REGIONAL COOPERATION STRATEGY ON INTERCONNECTED POWER NETWORKS IN INDOCHINA[1]

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Abstract

This research project is intended to examine the feasibility and future strategy of interconnected power networks in Cambodia, Laos, Thailand and Viet Nam in Indochina as one of regional cooperation efforts in its power sector. The study measured benefit of interconnected power networks in monetary terms, particularly focusing on the improvement of the whole system reliability, examined financial viability of the selected networks, identified conditions and issues for the realization of the networks, and made recommendations on future strategies of the governments and donors' assistance.

The study found that annual cost savings of up to US$63 million would be expected due to the reduction of additional investment for generating units through the improvement of system reliability, and the fuel cost saving through economic power exchange.

At the same time, however, it was revealed that the interconnected transmission project would not be profitable enough for an entity independent from the states or state-owned power enterprises to construct, operate and maintain. This is because the cost saving effect mentioned above is a form of national economic benefit, but is not a direct cash inflow from the project. Therefore, an association of the related countries or state-owned companies who would receive the national economic benefit should be considered as the most appropriate agency to construct, operate and maintain the interconnected lines. In addition, this implementation scheme would enable the fair cost and role sharing among the four countries in the light of each country's benefit from the system interconnection.

Finally, the study emphasized the importance of assistance to solve domestic problems of power sector in respective countries, such as upgrading of domestic transmission networks, as preconditions for the system interconnection.

Chapter 1 Foreword

Since the 1990's, a number of frameworks have been built for regional development cooperation in Indochina[2], and progress has been made in regional development in sectors such as transport, energy, communications and tourism. In the electrical power sector, projects have been planned and implemented

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1 This report summarizes and adds commentary to the report entitled " Regional Cooperation Strategy on Interconnected Power Networks in Indochina", which was Special Assistance for Development Policies and Project (SADEP) commissioned from Tokyo Electric Power Company, Inc. (study team members: Noboru Seki (Engineering Dept.), Yasuhiro Yokosawa (Transmission & Substation Construction Dept.), Nobuya Maekawa (Transmission & Substation Construction Dept.), Masahiko Toda (Overseas Business Center, Tokyo Electric Power Services Co., Ltd.) in 2001. For details of the study, see JBICI Research Paper No.18 "Regional Cooperation Strategy on Interconnected Power Networks in Indochina".

2 Leading examples include the "Greater Mekong Sub-region Program" by the Asian Development Bank, the "ASEAN Mekong Basin Development Corporation" by ASEAN and the framework formed by the Mekong River Commission.

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in fields such as hydroelectric and thermal power source development, development of power transmission and distribution networks and rural electrification. Regional and external cooperation have certainly yielded some of that progress for Indochina, but major disparities still remain between countries in the region. More efficient and effective action to close disparities in the region must go beyond development of the power sector tailored to the situation in each country, to a comprehensive power sector development strategy that looks at the region as a whole.

This study examined one strategy of comprehensive power sector development, which calls for interconnected power networks between four countries in Indochina (Cambodia, Laos, Thailand and Viet Nam, see Figure 1), to gauge its feasibility and optimum form. A number of studies to date[3] have indicated that interconnected power networks would have a major impact on the region as a whole in aspects such as a stable supply of electricity, optimum electric power source development and the promotion of rural electrification. However, those studies lacked grounds for the effects of interconnected power networks. Above all, they did not quantify the effects that would result just from the connection of networks, namely effects on the stability of power supply (system reliability improvement effects).

Therefore this study will conduct a quantitative analysis of the efficacy of interconnected power networks, with particular reference to system reliability improvement effects, and examine their feasibility. Based on the results of this examination, this paper studies the conditions for realizing interconnected power networks, and the challenges to be overcome, to make proposals on the policies each country should adopt and how they should be assisted in future.[4]

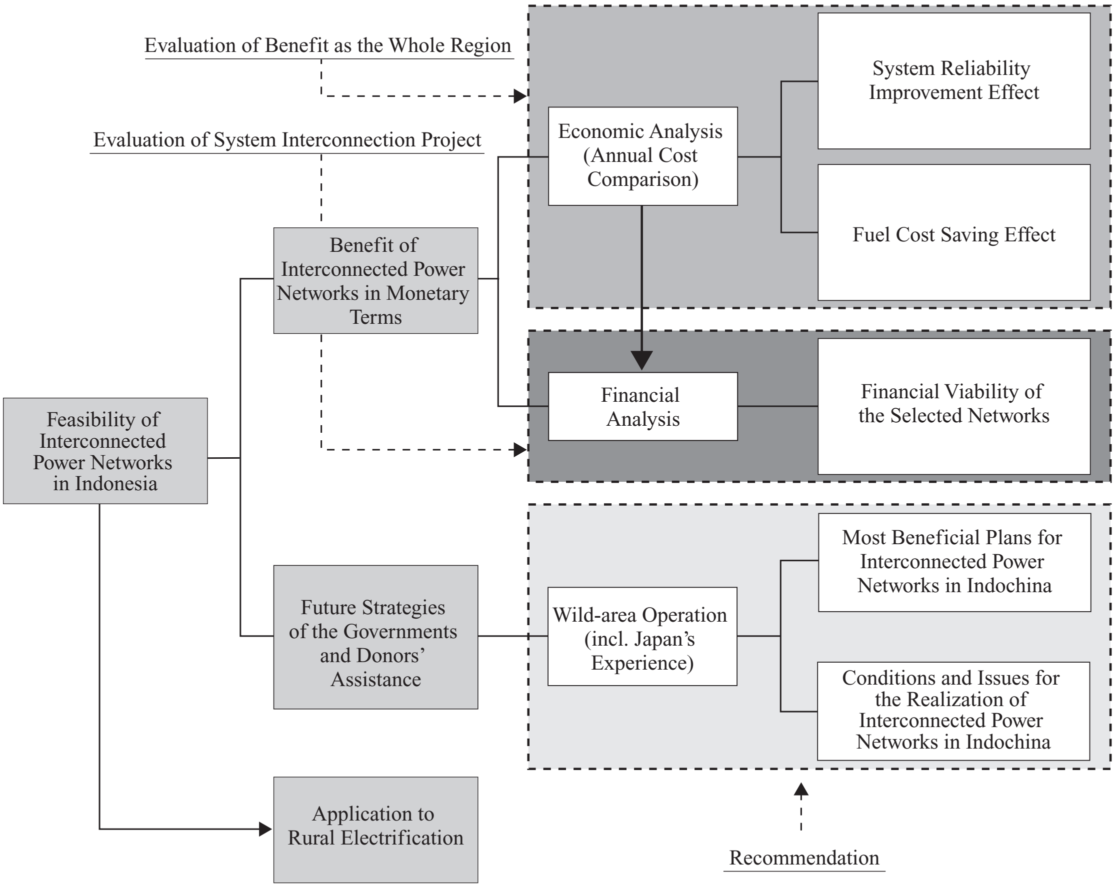
Figure 2 is a schematic of this study as a whole.

Figure 1 Map of Indonesia

3 "Mekong Integrated Transmission System Study (Basin-Wide)" (Newjec / MRC, 1996), "Power Trade Strategy for the Greater Mekong Sub-Region" (WB, 1999), etc.

4 Although it is not mentioned in this paper, this study also introduced examples of wide-area operation in Japan and discussed the potential for linkage between interconnected power networks and rural electrification.

Figure 2 Framework of the Study



Chapter 2
A Summary of the Power Sector

1. The Potential of Energy Sources

The countries of Indochina are geographically very close together, but their levels of economic development are highly diverse (Table 1), and there are also large differences in the potential of their energy resources.

(1) Cambodia[5]

Cambodia has many domestic rivers, such as the Bassac and Tonle Sap, and the Mekong, a major international river, flows through it from north to south. Its abundant water resources also include Lake Tonle Sap in the northwest.

The potential hydropower capacity of Cambodia as a whole is not known in detail, but an Asian Development Bank (ADB) report[6] estimates that there is 8.6GW with potential for economic development. The Cambodian Ministry of Industry, Mines and Energy (MIME) estimates potential hydropower capacity at 10GW.

The country's reserves of oil are estimated at 50~100 million barrels of crude oil, with reserves of 1.5~3.5 trillion cubic feet of natural gas.[7]

Cambodia also has abundant forestry resources, which are a source for firewood and charcoal, non-commercial energy sources that are still essential for daily life. However, the area of forest has been falling in recent years due to slash and burn agriculture and logging for export timber, both by mountain peoples.

5 New Energy and Industrial Technology Development Organization (NEDO) (1999).
6 Asian Development Bank. 1995.
7 The East-West Center, which has its headquarters in Hawaii, made a calculated estimate from geological data for adjacent areas off the coast of Cambodia.

Table 1 Present Situation of the Indochina Region

	Cambodia	Laos	Thailand	Viet Nam
Population (million persons)	1,140*	495*	6,147*	7,768***
Population density (persons/km^2)	63	21	120	234.3
GDP (100 million $)	31***	12**	1,250**	264*
GDP/capita ($/person)	271***	283**	2,045**	340*
GNP/capita ($/person)	253***	–	–	372**
Maximum power demand (MW) ***	123	165	14,918	4,477
Sold energy (GWh/year) ***	623	639	96,780	26,000
Load factor (%) ***	62.0	57.2	75.3	62.9
Electrification rate (%) ***	20	34	82	72
Potential hydropower capacity (MW)	10	27	15	16
Petroleum deposits (100 million barrels)	0.5 ~ 1.0	–	9	6
Gas deposits (TCF)	1.5 ~ 3.5	–	33	5
Coal deposits (100 million tons)	–	High potential	24	35

Note: * Data for 1998, ** data for 1999 and *** data for 2000.
Source: Ministry of Foreign Affairs (Japan) Official Web Site.

(2) Laos[8]

Laos is estimated to have 18GW[9]of technically feasible potential hydropower capacity, excluding the main course of the Mekong. However, less than 2% of that potential has been developed in the last 30 years.

Other energy resources include underground coal reserves that have been confirmed in many states, but only 1,000 tons per year (in 1994) of smokeless coal is being mined in the Bo Chan district of Vientiane Province. There is a plan to build a coal-fired power station with joint investment from Thailand, to send power to Thailand.

Laos, in the same way as Cambodia, uses non-commercial energy such as firewood as its main energy source, covering approximately 90% of its energy needs. Firewood production is rising by 3% per year (1991~1994).

(3) Thailand[10]

Thailand is estimated to have approximately 15GW of potential hydropower capacity. By April 2000, 3,900MW, approximately 26%, had been developed.

Oil is not Thailand's main energy source, but it is estimated to have domestic reserves of approximately 910 million barrels. At present, most of the oil consumed domestically is imported.

The country's natural gas reserves are estimated at approximately 33.3 trillion cubic feet, with 29.3 trillion cubic feet believed to be recoverable. Nearly all is produced from the gas fields in the Gulf of Siam, with most being used for power generation.

Various forms of lignite are distributed throughout the country, with estimate reserves of 2.4 billion tons. The Electricity Generating Authority of Thailand (EGAT) has developed two coal-fired power stations burning lignite for a total of 2.6GW, but recent environmental restrictions and opposition from the public will make it difficult to build new coal-fired power stations.

(4) Viet Nam[11]

The ADB[12] estimates that Viet Nam has a potential hydropower capacity of at least 300 billion kWh/year,

8 Japan Electric Power Information Center, Inc. (1998)
9 Japan Electric Power Information Center, Inc. (2000)
10 Electricity Generating Authority of Thailand. 2000b.
11 Japan Electric Power Information Center, Inc. (1999)
12 Asian Development Bank. 1995.

of which 181 billion is in the north, 89 billion in the center and 30 billion in the south. Of that, 82 billion kWh/year is estimated to have development potential.

In December 1997 the country's petroleum deposits were estimated at approximately 1.52 billion barrels[13], but the country has no domestic oil refineries, so it relies on imports for all the petroleum products it consumes.

Viet Nam is estimated to have 309 billion m^3 of natural gas reserves, mainly concentrated on the coast of the South China Sea.

Coal reserves are estimated at approximately 3.5 billion tons, of which 89.9% is in the Cam Pha, Hon Gay and Uong Bi districts.

The above summary shows that all these four Indochinese countries have abundant hydropower resources, and that petrochemical energy development is only advanced in Thailand and Viet Nam.

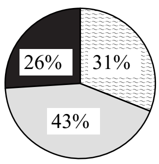
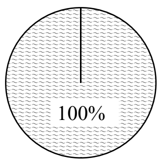
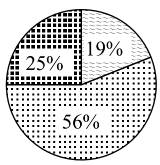
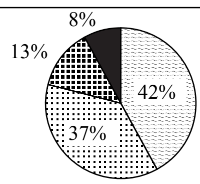
2. The Status of the Power Sector and Future Plans

The power sectors in Cambodia, Laos, Thailand and Viet Nam differ greatly in the scale of demand and the mix of power sources. By demand scale, Thailand is the largest of the four, with 14,918MW (recorded in 2000), followed by Viet Nam and Laos, with the smallest demand in Cambodia, at only 150MW (2000).

Growth rates in power demand are estimated at over 10% in Cambodia and Laos, around 6% in Thailand and around 9% in Viet Nam. This study estimates the demand in the year 2015, to increase by approximately 7 times the demand of 2000 in Cambodia, 6 times in Laos, 2.5 times in Thailand and 4 times in Viet Nam.

The countries have various power generation plant development plans to meet this demand growth. Cambodia plans development centered on domestic hydropower sources, Laos plans to cover all domestic power demand using hydropower, Thailand plans to develop thermal power sources burning gas, oil and coal, and import hydropower from neighboring countries, and Viet Nam's development will center on its domestic gas production. Thus each country plans to develop generation that centers on types of which it has an economic advantage with abundant primary energy resources. Table 2 shows power demand in each country and plans for development by 2015.

Table 2 Record and Forecast of Power Demand, and Future Development Plans

	Cambodia	Laos	Thailand	Viet Nam
Actual record (2000)	150 MW	172 MW	14,918 MW	4,477 MW
Forecast (2015)	694 MW	612 MW	38,519 MW	17,847 MW
Planned capacity (2015)	1,100 MW	790 MW	46,900 MW	25,800 MW
LOLE (Target value)	29 hr (160 hr)	4 hr (240 hr)	3 hr (24 hr)	Less than 1 hr (24 hr)
Hydro Gas+Oil Coal Other				

Note: LOLE values are for the case where existing development plans are implemented on schedule.
Source: Prepared on the basis of electric power development plans for each country.

13 Ito, M. 2001.

Chapter 3
Identifying the Effects of Interconnected Power Networks

1. The Definition and Effects of Interconnected Power Networks

(1) Definition of Interconnected Networks

In this research, interconnected power networks are defined as electrical transmission equipment that connects networks and is capable of bi-directional power exchange. Therefore even if an electricity transmission cable is for the purpose of transmission from a certain power source to a target network, it is an interconnected network if it has functions (power supply cable exploitation) that enable bi-directional power exchange between networks (see Figure 3).

The only interconnected network that currently satisfies this definition is the 100MW transmission line[14] that connects Udon Thani-1 and -2 Transformer Stations in Thailand and the Phone-Tong Transformer Station in Laos.

(2) Effects of Interconnected Networks

The effect of interconnected networks, that is to say, of system interconnection, is obviously that power can be exchanged between networks. The effects of interconnected networks can be broadly divided into two areas, system reliability improvement[15] and reduction in fuel cost.

System reliability improvement effects apply in cases where supply capacity suddenly becomes inadequate due to a major failure of generation equipment or a spike in demand. The affected network can receive supplies (assistive power exchange) through interconnected networks from other networks that have surplus power, avoiding a decline in system reliability. This effect enables a given level of system reliability to be achieved, with a lower level of reserve supply capacity in connected networks, than would be needed for isolated networks.

The fuel cost reduction effect occurs because economic power exchanges can be made between networks on the basis of differences in fuel costs[16], making it possible to buy power from another network if that is cheaper than generating within the local network.

2. Methods for Examining the Effects of Interconnected Power Networks

The effectiveness of interconnected power networks differs depending on the form of interconnection. Therefore we examined the ten cases in Figure 4, comparing each case in 2015 against the case in which system interconnection is not carried out (the base case). This comparison was used to quantify the economic effects of interconnected power networks by ascertaining the reduction in power supply equipment development enabled by system reliability improvement effect (calculated using RETICS, a tool for evaluating the reliability of system interconnection) and the annual cost saving due to fuel cost saving effect (calculated using PDPAT, a

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14 The interconnected network allows Laos to export surplus power from its Vientiane network to Thailand.

15 The reliability of a power network is defined as its ability to supply power without interruption. The indices for system reliability include Loss-of-Load Expectation (LOLE), Loss-of-Load Probability (LOLP) and Expected Undelivered Energy (EUE). LOLE was used for this study.

16 The cost of power generation is calculated by dividing the total annual cost of generation equipment by the annual power generation, which can be modified further to the equation below. As this shows, the cost of power generation, comprises fixed costs, like construction cost, which are not controlled by generation volume, and variable costs such as fuel, which vary with generation volume.

$$\text{Unit generation cost} = \underbrace{\frac{\text{Unit construction cost (\$/kW) x Annual expense rate}}{\text{Equipment utilization factor x 8760 (hours)}}}_{\text{Fixed cost}} + \underbrace{\frac{\text{Unit fuel cost (\$/kcal) x 860 (kcal/kWh)}}{\text{Thermal efficiency}}}_{\text{Variable cost (fuel cost)}}$$

Therefore, using facilities with high fixed costs at high work rates (base load) and using facilities with high fuel costs at low work rates (peak load) can reduce the cost of power generation. The cost of power generation can be used to gain a grasp of the most economic form of operation for each type of generation equipment, and the work rates of each type can be optimized for the pattern of demand, leading to a broad idea of the most economic power source mix.

Figure 3 Definition of Interconnection Line

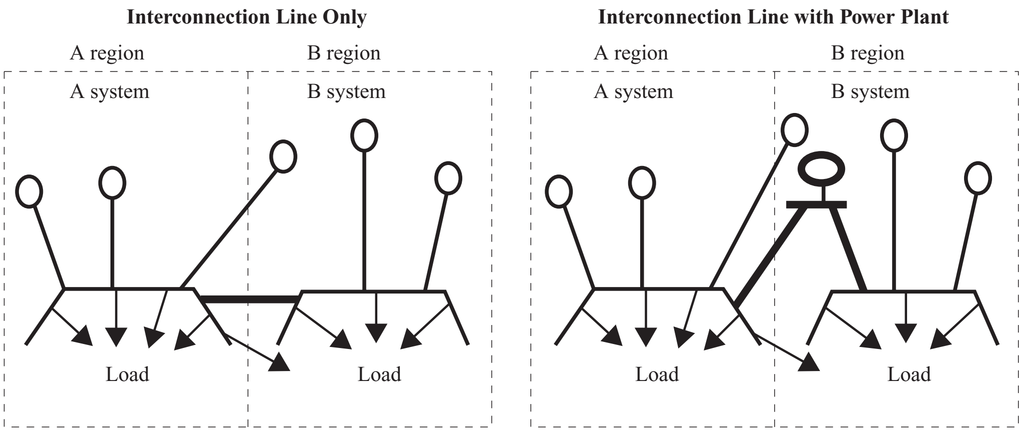
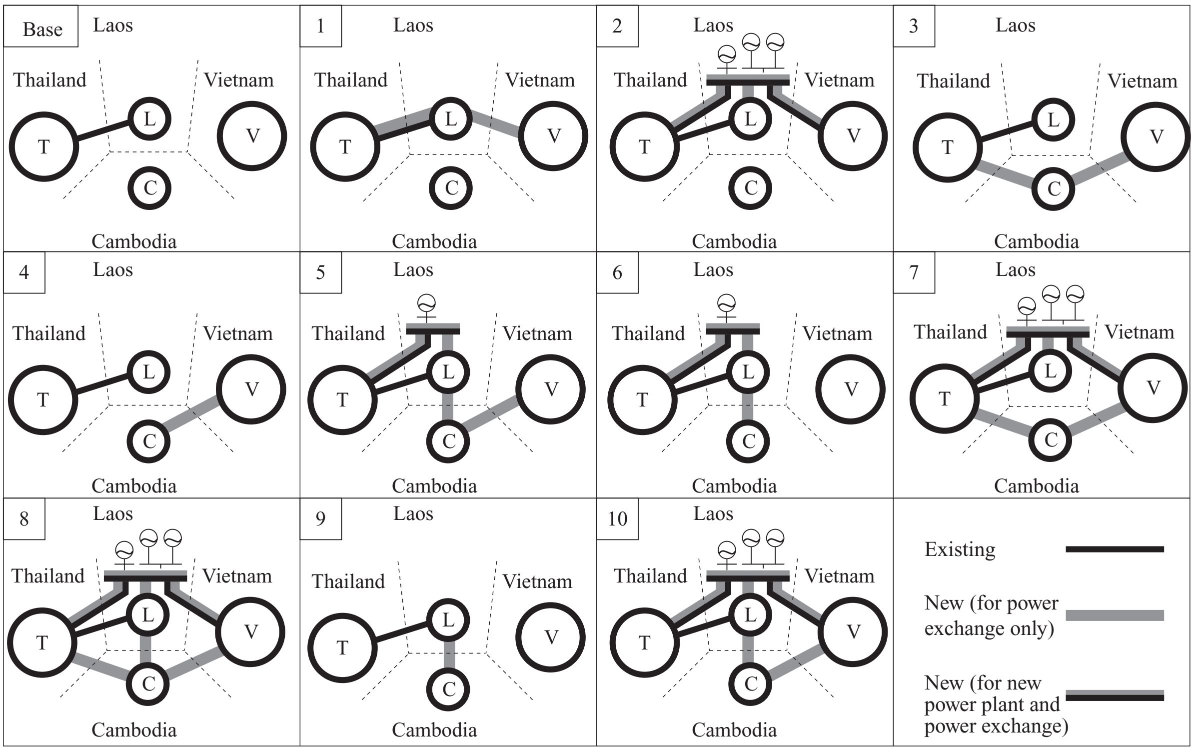


Figure 4 Interconnection Cases



power supply planning and policy assistance tool).[17] Numerous power development plans, including IPP projects, already exist in Indochina, and they are accompanied by many transmission line development plans. In several power line usage cases, the capacity of the transmission lines has been increased to add interconnected power network functions with a view to reducing construction costs.

17 Both RETICS and PDPAT are tools that Tokyo Electric Power Company, Inc. has been using for over 30 years. RETICS uses a Monte Carlo simulation to model the demand state in each interconnected network and use power exchange through interconnected networks to avoid power shortages wherever possible. It also calculates the Loss-of-Load Expectation (LOLE) for cases when power shortages cannot be avoided. Conversely, it can also calculate the quantity of power supply plant required in a network to satisfy a set target level of LOLE. PDPAT models supply and demand operation for each network, taking power exchange between networks into account, and using that status to calculate annual cost for each network. Power exchange between networks follows the following two stages: Stage 1: Assistive power exchange is provided from networks with spare supply capacity when the circuit concerned cannot meet demand from its own resources. Stage 2: If there is more spare capacity once the shortage has been eliminated through assistive power exchange, economical power exchange is used in cases where that is judged to be economic after consideration of usage costs for the interconnected network.

3. Results of Examining the Effects of Interconnected Power Networks

(1) Reduction Effect in Power Source Plant Development Due to System Reliability Improvement Effects

This section uses the example of Case 5 (linkage and interconnection line with power plant between Thailand, Laos, Cambodia and Viet Nam) to explain the results of the RETICS study, and presents the results for all 10 cases.

Figure 5 shows variations in the reductions of power source plant development with increases in linked power transmission line capacity in Case 5. The reduction in development increased with greater transmission line capacity, but the reduction in power source plant development reached a saturation point with 1,000MW of transmission line capacity, and around 410MW of capacity in the linked networks as a whole.

The results of equivalent examinations show improved system reliability through interconnection in all cases, with reduced power source plant development, which means investment for the development of new power sources could be deferred (Table 3).

Comparing the reductions in power source plant development for each case, the reduction in cases 4, 6 and 9 were three or more times higher than the other cases. The difference between these cases lies in whether or not there is interconnection between the networks of Thailand and Viet Nam, so it appears that Thai-Vietnamese interconnection would yield a major improvement in system reliability through interconnected networks. The reduction in power source plant development enabled by this interconnection would be around 400MW throughout the interconnected networks.

Figure 5 Possible Reduction of Reserve Capacity (Case 5)

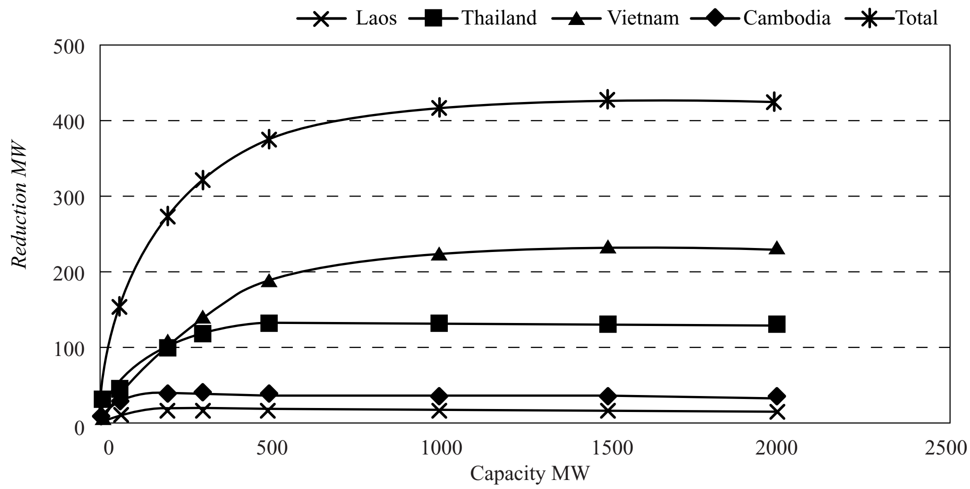


Table 3 Possible Reduction of Reserve Capacity

Case #	Transmission capacity (MW)	Possible reduction of reserve capacity (MW)
1	1000	-370
2	1000	-370
3	1000	390
4	100	-35
5	1000	-410
6	100	-100
7	500	-410
8	500	-410
9	100	-80
10	500	-410

(2) Reduction in Annual Costs through Fuel Cost Reductions

As in (1), this section uses the example of Case 5 (linkage and power supply line usage between Thailand, Laos, Cambodia and Viet Nam) to explain the results of PDPAT study, and presents the results for all 10 cases.

Construction unit costs and fuel costs based mainly on data provided by each country were used in the calculation of annual costs (Table 4). The calculation terms for fixed costs were fixed-installment depreciation, 10% interest and 1~2.5% for other costs.

Separate power exchange rates were set for assistive power exchange and economic power exchange. In the case of assistive power exchange, the network receiving power was assumed to pay the providing network a rate equal to 10¢/kWh as the fixed cost of peak power supply equipment, plus the maximum fuel cost at the time the power is exchanged. In the case of economic power exchange, the network receiving power was assumed to pay the providing network a rate equal to the average between the unit cost of the thermal generation fuel the receiver avoided using as a result of the exchange, and the unit fuel cost for the source of the exchanged power.

Table 5 and 6 show the reductions in annual cost for Case 5 (relative to the base case), and the reduction in power generation, as calculated by PDPAT.

Substituting the theoretical reduction in power source plant development calculated by RETICS into each country's power source development plans produces figures for the capacity of power plant development that can be deferred in each country under Case 5. Cambodia' network could defer a total of 37MW of coal-fired and diesel-fired power stations, Laos could defer 31MW of hydropower station capacity, Thailand could defer 100MW of gas-fired power stations and Viet Nam could defer 220MW of gas-fired power stations. The resulting reduction in fixed costs across the whole interconnected network would be equivalent to $40 million per year.

The changes in power generation would be increased generation from hydropower sources in the Laotian network and from gas-fired sources in the Vietnamese network, with a reduction of coal-fired generation in the Thai network. The fuel cost saving yielded by using hydropower generation on the Laotian network is particularly large. This effect of reducing fuel costs through economic power exchange is equivalent to $57 million per year across the whole interconnected network.

Therefore interconnected networks would yield a reduction of $97 million in annual cost in Case 5.

Table 7 shows the results of a comparison of annual cost reduction and the construction and annual costs of interconnection lines for each case (assuming a project lifespan of 15 years and a discount rate of 15%). The calculation of annual cost of construction for the transmission lines were calculated using the estimated service life and investment standards for each country. Therefore project lifespan was taken as 15, 20 or 25 years and the discount rate as 8%, 10% and 15% (Table 8). The annual cost of operation was taken as 1% of the construction cost for transmission lines, and 2% for transformer stations.

The results of the comparison confirmed that all cases would yield annual cost reductions, with cases 2, 5, 7 and 10 being the most economic of the ten cases. For example, with a project lifespan of 15 years and a discount rate of 15%, the results show annual cost reductions of up to $63 million. Cases 2, 5, 7 and 10 remained economical even with changes in project lifespan and discount rate.

(3) Characteristics of Cases with a Superior Economic Value

There were two main characteristics for the cases which were economically superior . The first is the presence of an interconnection between the Thai and Viet Namese networks, and the second is increased hydropower generation in the Laotian network.

The first characteristic is because the networks are large and require high backup capacity if they are to operate alone. Therefore interconnection increases the capacity of generation plant available for both sides to use, enabling a major reduction in power source plant development. When the interconnected networks are smaller, as in Cambodia and Laos, the power plant capacity available for use by both sides is limited by the backup capacity on a small power source plant development. Therefore the effects are not large.

Table 4 Unit Construction Cost and Unit Fuel Cost

Unit Construction Cost

Unit: US$/kW

	Cambodia	Laos	Thailand	Viet Nam
Hydro	1,200	940 ~ 2,360	830	1,200
Gas C/C	547	–	453	407
Coal	–	–	727	764

Unit Fuel Cost

Unit: ¢/10^3kcal

Fuel Type	Cambodia	Laos	Thailand	Viet Nam
Hydro	0.00	0.00	0.00	0.00
Gas	1.32	–	1.34	1.22
Coal	–	–	1.21	0.52
Oil	1.81	–	1.81	1.74
Diesel	5.52	–	2.99	3.40

Table 5 Annual Cost Saving (Case 5)

Unit: MUS$/yr

	Cambodia	Laos	Thailand	Viet Nam	Total
Fixed cost	-5	-8	-9	-18	-40
Fuel cost	-12	0	-60	+15	-57
Power purchase cost	+11	-11	+33	-33	–
Total	-5	-18	-37	-36	-97
Transmission loss	–	–	–	–	+10

Table 6 Energy Generation Change (Case 5)

Unit: TWh

Fuel Type	Cambodia	Laos	Thailand	Viet Nam	Total
Hydro	+0.0	+1.0	0.0	+0.3	+1.3
Pumped hydro	–	–	+0.0	-0.0	+0.0
Coal	–	–	-1.4	+0.2	-1.2
Gas	-0.2	–	-0.5	+0.7	+0.0
Oil	-0.2	–	-0.0	+0.0	-0.2
Diesel	+0.0	–	0.0	+0.0	+0.1
Total	-0.3	+1.0	-1.9	+1.3	+0.1
Power purchase	+0.3	-1.0	+2.0	-1.3	–

Table 7 Comparison of Economic Efficiency between Annual Cost Saving and Equipment Construction/Annual Operation Cost (Project Life: 15 years, Discount Rate: 15%)

Unit:MUS$/yr

Case #	Possible reduction (MW)	Construction and O&M cost				Annual cost			Difference	Rank
		Construction cost	O&M cost	Loss	Total	Fixed cost	Fuel cost	Total		
Case 1	-328	36	3	7	46	-27	-53	-80	-34	5
Case 2*	-338	15	1	5	21	-29	-55	-84	-63	1
Case 3	-434	40	4	11	55	-43	-14	-57	-2	10
Case 4	-18	2	0	1	3	-2	-8	-10	-7	9
Case 5*	-388	36	3	10	49	-40	-57	-97	-48	2
Case 6*	-51	4	1	4	9	-7	-27	-34	-25	7
Case 7*	-419	43	4	8	55	-39	-52	-91	-36	4
Case 8*	-422	56	5	9	70	-40	-56	-96	-26	6
Case 9	-90	3	0	3	6	-10	-4	-14	-8	8
Case 10*	-320	29	3	5	37	-30	-48	-78	-41	3

* In case of power supply cable exploitation.

Table 8 Comparison of Economic Efficiency between Annual Cost Saving and Equipment Construction/Annual Operation Cost (When Project Life and Discount Rate are Changed)

Unit: MUS$/yr

Case #	Difference between the annual cost saving and necessary annual cost		
	15 years, 15%	20 years, 20%	25 years, 8%
Case 1	-34	-47	-52
Case 2	-63	-66	-69
Case 3	-2	-11	-18
Case 4	-7	-8	-8
Case 5	-48	-56	-63
Case 6	-25	-27	-27
Case 7	-36	-46	-53
Case 8	-26	-39	-49
Case 9	-8	-9	-9
Case 10	-41	-48	-53

The second characteristic is largely due to the unique properties of the Laotian network. If the Laotian network included thermal power sources to meet peak demand, it would be able to incorporate equipment and operation plans for hydropower generation that would run at full capacity all year round. However, the network only has hydropower sources, so it can use only those sources to adjust its domestic supply and demand. Therefore even if there is abundant water in the rainy season it must be discharged without generation if domestic demand is less than the maximum output from hydropower sources.

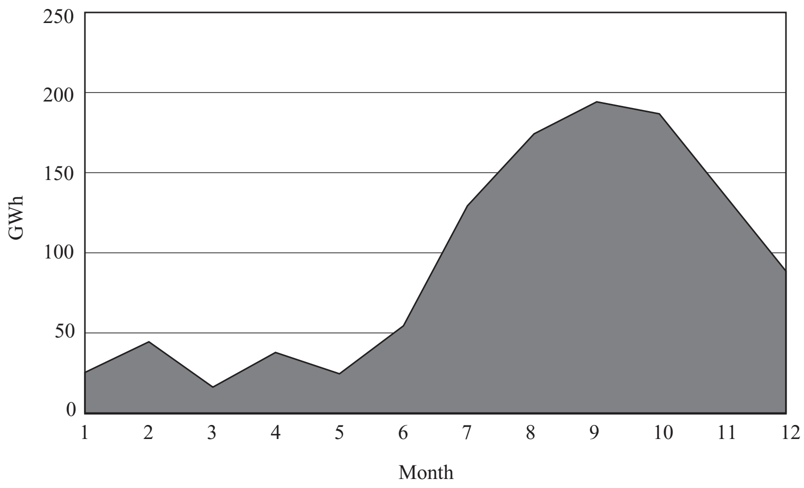
If the Laotian network is linked to others, the potential hydropower of the network (Figure 6) can be used by other networks through economic power exchange, saving fuel costs in the interconnected network as a whole. However, the fuel cost reduction that can be gained through effective use of potential hydropower generation capacity in the Laotian network is limited, because the usable hydroelectric potential is not large when the interconnected networks are small. Therefore, effective use of the potential hydropowerin the Laotian network requires linkage with another network that is large enough, relative to the potential hydropower, and also adjustable.

(4) The Most Economic Plans for International Interconnected Power Networks in Indochina

Judging by the above study, the most economic plans for international interconnected power networks in Indochina are Case 2, which only interconnects Thailand, Laos and Viet Nam, Case 5, which interconnects all four countries in an “N”-shape, Case 7, which interconnects them in a rhombus, and Case 10, which creates a loop through Laos, Cambodia and Viet Nam, with a connection between Thailand and Laos[18] (Figure 7).

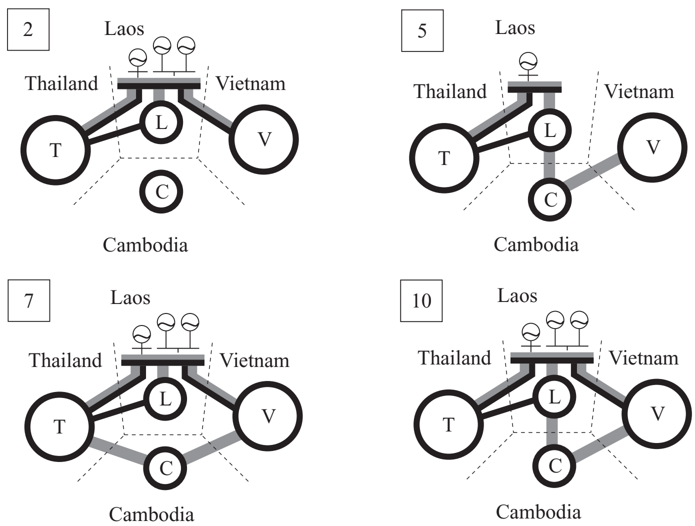
18 Case 1, which is the version of Case 2 with construction of a new interconnected network, and Case 8, the version of Case 10 with an added interconnection between the Thai and Cambodian networks, were the next most economic cases after the top four. Case 1 would have to be reconsidered if it was difficult to coordinate with existing plans for power supply lines, as would Case 8 if increased options for economical power exchange made the scale of the total network in the region inadequate.

Figure 6 Hydropower Potential in the Laos System in 2015 (Base Case)



Source: Prepared on the basis of data gathered from Laos Electric Power Public Corporation.

Figure 7 The Most Economic Plans for International Interconnected Power Networks in Indochina



Chapter 4
The Feasibility of Interconnected Power Networks

The examination in Chapter III demonstrated that interconnected networks can yield major effects to reduce power source plant development and fuel costs in Indochina. However, these reduction effects differ fundamentally from the kinds of effects that bring direct cash revenue to power companies and other stakeholders. Therefore it must be verified whether this development strategy can actually realize interconnected power networks. Therefore, this chapter analyzes interconnected power networks with a view to their business potential, to evaluate their feasibility.

1. The Business Potential of Interconnected Power Network Projects

This analysis uses the Financial Internal Rate of Return (FIRR) to evaluate the business potential of the construction, operation and management (O&M) of an interconnection line by a third party (referred to below as an interconnection line operator), independent from the power companies of each country and using, for example, a BOT system.[19] The cases studied here will be 2, 5, 7 and 10, which were demonstrated in the last chapter to be economic.

(1) Conditions for the Financial Analysis

The interconnection line operator aims to recoup the construction cost of the transmission line and the O&M cost purely through revenue from the power exchange amount passing through the interconnected network. Therefore the financial benefit in the financial analysis is the power exchange amount (kWh) multiplied by the unit charge (¢/kWh) for using the interconnected network, and the financial costs are the construction and O&M costs for the interconnected network. Three patterns were envisaged for the interconnected network project, with project lifespans of 15, 20 and 25 years[20]. The construction period for the interconnected network was put at four years.

(2) Power Exchange Amounts, Interconnected Network Unit Usage Charges and Advantages for Each Country

This analysis sets the power exchange amount as the amount of power passing through the interconnected network for economic power exchange. The interconnected network unit usage charge can be set as high as the difference in unit fuel costs between the two countries involved in the economic power exchange, but as economic power exchange that does not benefit both parties is not realistic, the charge is set at a level at which the two countries and the interconnected network operator split the benefit generated by the exchange. Specifically, charges of 1.0, 1.5, 2.0 and 2.5¢/kWh were envisaged. The benefit for the countries involved was put at 0.5 and 1.0¢/kWh.

Figure 8 illustrates the business scheme for interconnected network projects in this analysis.

(3) Financial Analysis Results

Table 9 presents the financial analysis results calculated for 2015 under the conditions stated in (1) and (2). Overall the FIRR values are low, and even for the case with the best results (Case 2, with a project lifespan of 25 years, benefits of 0.5¢/kWh for each country and interconnected network unit usage charge set at 1.5¢/kWh) the FIRR is only 6%.

2. The Feasibility of Interconnected Power Networks

The analysis in 1. above shows that an interconnected network project operated by a third-party company independent from the power companies of the two companies and preserving cost advantage for both

19 Build, Operate and Transfer

20 Thailand sets FIRR of 15% or more over 15 years as the criterion for investment in transmission line projects. The lifespans for general transmission lines are 20 years in Viet Nam and 25 in Thailand.

Figure 8 Image of the Interconnected Transmission Line Project

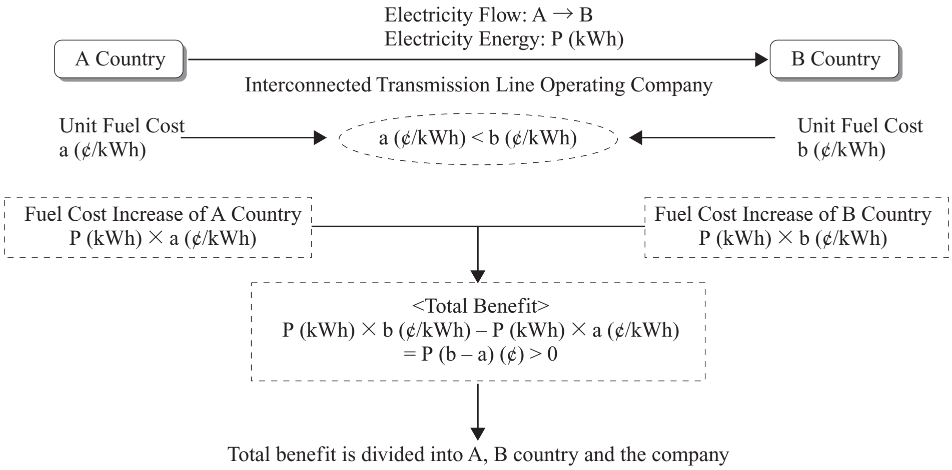


Table 9 Financial Analysis (FIRR, 2015)

	Project terms	25 years		20 years		15 years	
	Each benefit (¢/kWh) / Unit charge (¢/kWh)	0.5	1.0	0.5	1.0	0.5	1.0
Case 2	0.5	–	–	–	–	–	–
	1.0	**5.90%**	–	**4.78%**	–	**2.60%**	–
	1.5	**6.37%**	–	**5.30%**	–	**3.19%**	–
	2.0	**1.98%**	–	**0.43%**	–	-2.41%	–
	2.5	**1.50%**	–	-0.10%	–	-3.03%	–
Case 5	0.5	–	–	–	–	–	–
	1.0	**2.08%**	–	**0.55%**	–	-2.27%	–
	1.5	**2.33%**	–	**0.83%**	–	-1.95%	–
	2.0	-3.58%	–	-5.88%	–	-9.82%	–
	2.5	-3.31%	–	-5.57%	–	-9.45%	–
Case 7	0.5	–	–	–	–	–	–
	1.0	-3.09%	–	-5.32%	–	-9.15%	–
	1.5	-1.08%	–	-3.03%	–	-6.45%	–
	2.0	-2.10%	-12.55%	-4.19%	-16.25%	-7.82%	–
	2.5	-1.65%	–	-3.67%	–	-7.21%	–
Case 10	0.5	–	–	–	–	–	–
	1.0	-4.58%	–	-7.03%	–	-11.19%	–
	1.5	-0.31%	–	-2.15%	–	-5.41%	–
	2.0	-2.62%	–	-4.78%	–	-8.51%	–
	2.5	-2.28%	–	-4.39%	–	-8.06%	–

Note: "–" in the table indicates an FIRR value which could not be calculated.

companies in economic power exchange would not be able to yield a generally expected rate of return by 2015. This does not prove that the project itself is impossible, but that obtaining project funds will make it very difficult for the project to operate.

However, when the business potential of interconnected network projects in 2020 was analyzed, the results showed FIRR values of 15% or more for some cases, depending on the settings of interconnected network unit usage charges and benefits for the two countries. Thus, as networks increase in size, there are greater opportunities for economic power exchange, which are expected to improve the profitability of interconnected network projects.

Chapter 5
Challenges for the Realization of Interconnected Power Networks

1. Suggestions for the Realization of Interconnected Power Networks

The above study showed that, while interconnected networks have major economic effects, it will be difficult to develop interconnected network projects on a business basis. However, this result occurred because if a third-party operator independent from the power companies of each country carries out the construction and O&M for the interconnected network, there are national economic benefits in the form of deferment of new investment in power sources due to improved system reliability and fuel cost savings from economic power exchange, but the interconnected network operator does not benefit from those effects.

Therefore it would be better if an agency or power company of the countries, which enjoy national economic benefits carried out the construction and O&M of the interconnected power network.by A consultative organization is also required to discuss fair division of construction and O&M costs and appropriate interconnected network unit usage charges for the countries, which benefit from the interconnected networks.[21] Such a scheme would also make it easier to unify the technical standards and protocols necessary for complex network operation.

However the consultative organization must take a neutral, third party position, isolated from the two parties. The important question of what kind of agency with how much authority is required to achieve fair operation should be considered carefully with reference to the interconnected network operation method[22].

2. Challenges for the Realization of Interconnected Power Networks

There are a number of conditions and challenges which must be overcome before full benefit can be derived from the economic effects of interconnected networks, which have been verified in this study.

(1) Conditions and Challenges to Realize Benefits from Fuel Cost Reductions

The greatest impact for fuel cost reduction comes from potential hydropower capacity in Laos. Therefore the state of hydropower sources in Laos should be investigated in as much detail as possible and included in the examination of fuel cost reductions.

In this study it was not possible to obtain detailed

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21 Even this kind of system cannot necessarily solve the problem of profitability for interconnected network projects, but the use of low-interest public funds and encouragement for public-private partnership are necessary measures to hold costs to a minimum until the point where business feasibility improves.

22 The operation of interconnected networks can be broadly divided into two types:
1) "Negative operation", in which each country basically tries to cover its needs by its own abilities, and only uses the interconnected network when it has an excess or shortage of supply.
2) "Positive operation", in which each country thinks of the whole network linking demand and equipment and makes the greatest possible use of interconnected networks to make the most economic use of its equipment. Positive operation derives the greatest benefits from the network as a whole, but it increases dependence on the interconnected network, which increases the impact of accidents affecting the interconnected transmission lines.

data on the planned sites of new hydropower development, which means the data must be inferred from the characteristics of the sites. However, hydropower differs from thermal power in that it is very strongly influenced by site characteristics. Therefore when data estimated from the characteristics of other locations is used, estimation errors could influence the final results. Detailed analysis in future will require detailed and accurate data based on local characteristics.

(2) Conditions and Challenges Related to System Reliability Level

This study examined reliability using a simulation taking LOLE (Loss of Load Expectation) as the indicator of system reliability in the four countries, with the LOLE value set at 24 hours. The system reliability differs between countries at present.

Interconnection between networks at very different levels of reliability concentrates all the advantages on the side with lower reliability (high LOLE value). The system reliability of the network as a whole improves, but the network which had a high level of reliability before interconnection will be affected by the network which had lower reliability, and its reliability could even decline as a result. Therefore the countries involved in network interconnection should strive to bring their system reliability levels to similar levels.

(3) Conditions and Challenges Related to Domestic Network Development Planning

This survey assumes that there are no limitations on transmitting power between regions within each country's domestic network, and that the interconnected networks between countries are planned to link the transformer stations closest to the border. However, the domestic networks of Laos and Cambodia are completely undeveloped, and the Vietnamese network is limited in the capacity of transmission lines linking the north and south of the country. As the countries' networks expand in future, their domestic networks are expected to be developed and improved, but the magnitude of effects to be realized from interconnected networks varies with the level of development of the domestic networks. Therefore development plans for domestic networks must be prepared with care to avoid impairing the effects of interconnected networks.

(4) Conditions and Challenges for Operating Interconnection Lines with Power Plants

When the capacity of a transmission line planned as a power supply line is to be increased, it would be effective to add interconnected network functions if possible, as that would save construction costs, as mentioned above. As the most economic plans proposed in this study for interconnected networks (Cases 2, 5, 7 and 10) are those that use power supply lines, realization of these plans will require consistency with the transmission line construction plans that accompany power source development. When development plans are drawn up for power sources and transmission lines, the capacity of the transmission lines will have to be decided with due consideration of their future use in interconnected networks.

Chapter 6
Support for the Realization of Interconnected Power Networks

This chapter will discuss the policies for future assistance for interconnected power networks, based on the preceding results, suggestions and challenges.

1. Assistance for Status Analysis Required for Preparing Interconnected Power Network Plans

The building of interconnected power networks will have to be preceded by collation of the various data required for the preparation of interconnected power network plans, and examination of specific plans.

As described in Chapter 5, among the various data required for preparation, there is a lack of accurate data for the sites of planned new hydropower developments in Laos and Cambodia. Without data on the characteristics of specific sites, it is not possible to consider plans accurately and in detail, so assistance for building a data-gathering system is important.

Within Indochina, other than Cambodia and Laos, there is also a plan for interconnection with Yunnan Province in China, so detailed data will also have to be gathered for this province.

Consideration of specific interconnected network plans will have to include a feasibility study, which will be needed to examine the most economic plans of those presented in this study, in order to assess their effects and feasibility accurately. The JBIC SAPROF and JICA development study schemes should be able to make contributions in many areas concerning the feasibility study.

2. Assistance to Prepare the Conditions for Building Interconnected Power Networks

In addition to the preparation of all necessary data and examination of specific interconnected network plans, assistance will be required to prepare conditions within and between the countries concerned to ensure realization of the intended benefits. The main example of that kind of preparation would be the development of domestic networks and matching of their system reliability levels.

Development of domestic networks would consist of assistance for hardware and systems development in Cambodia and Laos, and expansion of the capacity of Viet Nam's North-South power transmission link. Matching of reliability levels will involve the preparation of systems for discussion and study between countries to coordinate their interests and determine appropriate levels of system reliability. This involves the establishment and operation of a consultative body, which will be discussed in 3. below.

3. Assistance for the Construction, Operation and Management of Interconnected Power Networks

Once a plan for an interconnected network has been drawn up, the establishment of the consultative body and executing agency will be important for the implementation of the project. The consultative body will manage coordination and cooperation between the countries to balance their interests on construction, operation and management of the interconnected power network and build related rules, and the executing agency will operate the project impartially. It is also important to give these agencies appropriate degrees of authority.

Assistance to set up this kind of implementation scheme for interconnected power network projects should include the following measures for the hardware and systems aspects of the project.

(1) Assistance for Hardware Aspects

Needless to say, assistance for hardware aspects includes financial assistance for the construction of the interconnected network and equipment for network operation[23]. The results of the above financial analysis indicate that the risks of interconnected power network projects would be greatly reduced by the availability of public funds.

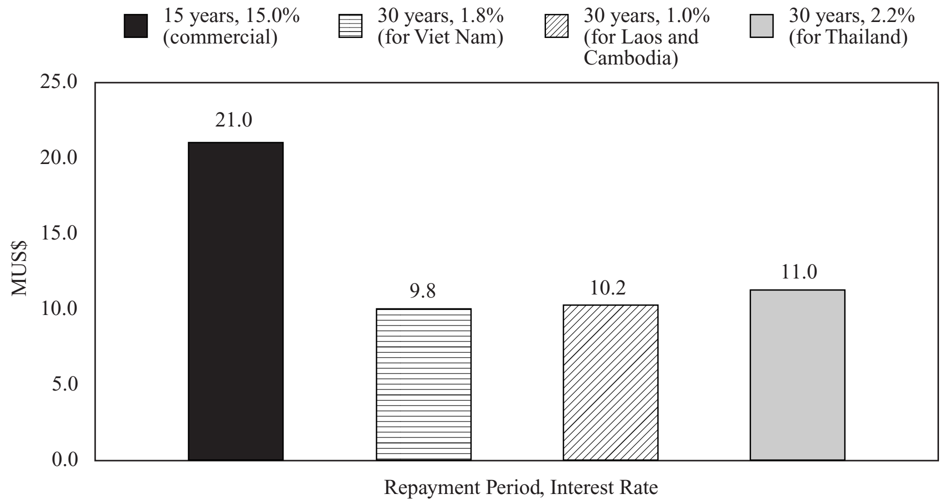
Taking Case 2 as an example, we compared the burden of annual costs with a project lifespan of 15 years, 15% interest, and for three cases assuming the availability of public funds, as follows:

- Project life of 30 years and 1.0% interest (the lending conditions for Cambodia and Laos).
- 30 years and 1.8% (the lending conditions for Viet Nam).
- 25 years and 2.2% (the lending conditions for Thailand).

Compared to the use of commercial funds, the annual cost is less than half in these three cases (see Figure 9).

23 Equipment such as the SCADA system for smoother information exchange between countries, and network operation systems for wide-area management.

Figure 9 Annual Cost Comparison of Commercial and Public Loan (Case 2)



(2) Assistance for System Aspects

Assistance for system aspects consists of intellectual assistance in areas such as approaches to the burden of construction, management and operation costs, methods for setting transmission line usage charges, examination and solution of network operation problems and the setting of operation rules. However, provision of assistance for these systematic aspects will require thorough debate on the optimum wide-area operation system for Indochina, based on in-depth study and consideration of leading examples of wide-area operation in Japan and the West. Also, considering the strong regional dependency of the electrical power industry, there appears to be a need for thorough study and research into the characteristics of Indochina, as has been done for other regions.

Chapter 7 Conclusions

Development in the electrical power sector commonly requires large amounts of time and capital, and for developing countries with limited access to funds. The key question is how to proceed efficiently and effectively in development with the limited funds available. It will be difficult to deliver a stable supply of high-quality power to meet rapidly growing demand without overcoming the funding issue, but interconnected power networks are an effective method with strong potential as a public-benefit task to be addressed by electricity projects[24].

This study focuses on examining "system reliability", but it also suggests that interconnected power networks will be valuable for "environmental conservation", by reducing fuel consumption, and for universal service, through reduced annual costs. Indochina is a diverse region in terms of its market sizes for energy resource potential and power. The greater and wider the diversity, the greater the effects that can be gained through standardization in interconnected networks, which in return, increases the significance of such networks.

The right methods for wide-area operation in Indochina will be an important issue to consider in future. We hope this report will be of use in establishing fairly-distributed wide-area operation systems with a view to building interconnected networks in Indochina.

24 This refers to benefits such as system reliability, energy security (promotion of the best mix of power sources to build a system able to carry on stable supplies even when procurement of one type of fuel is impeded), universal service (delivery of a service of uniform price, quality and other attributes to all users) and environmental conservation.

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