nation is a small territory with high population density, it is difficult to introduce large-scale coal-fired thermal power or nuclear power plants. Currently, over 80 percent of Singapore's power supply is generated by imported pipeline gas and liquefied natural gas (LNG).
Thailand	● Since it takes time to establish new power plants, the country's rapidly increasing power demand is addressed by actively investing in power projects in neighbouring countries. ● The ratio of gas for power source is especially high, and its reduction is a task for the future. To diversify energy sources and reduce generation costs, electricity imports from neighbouring countries are positioned as one option.
Viet Nam	● Since the country is long from north to south, loss in power transmission is large, and power imports are more economical and efficient for some areas. ● Power demand is rapidly increasing, and in contrast the development potential of domestic power resources is likely to be reduced.

Is the system adequate to strengthen power transmission interconnection in the future? Let us visit the current situation of the 'power business system', 'power infrastructure development plan', and 'technical standards'.

Power market structure	● In many countries, a dominant national enterprise exists and a single-buyer system is adopted. ● The establishment of a regional institutional framework for cooperation or unification of regulations on power trading has started.
Power infrastructure development plan	● There is no common management or evaluation system for the region. ● Potentially HAPUA takes this role but should strengthen it.
Technical standards	● Currently vary depending on the country and project. ● Potentially HAPUA formulates common technical standards and rules.

1.1. Structure of the Power Market

A large part of the power sector in ASEAN countries used to be monopolised with a vertically integrated national enterprise. However, amidst rapid increase in power demand since the 1990s, to realise early expansion of power supply sources and provision of effective power services, structural reforms and introduction of the principle of competition were considered,[1] and privatisation and liberalisation progressed gradually.

[1] In 1998, the ASEAN countries fell into serious investment funds shortage due to the Asian financial crisis, and they requested various international financial institutions for supply of funds. As a condition of lending though,

Currently, the single buyer system is adopted by many ASEAN countries, and the transmission sector is separated albeit in different forms. Generally, while only the power-generation sector is liberalised and independent power producers (IPPs) enter the market, the single buyer purchases all the generated electricity and sells it exclusively to power distributors. From such point of view can parties in the import and export of electricity be identified. As a side note, competition is introduced into both the wholesale and retail sectors in some countries (i.e. Singapore and the Philippines), and the price pool system, which is far more deregulated than the single buyer system, is adopted in such countries.

Meanwhile, amidst the gradual advancement of structural reforms for traditional vertically integrated power systems, it has become important to strengthen the roles of regulatory bodies that control an entire power sector. For instance, under the single buyer system, regulatory bodies are required to perform price control including determination of the cost for ancillary services and calculation of power transmission costs, in addition to conventional work. On this point, with the placement of regulatory bodies, rules that ensure transparency and independence of transmission companies and transmission system operators (TSOs) will prove worthy. In general, the system of regulatory bodies in the ASEAN countries is bipolarised depending on the country, where regulatory bodies are divided into those politically independent bodies and those organised under relevant ministries.

Power trading in ASEAN countries is currently limited to bilateral trading and projects centred on direct power transmission from power plants to areas of demand. Therefore, it is possible to operate power systems without specifically forming detailed rules. However, if interconnections in the future span more than two countries and power trading becomes bidirectional, a cooperative organisation by the regulatory authorities of each country for formulating common rules or realising fair management of power transmission lines will become necessary.

---

international financial institutions demanded market reforms of loan-receiving countries. This has led to promotion of structural market change in ASEAN countries.

Figure 3-1. Structure of the Electricity Supply Industries in ASEAN

	Regulators: Independent	Regulators: Department	Structure
Brunei: DES Dept. of Electrical Services		✓ under the Minister of Energy	Single Buyer
Cambodia: EAC Electricity Authority of Cambodia	✓ Set up in 2001		Single Buyer
Indonesia: DEMR Dept. of Energy& Mineral Resources		✓ under Ministry of Energy & Mineral Resources	Single Buyer
Laos (DOE) Department of Electricity		✓ Under the Ministry of Energy and Mines (MEM)	Single Buyer
Malaysia Energy Commission	✓ Set up in 2001		Single Buyer
Myanmar		✓ under the Ministry of Electric Power 1& 2	Single Buyer
Philippines: ERC Energy Regulatory Commission	✓ Set up in 2001		Price Pool
Singapore: EMA Energy Market Authority		✓ under the Ministry of Trade and Industry	Price Pool
Thailand: ERC Energy Regulatory Commission	✓ Set up in 2007		Single Buyer
Vietnam: ERAV Electricity Regulatory Authority		✓ under the Ministry of Industry (MOI)	Cost Base Pool

Note: Lao PDR's Department of Electricity is now Lao PDR Department of Energy Policy and Planning.
Source: ERC's Role to Enhance Power Supply Security, February 2014.

Regarding this, a formal network under ASEAN was established with the timeline below.

- The Energy Regulatory Commission of Thailand has hosted annual meetings of ASEAN energy regulators since 2010.
- The 1st ASEAN Energy Regulators Network (AERN) meeting was held in March 2012.
  - Draft of AERN's terms of reference was circulated to ASEAN member states for comments.
  - The Energy Regulatory Commission of Thailand organised an interim AERN meeting on 28–29 August 2012 in Bangkok to finalise the terms of reference and work plan of AERN.
- The second AERN meeting was held in March 2013.
  - Final draft terms of reference of AERN and AERN work plan for 2012–2013
  - Preparation for the 31st Senior Officials Meeting on Energy in Indonesia
  - AERN chairmanship transition in 2014
- AERN will focus on regulatory issues related to regional power trade.

As such, the establishment of a regional institutional framework for cooperation or unification of regulations on power trading has started in ASEAN.

1.2. Power Infrastructure Development Plan

The benefits of establishing international interconnection transmission lines in the ASEAN region are obtained through 1) reduction in quantity of power plant development, and 2) effective utilisation of cheaper fuel for power generation in the region including potential hydropower.

About the first benefit, establishment and enhancement of interconnection power transmission lines can secure the same level of power supply reliability for a lower reserve supply capacity than what is considered necessary for a single network. However, this financial effect can be maximised by incorporating into the energy mix electric power interchange with other countries as one of supply abilities and by reducing duplicated investment in the development of power plants and interconnection transmission lines. That is because the establishment of power plants on the premise of self-sufficiency contributes to the improvement of a country's supply reliability, yet has an adverse effect to reduce the necessity and benefit of cross-border transmission lines for the ASEAN region as whole. Therefore, for this benefit to materialise, relevant parties of each country need to recognise this and prioritise construction of interconnection transmission lines over construction of a country's own power sources.

Most development plans for both power plants and transmission and distribution lines in ASEAN countries are formulated to maintain their own electricity supply and demand balance without import. Additionally, existing cross-border transmission lines are constructed at project-to-project basis, thus there is no coordinative formulation of plans or operation and management that are systematic and integrated for the entire region.

Regarding the second benefit, for instance, actively promoting the development of hydropower generation facilities through the IPP method and selling the generated power to countries of high demand within the region to acquire foreign currency are planned in Lao PDR, Cambodia, and Myanmar. However, most plans are one-on-one correspondence between some export-only power plants and power-importing country, or power plants are directly connected by power transmission lines to areas of demand and all electric power generated is traded according to power purchase agreements. Thus, even the surplus power generated cannot be interchanged for other systems. Meanwhile, most hydropower stations developed for domestic demands do not have interconnecting transmission lines with systems in other countries. Since electric power generation must always be maintained at a level that matches the demand, water not used for power generation, for instance, is often discharged for no specific use.

What is required to effectively utilise such surplus power and power that could be generated if the idle discharge was utilised and to reduce fuel costs is a system that systematically coordinates power infrastructure development in each country and manages and evaluates establishment of power transmission networks that interconnect with systems in other countries.

1.3. Technical Standards

Each ASEAN member country carries out power supply and system operation by its own technical standards. Basically, there is no systematic or united management for the entire region. Also some countries have internal problems concerning the power business, such as weak organisation system, absence of an organisation that properly monitors the system for the entire nation, inadequate electric power technical standards, and improper system operations.

The current electric power trading across borders is mainly trading power generated by specific power plants. Power flow is often one-sided and trading is positioned as a power source with transmission line per project rather than a system interconnection. Thus, some countries adjust supply and demand only by a small number of power plants in fixed-power export destinations. Additionally, since only a small number of interconnections exist, power trading is unlikely causing crucial damage to power supply or system stability.

However, power systems are expected to grow in complexity and operational problems a cause for concern as the development of cross-border transmission lines progresses and interconnection expands in the future. While interconnections have advantages in terms of stable power supply and economic operation, failure of one interconnection may cause wide-area impact. For instance, an accident occurring in one country can infect the entire system and induce massive power outage.

Thus, as transmission interconnections become denser, measures to prevent the spread of power system faults will be necessary. Therefore, it is important to establish region-wide common technical standards and rules based on advanced power system technology, where coordination by HAPUA and/or other regional organisation would be effective.

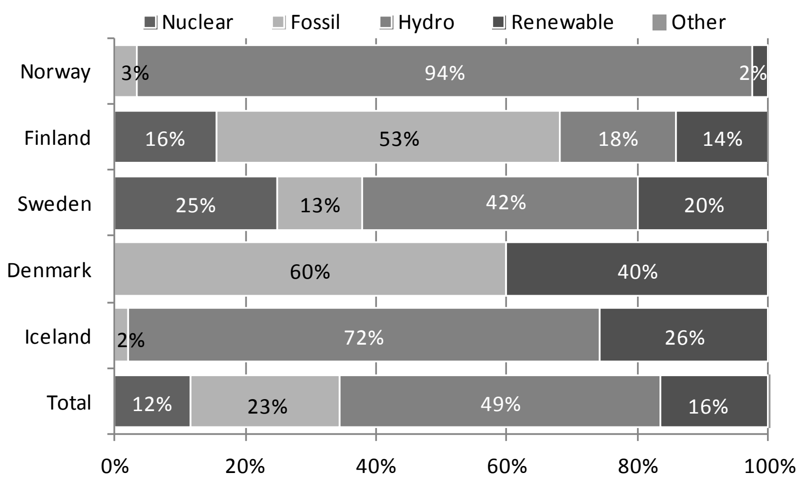
2. An Example of Nordic International Interconnection

Hydropower is the main power source for Norway, nuclear and hydropower for Sweden, thermal power for Finland, and thermal and renewable power for Denmark. Due to such differences in the energy mix, a long tradition in energy policy cooperation exists amongst Nordic countries. The political parties of Scandinavian countries widely recognise that individual country's possession of reserve power supply capacity incurs high costs. For that reason, interconnection of power systems has long been established and electric power interchange has been practised in the region.

In the ASEAN region, cross-border power transmission projects are in progress, centred on the ASEAN Power Grid and Greater Mekong Subregion, to maximise the use of potential power generation resources in the region. However, due to various reasons, progress on some projects has not been going smoothly.

This section outlines the Nordic cooperation and describes in detail the lessons learnt from such venture. This precedent may be useful in establishing a transmission network in the ASEAN region.

Figure 3-2. Net Generating Capacity of Nordic Countries (as of 31 December 2013)



MW

	Nuclear	Fossil	Hydlo	Renewable	Other	Total
Norway	0	1,090	30,753	757	0	32,600
Finland	2,752	9,312	3,168	2,484	21	17,737
Sweden	9,531	4,999	16,150	7,593	0	38,273
Denmark	0	8,886	9	5,960	0	14,855
Iceland	0	52	1,860	663	0	2,575
Total	12,283	24,339	51,940	17,457	21	106,040

Source: ENTSO-E, Yearly Statistics & Adequacy Retrospect 2013.

2.1. Background of Nordic Cooperation

International interconnection lines amongst countries in the Nordic region have been developed since the 1960s as an economic operation for countries (Denmark, Finland, Iceland, Norway, and Sweden) with different energy mixes. In 1963, Nordel was established as an association for electricity cooperation in the Nordic region. In July 2009, Nordel was integrated with cooperative institutions of system operators in other regions of Europe, and ENTSO-E was launched as the legally mandated body of transmission system operators (TSOs) in Europe. Even now, the former name is inherited within ENTSO-E as the synchronous areas of the Scandinavian Peninsula and eastern Denmark.

The background of Nordic cooperation is described below, based on the *Nordel Annual Report* and the Nordic Grid Code.

Up to the 1960s, there was a strong national focus and rising demand for interconnection in the Nordic region. The first steps toward such endeavour were made by the power companies, all of which basically were state owned and vertically integrated.

During the 1960s, as electric power consumption increased considerably in the Nordic countries, the opportunities for linking together different power generation portfolios and creating shared reserve margins attracted great attention. The members of Nordel were seeking benefits from coordinating the expansion and operation of their grids.

In the 1990s, to increase efficiency in the electrical sector, Nordic countries, starting with Norway, elected to expose electricity generation and trading to competition, and to separate these functions from the transmission function which had a natural monopoly state. As there has been a trend since the 1980s toward free competition both in the European Union and elsewhere in the world, Nord Pool, the world's first international electric power exchange, was launched in 1996. Contributing to the rapid development of the open common Nordic electric power market were a well-functioning electric power system and a good tradition of cooperation within Nordel.

Nordel was a body for cooperation amongst TSOs in the Nordic countries whose primary objective is to create the conditions for, and to develop further, an efficient and harmonised Nordic electricity market, regardless of national borders. Nordel also served as a forum for contact and cooperation between TSOs and representatives of the market players in the Nordic countries. To create the right conditions for the development of an efficient electricity market, it was important for TSOs to meet with the market players for mutual exchange of views.

Nordel's strategy was formulated on the vision that Nordel would act as one Nordic TSO and be the basis for a harmonised Nordic electricity market; be in the front rank in the development of the Nordic electricity market; be a strong force in the development of the European electricity market; and be able to react quickly to challenges, make decisions, and have a shared commitment to implement them.

The Nordel vision resulted in a number of tasks as follows:

- System development and rules for network dimensioning, including coordination of grid investments and congestion management
- System operation, operational security, reliability of supply, and exchange of information
- Principles of transmission pricing and pricing of ancillary services, including transit solutions
- International cooperation
- Maintaining and developing contacts with organisations and regulatory authorities in the power sector, particularly in the Nordic countries and Europe
- Preparing and disseminating neutral information about the Nordic electricity system and market

Most of Nordel's work was carried out by its permanent committees, i.e. planning committee, operations committee, and market committee, made up of the leaders responsible for corresponding sectors in the TSOs. The working groups were composed of technical specialists from the TSOs.

The planning committee was responsible for technical matters of long-term nature concerning the transmission system and the exchange of information in relation to the expansion of the electricity system. The objectives of the planning committee were:

- To achieve continuous and coordinated Nordic planning between the TSOs, so that the best possible conditions could be provided for a smooth-functioning and effectively integrated Nordic electricity market.
- To initiate and support changes in the Nordic power system, which would enable satisfactory reliability of system supply through the effective utilisation of existing and new facilities.
- To be instrumental in developing the Nordic power system. When planning transmission facilities, impact assessments must integrate the need to preserve and protect the natural environment.

To achieve the above-mentioned objectives, the following means were defined:

- The planning committee drew up future scenarios for the expansion of the Nordic power system with a time horizon of up to 20 years.
- Each year, the planning committee presented prognoses for future energy/power balance, energy forecast on normal and dry years, and power forecast on normal peak load and extreme peak load.
- Every second year, the planning committee presented a summarised Nordic Grid Master Plan which primarily consisted of projects that had an effect on the capacities amongst the Nordic TSOs.
- The planning committee continuously updated the Nordic Grid Code and had overall responsibility for the continuous updating of recommendations for shared rules of the dimensioning transmissions (planning criteria) for the TSOs and the Nordic main grid (Planning Code).
- The planning committee also had overall responsibility for compiling and updating common system-oriented requirements for future connection of generation, transmission, and consumer facilities to the grid (Connection Code).
- The planning committee ensured the gathering, updating, and application of shared grid, electricity supply–demand data. Planning tools were the responsibility of each TSO but Nordel played a coordinating role in relation to the TSOs choosing tools that facilitate their work.

The operations committee was responsible for short-term issues concerning joint operation of the various subsystems in the interconnected Nordic transmission system and for defining a technical and market-focused framework for grid operation.

The operations committee coordinated operational cooperation between the Nordic TSOs and aimed to promote the ideal utilisation of the Nordic electricity transmission system as per market needs, taking into account the agreed technical quality and operational reliability.

The committee's work focused on system operation issues which concern the utilisation of the grid, operational reliability, as well as congestion and balance management. The Nordic system operation agreement constituted the formal foundation for this cooperation.

The market committee's goals were:

- to contribute toward creating a borderless Nordic market for the market players, thereby augmenting the market's efficiency and functionality; and
- to contribute toward the rules of play in Europe being formulated in such a way as to promote a positive market trend and an efficient interplay with the Nordic market.

2.2. Nordic Grid Master Plan

The Nordic TSOs have a long tradition of cooperation on grid development, market development, and operational questions. Before ENTSO-E was founded in 2009, the Nordic TSOs had produced several grid development plans under the Nordel umbrella:

- 2002: Nordic Grid Master Plan analysing the bottlenecks

The basis for the transmission planning and long-term capacity allocation in the Nordic region was the Nordic Grid Master Plan. This was the first joint Nordic Grid Master Plan building upon many years of Nordic cooperation in grid planning. The plan looked at the future transport patterns in the Nordic transmission network and identified a number of important cross-sections which were to be subject to more detailed analyses in the plans that followed. The Grid Master Plan was not an investment plan, but identified the cross-sections that were further analysed.

In the analysis for the plan in 2002, the foreseen future energy balance in the Nordic area for 2005–2010 was negative with increasing demand and decommissioning of old generation units and very few new plants taken into operation. The analysis indicated an energy shortage and increasing interdependency on trade with neighbouring regions and a need for energy imports to the Nordic area. This identified two major predicted transmission patterns: in the east–west direction through the area, from Russia through Finland and Sweden to Norway and possibly to the United Kingdom, and north–south between Norway/Sweden and the Continent.

- 2004: Priority cross-sections defining five prioritised projects

The follow-up to the Nordic Grid Master Plan 2002 was presented in 2004 in the priority cross-sections report, where an updated analysis of the predicted situation for 2010 was performed. The energy balance for the Nordic area looked more positive for 2010 than in the previous plan with the Nordic area roughly in balance between generation and demand. Behind the assumption were plans for new nuclear power in Finland as well as gas-fired generation and wind power in Norway.

The analysis identified typical transmission pattern in the Nordic area. Several transmission constraints were expected in these transport channels.

The report concluded that Nordel had identified five critical cross-sections that would be beneficial to reinforce.

- Between Central and Southern Sweden (Snitt 4)
- Between Funen and Zealand in Denmark (A Great Belt connection)
- Between Finland and Sweden (A new Fenno–Skan connection)
- Between Norway and Sweden (A new Nea–Jarpstrommen connection)
- Between Norway and Denmark (A new Skagerrak connection)

These five reinforcements were presented as a common Nordic reinforcement package, and the actual investments were to be handled bilaterally between the involved TSOs.

- 2008: Nordic Grid Master Plan; three new projects, analysing the connections to the Continent

A new Nordic Grid Master Plan was presented in 2008. It looked at the situation in the Nordic area and the capacity to neighbouring countries given that the reinforcement package from the previous plan was implemented. The analysis was made in a scenario representing 2015 with the reinforcements in operation. Possible further reinforcements were identified and tested for robustness in four scenarios representing different energy market developments until 2025. The scenarios covered a spread of Nordic energy balances from a large surplus to a substantial deficit.

Based on the analysis, Nordel recommended that the TSOs started planning to reinforce the following internal Nordic cross-sections. All these reinforcements showed positive benefits in all four future scenarios.

- Between Sweden and Southern Norway (realised through the South–West link)
- Between Sweden and Norway north–south axis (realised through Orskog–Fardal)
- Arctic region (realised through Ofoten–Balsfjord–Hammerfest)

● 2009: Multiregional plan together with Baltic, Polish, and German TSOs

An extended, multiregional study was performed in 2008–2009 by TSOs from Nordel, BALTSO (the organisation of TSOs in the Baltic states) and Poland. The aim was the development of a coordinated extension plan of interconnections from the Baltic states to Poland and to the Nordel area to satisfy transmission needs between the regions. The study looked at the socio-economic benefits of three specific interconnectors: Estonia–Finland, Lithuania–Poland, and the Baltic states–Sweden

The methodology was similar to the previous Nordel study, using one base scenario for 2015 and three scenarios for 2025 and with benefits calculated from market model analysis.

The overall conclusion was that a solution with all three interconnections was the best solution. The results showed that the capacity provided by the interconnectors would be needed already in the scenario for 2015.

In 2009, European TSO cooperation was gathered in the new ENTSO-E organisation and regional cooperation in Nordel was suspended. Also, the cooperation on pan-European and regional grid development was reorganised, establishing regions comprising several countries in one region. This was an excellent opportunity for the Nordic TSOs to embed their existing cooperation into a wider regional context, thus ensuring further integration of the countries involved.

2.3. Nordic Grid Code

Each Nordic country had, until June 2004, its own instructions, but in June 2004, Nordel introduced a common Nordic Grid Code. The formulation of this common code for the Nordic grid was a step towards the harmonisation of the rules that governed the various national grid companies. The purpose of the Nordic Grid Code was to achieve coherent and coordinated Nordic operation and planning between the companies responsible for operating the transmission systems, in order to establish the best possible conditions for developing a functioning and effectively integrated Nordic power market. A further objective was to develop a shared basis for satisfactory operational reliability and quality of delivery in the coherent Nordic electric power system.

The Grid Code was made up of general provisions for cooperation, planning code, operational code (system operation agreement), connection code, and data exchange code (data exchange agreement amongst the Nordic TSOs).

The operational code and the data exchange code were binding agreements with specific dispute solutions. The planning code and the connection code were rules that should be observed. Ideally, these rules should be identical rules. However, this was not yet the case, partly for historical reasons and partly because the different subsystems were subject to different legislations and supervision by different official bodies.

The first edition of the Nordic Grid Code was based on Nordel's former rules (recommendations), the system operation agreement, the data exchange agreement, and national codes. Therefore, the content of the code still showed traces of being taken from numerous sources.

However, an objective was that the Nordic Grid Code should be a starting point for harmonising national rules, with minimum requirements for technical properties that influence the operation of the interconnected Nordic electric power system. The Nordic Grid Code must, however, be subordinate to the national rules in the various Nordic countries, such as the provisions of legislation, decrees, and the conditions imposed by official bodies.

3. Indications from the Nordic Model for Establishing an ASEAN Intra-regional Interconnection Network

The first point for attention is the power market structure. Contrary to the single-buyer system adopted in the ASEAN region (excluding some countries), the Nordic region formed, in 1996, a completely liberalised power trading market called Nord Pool, and transaction was carried out based on this. It must be noted, however, that unbundling of the transmission sector is not a requirement for interconnection itself.

Since the 1960s, as the rapidly growing electric power system in the Nordic region was being connected to relatively weak transmission interconnections, Nordel had to solve problems of control and stability. The long-term solution was to make the transmission interconnections more robust. Nordel's recommendations formed the basis of the technical regulations for generation and grid operations in the Nordic countries. The rules were complied with by all parties and came to provide the foundation for any formal regulations required in the individual countries.

Adoption of the liberalisation model in the power sector is progressing in many countries. It is, however, considered generally appropriate to take careful steps and procedures while observing the development stages of the power market, starting from the single-buyer system (where the competition principle is introduced to the generation sector only) to gradual development of the wholesale power market, and eventually to a fully liberalised and competitive market. In almost all countries in the ASEAN region, the important task is to secure supply capability that can meet the ever growing power demand in a steady and economic manner. Adopting a single-buyer system is the right course of action.

Meanwhile, essentially required to vitalise electric power interchange in the ASEAN region is an advisory and recommendatory association like Nordel for closer electricity cooperation in ASEAN countries. Regarding this, the HAPUA working group has suggested a road map to materialise the ASEAN Power Grid (APG) with the establishment of the ASEAN Electricity Regulators, the ASEAN Transmission System Operators, and the ASEAN Grid Planners. The electricity regulation activity is already performed by the ASEAN Energy Regulators Network (AERN). For the two remaining new functions of grid operation and planning, the HAPUA working group is pursuing the study on the formation of the ASEAN Power Grid Transmission System Operators Institution and the ASEAN Power Grid Generation and Transmission Systems Planning Institution.

Results of these studies are expected to be finalised and to be ready for endorsement by the 32nd meeting of the HAPUA Council in 2016.

The second point of attention is the power infrastructure development plan. The development plans in the ASEAN region basically presuppose maintenance of supply and demand balance in individual countries. As a result, while the interconnection projects in the region are progressing, no system systematically and collectively evaluates or manages them. In the Nordic region, the Nordel planning committee developed the Nordic Grid Master Plan, conducted region-wide transmission planning, and proposed long-term capacity allocation until the establishment of ENTSO-E in 2009.

Compared to Europe, the US, and other regions, the power demand in the ASEAN region keeps on growing, and development of more power sources will become necessary in the future. To economically and reliably secure power sources in this region, the challenge is the formulation of power supply plans that assume power interchange of neighbouring countries and development plans on associated transmission lines with overall optimisation.

The third point of attention is technical standards. The current interconnections in the ASEAN region are bilateral and, therefore, no region-wide rules and system operations are carried out by the individual technical standards of member countries. When interconnection expands and the system becomes complex in the future, the possibility of an accident occurring in one country infecting the entire system and inducing massive power outage will become a major concern. For that reason alone, harmonising rules and recommendations in a common grid code will be an important issue.

CHAPTER 4

Major Findings and Policy Recommendations

In this report, specific routes for further examination were selected from prospective international interconnection lines obtained from the FY2013 survey. The study carried out preliminary planning work and cost estimation for the selected interconnection routes. Then it estimated unit power transmission cost based on projected transmission demand. The concept of electric power interchange in the ASEAN region has already taken off in the form of the ASEAN Power Grid and GMS Power Master Plan.

1. Analysis Results of Specific Routes

For some auspicious routes, the benefits and costs of transmission interconnection were evaluated. The results are shown in Table 4-1.

Table 4-1. Possible Interconnection and Cumulative Costs and Benefits

Case		Gross benefit (A)		Cost (B)		Net benefit (C)=(A)-(B)		Benefit/Cost ratio (D)=(C)/(B)
		[Million US$]	[US¢/kWh]	[Million US$]	[US¢/kWh]	[Million US$]	[US¢/kWh]	[-]
B	THA—LAO	21,387	3.77	1,506	0.26	19,881	3.51	13.2
E	VNM—LAO—THA	24,707	3.68	2,097	0.32	22,610	3.36	10.8
G	LAO—THA—MYS—SGP	27,490	3.88	2,000	0.28	25,490	3.60	12.7

kWh = kilowatt-hour, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
* Case G is estimated not as a new route but as reinforcement of existing facilities.
Source: Author.

- In terms of net benefit from 2025 to 2035, Case G is estimated as the most beneficial interconnection.
- In terms of unit net benefit, Case G is estimated as the most beneficial interconnection.
- In terms of average return on investment, Case B is estimated as the most beneficial interconnection.

How much is the construction cost for specific routes? A comparison is made here using the electricity charge in Thailand as an example. The construction cost was estimated to be US¢0.25, US¢0.29, and US¢0.26 per kWh for Cases B, E, and G, respectively. Meanwhile, according to the Energy Regulatory Commission of Thailand, total retail tariffs (as of June 2012) broken down by business are US¢10.20 per kWh, where generation accounts for US¢7.96 (of which Electricity Generation Authority of Thailand fuel cost accounts for US¢2.10); transmission, for US¢0.89; and distribution and retail, for US¢1.33[1].

As a result, to recover the construction costs in the form of consignment charges, the current transmission costs will have to be raised by around 30 percent. However, taking into account the long-term benefits from the interconnection including improved supply reliability for the entire region and reduced generation fuel costs, investment into establishment of international interconnection should be seriously considered.

2. Policy Recommendations

Operation of interconnecting transmission lines may be roughly divided into passive and active operation. In passive operation, interconnecting transmission lines are used only when an excess or shortage in power supply ability emerged for some reason. This is premised on the concept of self-sufficiency where each country maintains the supply and demand balance. In active operation, interconnecting transmission lines are used to maximise the economy of facility operation by balancing the power supply capacity of each country and the demand in the entire region. The latter may be what ASEAN is aiming for since power demand is rapidly increasing in every country and improved power trading within the region is desired.

However, as cross-border transmission interconnections develop and the use of interconnections expands along with the increase in benefits receivable by the entire system in the region, reliance on system interconnections also increases. For that reason, it becomes necessary to carefully carry out structure formulation and system design for the management and operation of interconnections while the ASEAN countries are still

[1] Total retail tariff: 3.2387 baht/kWh, generation: 2.5261 baht/kWh (of which EGAT fuel cost: 0.6656 baht/kWh), transmission: 0.2817 baht/kWh, and distribution and retail: 0.4210 baht/kWh converted in to US dollars using the monthly average exchange rate of 1 baht = 0.0315 US$ as of June 2012.

considering and deliberating. Additionally, to accelerate the current interconnection projects in the ASEAN region and obtain the benefits of electric power interchange, some potential conditions need to be satisfied.

This study proposes the establishment and appropriate authorisation of ASEAN-wide regulatory and consultative bodies, overall optimisation and adjustment of power infrastructure development plans, and harmonisation of technical standards.

2.1. Establishment and Appropriate Authorisation of ASEAN-wide Regulatory and Consultative Bodies

Many ASEAN countries currently adopt the single-buyer system where a single buyer purchases all electricity generated and sells it exclusively to power distributors. In some ASEAN countries such as Singapore, the introduced principle of competition includes the wholesale and retail sectors and where the price pool system is also adopted. Amidst the gradual structural reforms for traditional vertically integrated power systems, it is important to strengthen the roles of regulatory bodies that control the power sector in the ASEAN region.

To accelerate several interconnecting transmission line plans that have already been formulated for the ASEAN region and relevant projects currently in progress, it is important to coordinate the interests and formulate various rules pertaining to establishment and management of interconnecting transmission lines; establishment of consultative bodies that ensure fair and transparent operation, and appropriate authorisation of the bodies; and cooperation and collaboration by all countries.

To realise the ASEAN Power Grid, the HAPUA working group is studying the formation of the ASEAN Power Grid Transmission System Operators Institution and the formation of the ASEAN Power Grid Generation and Transmission Systems Planning Institution as two consequent activities. Findings from these studies are expected to contribute to the establishment of the ASEAN Electricity Regulators, the ASEAN Transmission System Operators, and the ASEAN Grid Planners as federations of relevant organisations from countries to ensure fairness and transparency in the use of a region-wide power system.

For this, ASEAN countries may reference the structure of Nordel. As mentioned, most of Nordel's work was carried out by permanent committees of leaders responsible for the corresponding sectors in the Nordic TSOs and working groups of technical specialists from the Nordic TSOs. The role sharing of Nordel's planning and operations committees is most likely to be referenced and applied on ASEAN transmission network operation where many countries adopt a single-buyer system.

2.2. Overall Optimisation and Adjustment of Power Infrastructure Development Plans

In general, power demand in ASEAN countries is expected to keep increasing greatly due to steady population growth and robust economic growth. Construction of many power plants may take place in the future. Along with the increase in electric power generation, new establishment and reinforcement of transmission lines will become necessary. Amidst such situation, the power infrastructure development plans for the ASEAN countries are generally formulated so that there will be no shortage in power supply capability without relying on power interchange. Meanwhile, transmission interconnection projects by the ASEAN Power Grid and GMS Power Master Plan are progressing, and duplicated investments are a possibility if these plans remain uncoordinated.

Interconnecting transmission lines reduces power source facility development and improves the system's supply reliability. Such benefit, however, can mean something only when the relevant parties of each country recognise this and postpone the construction of power source facilities which may become redundant anyway with interconnection. For that, it may be essential to formulate power supply plans that assume power interchange with neighbouring countries and associated transmission line development plans for the entire ASEAN region. Specifically, revaluation of power source development and transmission line development plan of individual countries, and proposals for overall optimisation by an organisation of specialists in the region may prove helpful.

Meanwhile, it is also important to ensure that domestic system development projects are integrated with the overall optimisation of power infrastructure development. Looking at the current situation of domestic systems in the ASEAN region, undeveloped areas in countries with hydropower potentials such as Lao PDR, Cambodia, Myanmar, and Viet Nam have problems in the transmission line capacity that interconnects the north and the south. In a feasibility assessment of selected routes of this study, interconnecting transmission lines across countries are to interconnect substations closest to the borders, assuming there are no restrictions on inter-region power transport by the domestic system in each country. Such assumption implies that the actual benefits received vary depending on the situation of domestic system development.

In countries and areas where domestic transmission networks are insufficient, international interconnection lines are expected to cover the insufficiency. On the other hand, to fully utilise the energy resources in the region, it is important to establish and enhance the domestic transmission networks so that the domestic systems do not become a cause of bottlenecks.

2.3. Harmonisation of Technical Standards

The current international interconnections in the ASEAN region are limited to bilateral trading and, therefore, no region-wide common grid code or interconnection rules and system operation are carried out by the technical standards of each county or project. Meanwhile, some countries have weak organisation systems of the power business and have no organisations monitoring the system for the entire nation, or have inadequate technical standards and improper system operation.

At present, where interconnections are minimal, there is little concern over such problems making huge impact on the stability of the power supply or system for the entire ASEAN region. However, once interconnection expands and the system becomes complex, the risk of an interconnection’s failure infecting the entire system becomes higher. Therefore, to operate the system as a stable ASEAN-wide network, harmonisation of standards for operating the system or connecting to the system in each country will be required.

To maintain a certain level of system stability in the ASEAN region, all participating countries should coordinate operations. To that end, it is necessary to formulate several standards including those for maintaining stability when equipment faults occur in a system (reliability standards), for maintaining balance amongst systems, and for protecting the system in preparation for potential system instability.

Regarding connection standards, maintenance of system stability will require formulation of minimal transmission connection rules which focus on the power quality. Matters to be addressed in connection rules include frequency, voltage, and tolerance for sudden voltage fluctuations and for voltage drop.

Furthermore, maintaining consistency in the level of supply reliability amongst countries should be made as it is the foundation of harmonisation of technical standards. When systems with greatly different supply reliabilities are interconnected, those with lower supply reliability acquire more benefits than the other systems. At present, the supply stability of ASEAN countries varies, and discussions and investigations on the coordination of interests amongst countries and determination of appropriate reliability levels need to be carried out towards the establishment of the international interconnecting transmission network.

2.4. Other Necessary Actions

International interconnection projects essentially require establishment of an implementation system that takes charge of coordination of interests and formulation of various rules pertaining to development, management, and operation of power infrastructure, in addition to cooperation and collaboration by countries involved.

To establish such an implementation system, the following points need to be carried out in practice on both the hardware (tangible) and software (abstract) aspects.

On the hardware side, above all, financing the construction of interconnection lines and system operation facilities is required. In some cases, recovering costs by the earnings alone from the transmission line toll may be difficult. Additionally, a single company may not be able to raise funds for the entire project. On such occasions, power companies or agencies of each country may be required to supplement funds, considering the massive economic benefits each country will gain from such endeavour. Specifically, cost control will be required until profitability improves, including utilisation of low-interest public funds and promotion of public–private partnerships.

On the software side, cost sharing on the construction and operation of interconnection lines, setting of transmission line tolls, emergency cut-off measures, and other issues related to system operation need to be addressed. Since situations vary depending on the lines, including the facility system and the concept of benefits, sharing on development of transmission lines will require careful consideration to smoothly build consensus amongst a wide array of parties involved. Additionally, setting transmission line tolls poses dilemma between (a) the incentive for setting the unit toll as high as possible for improved profitability and (b) promoting interconnection by operating and managing each country’s consignment charge for interchange of electricity within the appropriate price ranges. While the significance of international interconnection is in the reduction of generation costs through utilisation of potential hydropower and the cheap fuel costs of thermal power, overpriced transmission line tolls would dilute the benefits of power interchange. Regarding such software issues from precedents in Western countries, ASEAN countries may be required to thoroughly discuss the kind of wide-area operation system appropriate and effective in the ASEAN region.

Also note that an increase in the volume of power trading automatically results in non-negligible transaction costs incurred from power trading itself. If this becomes the case, it may be realistic to prepare in advance and utilise wisely a model contract that stipulates methods and conditions of power trading.

3. Summary

Nordel, a Nordic cooperation programme in electric power supply, was established in 1963, and its background circumstances are similar to the current situation in the ASEAN region. During the 1960s, when electric power consumption increased considerably in all the Nordic countries, the opportunities for cooperation, linking together different kinds of generation portfolios, and creating shared reserve margin attracted greater attention amongst members of Nordel who were seeking benefits from coordinating the expansion and operation of their grids.

As the rapidly growing electric power system would have to be connected to relatively weak transmission interconnections, Nordel had to solve problems of control and stability. The long-term solution was to make more robust transmission interconnections. Nordel's recommendations formed the basis of the technical regulations for generation and grid operations in the Nordic countries. The rules were complied with by all parties and came to provide the foundation for any formal regulations required in the individual countries.

Such establishment of transmission interconnection network in the Scandinavian region offers substantial useful suggestions to ASEAN countries. It tells us that a regional transmission interconnection network is not something that can be built in a day, but by slowly overcoming issues and repeatedly revising and improving the relevant standards. In the Nordic region example, it took about 50 years from the conclusion of the first interconnection operation agreement (1912) to the launch of Nordel (1963) and approximately 30 years for liberalisation of the market (Nord Pool started in 1996). Activities to enhance the transmission interconnection in the ASEAN region have just started. While it may be possible to promote the projects efficiently by adopting lessons learnt from precedents, it is not something that can be achieved in a short time.

Also, the conditions unique to ASEAN countries need to be taken into account. While the stage of economic development of the four Nordel countries at that time was similar, there are major differences in those of ASEAN countries aside from the number (10) of countries constituting the regional body. It is not practical for ASEAN to uniformly formulate rules in accordance with the situation of its most developed member country. In that sense, searching for ASEAN's own power market model, instead of merely copying precedents from Western countries may be desirable.

Furthermore, the ASEAN region is in the stage of forming massive electric power infrastructure and extra attention is needed so as not to interfere with it. In Nordel, the liberalisation of the market and the formulation of the wholesale market were carried out as the final stage of international interconnection and power trading system development. In general, liberalisation of the market and introduction of competition bring higher efficiency to the market while they, in effect, suppress investment into infrastructure. Liberalisation of the market is appropriate in the Organisation for Economic Co-operation and Development (OECD) countries where the formation of basic infrastructure has been completed, but runs the risk of sparking shortage in infrastructure investment and supply in developing countries where infrastructure formation is under way. For that reason, step-wise activities and careful system designs are required.

Nonetheless, enhancing transmission interconnection lines and power trading in the ASEAN region obviously bring benefits to the region, and promoting activities towards their realisation would prove to be fruitful.