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PRIMARY RESEARCH

A study of success in liquefied natural gas receiving terminal

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Index Terms
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LNG Receiving Terminal
Critical Success Factor

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Abstract— This research will present the procedure to obtain the storage capacity, the type of LNG receiving terminal, and Critical Success Factors (CSF) as well as control measures for such factors, which are appropriate for Phra Nakhon Tai power plant. This research methodology starts from determining the terminal's storage capacity from the demand of natural gas of Phra Nakhon Tai power plant. Then, the storage capacity and the calculated natural gas demand will be used to select the type of LNG receiving terminal which is appropriate for the power plant. The selection criteria will come from a study of a group of countries with LNG receiving terminals and have similar sea state characteristics to Thailand and from reviewing related literature. Subsequently, when the type and the terminal's storage capacity are known, the next process will be to create measures by starting from analyzing the CSF for the establishment of the terminal by applying the concept of Balanced Scorecard and using those CSF to create control measures. Once measures of each factor are known, they will be evaluated to find the compatibility between the factor and the measures. The final results achieved will be the result of categorizing control measures of critical success factor into 3 phases for the establishment of a LNG Receiving Terminal in the Gulf of Thailand to supply natural gas to Phra Nakhon Tai power plant continuously. It was found that they can be categorized into 4 aspects, namely Metocean, logistics, environment, and economics. Hence, this research is the first research that will study all four aspects and analyze factors for LNG receiving terminal establishment in each aspect as well as their control measures.

I. INTRODUCTION

Currently, Thailand's electricity generations are mostly from fossil fuel consumption. This is 84% of total electricity generation, being 20% coal and 64% natural gas [1]. In addition, with the problems caused by electricity generations whether it is residual toxin in soil and water source, or air pollution caused by coal burning which is a threat to the environment and health of people in the communities in the surrounding area of coal-fired power plants, there is resistance from communities which results in failing to increase amount of coal consumption as a fuel for electricity generations in Thailand. From the survey of natural gas in Thailand in 2015 by [2], it was found that the amount of proven reserves of natural gas is at 0.2 Trillion cubic meters. Hence, from the natural gas consumption in 2014 which was 52.7 billion cubic meters, natural gas available in Thailand will be sufficient only for another 5.7 years. Meanwhile, the PDP 2015 has a plan to build combined cycle power plants using natural gas as main fuel for electricity generations. Therefore, EGAT has to import natural gas from overseas to be used as a fuel to supply emerging combined cycle power plants. One of the most efficient ways to import in the present is to import it as LNG which has an importation process as shown in fig. 1.

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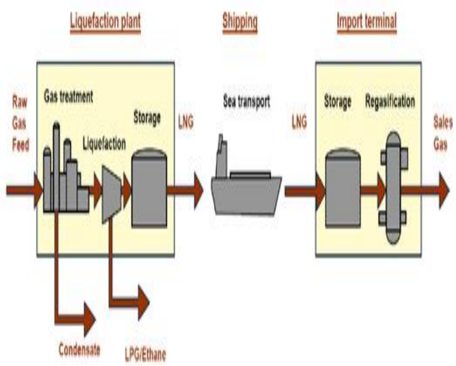

Fig. 1 . Process of natural gas importation in the form of LNG Chain (Source: The international group of liquefied natural gas importers) [3] and [8]

From such form of natural gas importation, it is necessary to have storage to store natural gas from ships and a regasification to convert LNG back into natural gas. The combination of these two components is called a LNG Receiving Terminal which can be categorized into 4 main groups as follows:

- On-shore.
- Off-shore gravity based structure (GBS).
- Off-shore floating storage and regasification unit (FSRU).
- Off-shore transport and regasification vessel (TRV).
- Off-shore transport and regasification vessel (TRV).

II. LITERATURE REVIEW

Literatures related to establishment of LNG receiving terminals were studied in this research and it was found that the important common points that most researchers would focus on first are the storage capacity and the type of the terminal [9], [12] and [13]. These two parts will be the indications of different type of LNG receiving terminals such as limitations on locations, delivering methods, environment impacts, and capitals. When each researcher knows the storage capacity and type of the terminal, the study will focus on the aspect that he/she is interested in. For instance, [4] focused on metocean. This research mentions the location for LNG Offloading in 3 locations, including the Northwest Shelf of Australia, the Southern North Sea, and the Gulf of Guinea. The focus was to collect data of sea states of all 3 locations which includes wind-sea condition and swell condition. Then, these data were formed into statistical data and the ability to offload LNG in each location was compared to determine its LNG Offloading efficiency. [5] focused on environment by conducting a survey and analysis to identify the characteristics of potential hazards during regasification process through a new technique called Dynamic Procedure for Atypical Scenarios Identification (DyPASI). Then, these characteristics were compared to a study in the form of Environmental Impact Assessment (EIA) to increase reliability of DyPASI technique. [6] focused on economics and logistics. They have described a model to calculate the maximum profitable point in regasification of LNG from storage tanks at importation terminal in relation to a natural gas spot market [10]. This was presented in 3 numerical resolution strategies including a posterior optimal strategy, a rolling intrinsic strategy, and a full option strategy based on a least-squares Monte Carlo algorithm. However, after all, the researcher has not found any literature which concludes the aspects and factors which are essential for success in establishment of a LNG receiving terminal. Most literatures conclude in the form of necessary things and processes that have to be done which are just parts of LNG receiving terminal establishment. Therefore, the researcher has summarized aspects in different areas that other researchers had studied. It was found that they can be categorized into 4 aspects namely Metocean, logistics, environment, and economics. Hence, this research is the first research which will study all four aspects and analyze factors for LNG receiving terminal establishment in each aspect as well as their control measures.

III. METHODOLOGY

The methodology of this research is divided into 4 main processes as follows:

A. The Process of Determining Terminal's Storage Capacity

Phra Nakhon Tai power plant data will be researched. This includes maximum power capacity, working hours, efficiency of electricity generation, and quality of natural gas which will be used to calculate the value of annual demand of natural gas as in Eq.1:

$$D_{\text{NG}} = \frac{3600 \times p_{\text{Max}} \times W_{\text{Y}}}{G_{\text{GCV}} \times E_{\text{T}}} \quad (1)$$

D_{NG} is the demand of natural gas (Nm3 / year),
3600 is a constant value to convert MW to MJ/hour,
E_{T} is % efficiency from type of engine,
p_{Max} is the maximum power capacity (MW),
W_{Y} is an annual working hour (hours/year), and
G_{GCV} is the Gas Gross Calorific value (MJ/m3). After achiev-

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ing natural gas demand, such value will be converted into a value for LNG by using conversion factor in Eq.2.

$$D_{\text{LNG}} = 0.00076 \times D_{\text{NG}} \quad (2)$$

Where:
D_{LNG} is the demand of liquefied natural gas (MTPA), and
0.00076 is a conversion factor to convert NG (m3) to LNG (Ton).

After that, the LNG demand will be compared with value from existing NG Receiving Terminal in the country which has the most similar geographic and sea state to find the storage capacity of the LNG receiving terminal.

B. The Process of Selecting an LNG Receiving Terminal Type

Characteristics of sea state in the Gulf of Thailand will be researched. The sea state can be divided into 9 levels as shown in Table.1. Sea state in the Gulf of Thailand will be used as criterion to determine group of countries which will be researched. These countries must have similar sea state characteristics. Then, data of receiving terminals in such countries will be studied in terms of potentiality in NG, storage capacity, and other limitations to create selection criteria to choose type of terminal between on-shore and off-shore to select type of terminal for Phra Nakhon Tai power plant as a next step.

TABLE 1
WORLD METEOROLOGICAL ORGANIZATION SEA STATE CODE

WMO Sea State Code	Wave Height	Characteristics	Character of the Sea Swell
0	0 m	Calm (glassy)	None
1	0 to 0.1 m	Calm (rippled)	Low (short)
2	0.1 to 0.5 m	Smooth (wavelets)	Low (Long)
3	0.5 to 1.25 m	Slight	Moderate (short)
4	1.25 to 2.5 m	Moderate	Moderate (Average)
5	2.5 to 4 m	Rough	Moderate (Long)
6	4 to 6 m	Very rough	Heavy (short)
7	6 to 9 m	High	Heavy (Average)
8	9 to 14 m	Very high	Heavy (Long)
9	Over 14 m	Phenomenal	Confused

C. The Process of Analyzing the Critical Success Factor

For the procedure of finding the Critical Success Factor (CSF), the researcher will apply the concept of Balanced Scorecard. Such concept is a process and management tool to measure the success of a project which the researcher found to be suitable for analyzing of CSF. This will start from finding aspects from documents and literatures which are related to the establishment of terminals.

Then, after the objectives of each aspect of a terminal establishment are specified, Key Performance Indicator (KPI) of each objective will be set to use as an indicator of success of a terminal establishment. After that, Performance Indicator (PI) which results in each KPI will be searched for in order to analyze for CSF from these PIs as shown in fig. 2.

Fig. 2 . The process of analyzing for critical success factor

D. The Process of Creating and Categorizing Control Measures of Critical Success Factor of a Terminal

For this process, it will begin with sorting CSF into endogenous factor and exogenous factor. Endogenous factor will be used to set up control measures by using approaches of determination, selection, and control, whereas exogenous factor will use risk management approach to create

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control measure by starting from identifying risk from such factors and create method for risk management from this type of factor by using retention, reduction, transfer and avoidance as shown in fig. 3.

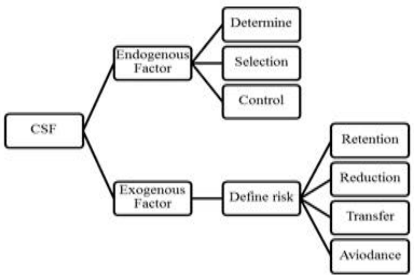

Fig. 3 . Approaches to create control measures for endogenous factor and exogenous factor

After achieving control measures for all CSFs, such measures will be used to develop a questionnaire for experts in each relevant field to evaluate for compatibility between control measures and CSF for the establishment of NG receiving terminal in the Gulf of Thailand by Phra Nakhon Tai power plant and to score control measures that comply with CSF according to established criteria which have 4 subjects including the impact on the goals and objectives of the project, the need to be used, expected benefits, and resource utilization or the cost of operation.

After that, the mean of the score of measures which experts evaluated that they are compatible will be calculated to rank the measures and specify criteria to classify control measures into 3 phases: short-term measure, intermediate measure, and long-term measure.

IV. RESULTS

A. Terminal's Storage Capacity

As a result of studying data of Phra Nakhon Tai power plant which will be built by the PDP 2015, the researcher found that the details are as shown in table 2.

TABLE 2
DETAILS OF PHRA NAKHON TAI POWER PLANT

Power plant type	Combined cycle power plant
Maximum power capacity	1,300 MW
Annual operating hours (hours/year)	7,800 hours per year
% Efficiency of the generator	40%
Gas gross calorific value (GCV)	41.0 MJ/m^3

TABLE 3
DETAILS OF A LNG RECEIVING TERMINAL IN THAILAND

Name of the LNG Receiving Terminal	Map Ta Phut
Potentiality in LNG (MTPA)	5 MTPA
Number of storage tanks	2(160,000)
Storage Cap.(m3)	320,000

The data were used to calculate annual NG and LNG demand by Eq.1 and Eq.2 as stated in methods section.

$D_{\text{NG}} = (3600\times1300\times7800)$

$= 2,225,853,659$

$= 2.23\times10^9 Nm^3/year$

$D_{\text{LNG}} = (0.00076\times2.23\times10^9)$

$= 1.6948 MTPA$

The LNG receiving terminal which was used to compare to determine the storage capacity of Phra Nakhon Tai power plant is Map Ta Phut LNG Terminal which is the only LNG receiving terminal existing in Thailand. It is located in Map Ta Phut industrial estate, Rayong province. Details of such terminal are shown in Table 3. After comparing annual demand of the power plant with a maximum annual capacity of Map Ta Phut Terminal, storage capacity of the terminal which will be established was found to be 108,467 m3.

B. Type of LNG Receiving Terminal

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From the results of the study of sea state in the Gulf of Thailand as shown in fig.4, it can be seen that Thailand has sea state characteristics between level 3 and 4 and that countries in Southeast Asia have similar level of sea state. The countries that have LNG receiving terminals in Southeast Asia include Indonesia, Malaysia, and Singapore. Therefore, the researcher studied details of LNG receiving terminals in these countries and set criteria to select the terminals as shown in table 4.

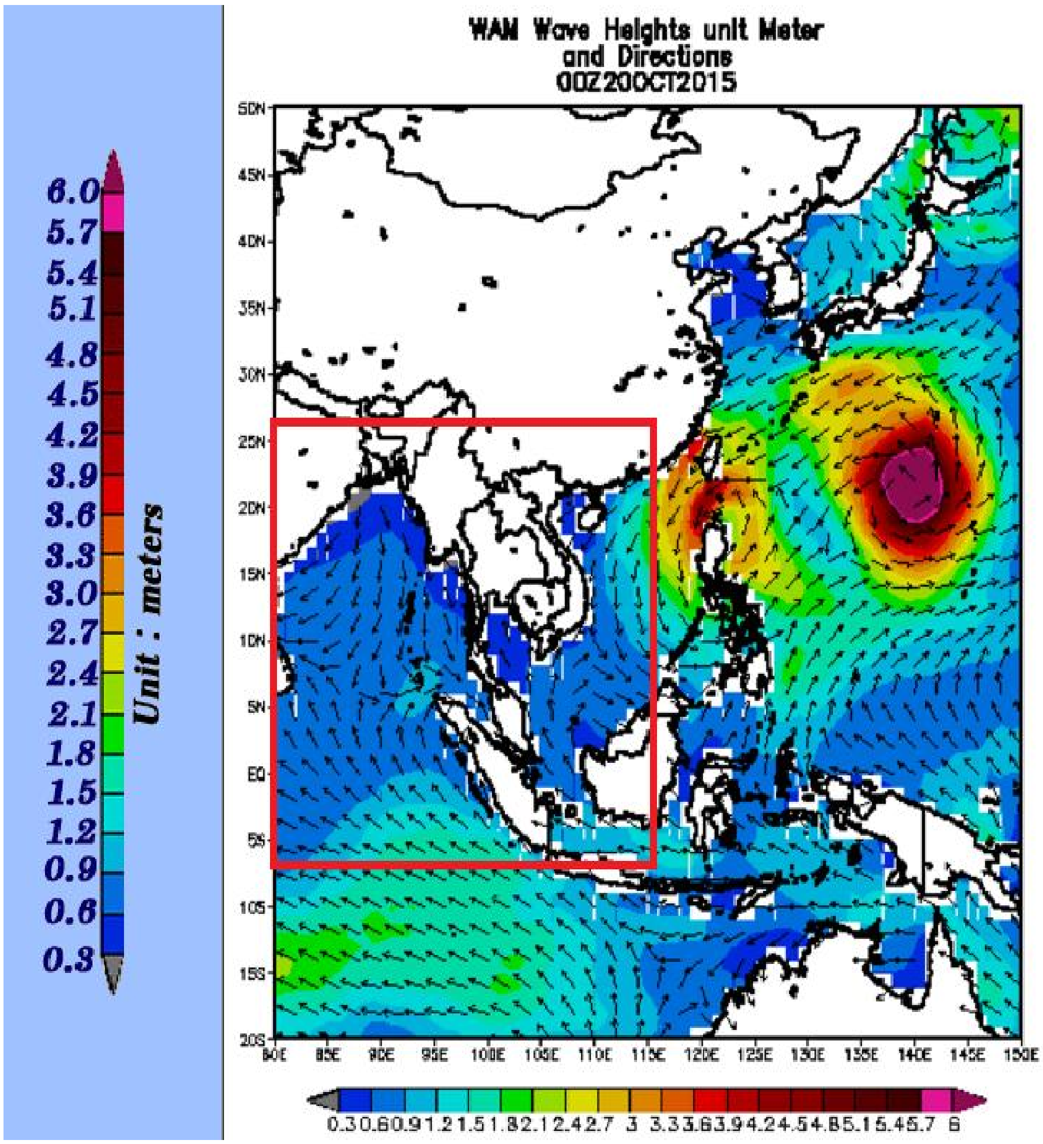

Fig. 4 . Characteristics of sea state in Thailand (Source: Thai Marine Metrological Center)

Furthermore, with the result calculation of the NG demand and the storage capacity, when choosing the type of the terminal from established selection criteria, it was found that the LNG receiving terminal which will be established is more similar to the type of off-shore than on-shore.

After finding the type of the LNG receiving terminal which will be established to be more similar to an off-shore type, the researcher reviewed the literature and relevant documents more since in the Southeast Asia region, there is not any country that has a terminal in the form of an off-shore TRV. From the research of [5] and [7] the potentiality in NG and the storage capacity were described as well as the limitation in terms of the water depth of each type of off-shore terminal. Such details were combined with the details that the researcher had previously studied and shown in table 5.

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TABLE 4
CRITERIA FOR SELECTION OF ON-SHORE AND OFF-SHORE TERMINALS

	On-shore	Off-shore
Potentiality in NG (Nm3/year)	2.4 × 109 – 12.5 × 109	2.4 × 109 – 5.2 × 109
Storage Cap.(m3)	320,000 – 592,000	125,016 – 260,000
Examples of real terminals or projects	Map Ta Phut (Thailand) Jurong (Singapore)	Lampung (Indonesia) Nusantara Regas Satu (Indonesia) Melaka (Malaysia)

TABLE 5
SELECTION CRITERIA FOR EACH TYPE OF AN OFF-SHORE TERMINAL

Layout	Off – Shore GBS	Off – Shore FSRU	Off – Shore TRV
Water Depth (m)	≥ 20	≥ 20	≥ 35
Potentiality in NG (Nm3/year)	5.2 x 10^9– 14 x 1010^9	2.4 x 1010^9 – 5 x 1010^9	Affected by journeys 18 x 10^6 Nm^3/Day
Storage Cap.(m^3)	250,000 – 330,000	125,000 – 173,000	138,000–150,900
Examples of Real Terminal or project	- Rovigo terminal(Italy) - Port Pelican terminal (Louisiana – USA) - Baja California (Mexico) Nusantara Regas Satu - Melaka (Malaysia)	- Livorno (Italy) - Tritone - Offshore Marche (Italy) - Lampung (Indonesia) Vessel "Explorer" (Indonesia)	Excelerate Energy fleet examples Vessel "Excelsior"

From the selection criteria for each type of an off-shore terminal, it was found that with the limitation of the water depth in the Gulf of Thailand which is less than 35-meter depth, an off-shore TRV terminal type cannot be applied. Furthermore, considering the NG demand and the calculated storage capacity of the terminal, it was found that an off-shore FSRU terminal is more appropriate than other types to apply to Phra Nakhon Tai power plant.

C. Critical Success Factor for the Establishment of a Terminal

The research result found that the aspects for the establishment of a LNG receiving terminal includes 4 aspects including metocean, logistics, environment and economics, ordered by priority. After obtaining such aspects, the researcher determined objectives and developed KPIs of each aspect as well as PI of each KPI as shown in table 6. When using them to analyze for CSF which affects PI, the results are as shown in table 7.

V. SYSTEM ARHITECTURE

Positioning on directions east-west and north-south of a solar panel (that is on a trajectory sun tracking device) is reduced to ordering automatic motor on the two axes of orientation system (Figure 1).

Position of the sun was calculated using formulas to approximate azimuth and elevation angles of the sun.

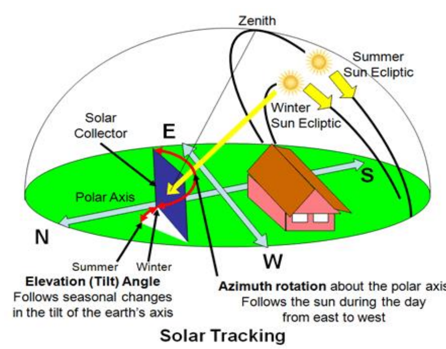

Fig. 5 . Elevation angle and azimuth rotation [4]

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TABLE 6
OBJECTIVES AND KPIS

Perspective	Objective	Key Performance Indicator (KPI)	Performance Indicator
Metocean	To find a location of the LNG receiving terminal	The location of the terminal has to be operational (Target = 24 Hour/Day)	PI1-3
Logistics	The Power plant receives NG for electricity generation continuously	The rate of NG supply to the power plant (Target = 6.39 x 106 m3/day)	PI6-11
Environment	A permit for the establishment of the terminal	Environmental Impact Assessment (EIA) (Target = Pass)	PI12-15
Economics	Analyze for the value of the investment	Economic Internal Rate of Return (EIRR) (Target > i)	PI16-18

TABLE 7
RESULT OF ANALYZING FOR CSF OF EACH PI

No.	Performance Indicator	Critical Success Factor (CSF)
PI1	The average water depth throughout the year of the area of the terminal	Water depth
PI2	Sea temperature in the area of the terminal	Sea temperature
PI3	The average wind speed throughout the year in the area of the terminal	Wind speed
PI4	Wind speed while Unloading LNG	Wind speed
PI5	Wave height while Unloading LNG	Wave, Tidal current
PI6	The number of cycles of unloading	LNG export destinations
PI7	The average speed of LNG-carrier ship	Type and size of the ship
PI8	Maximum duration between LNG unloading	Type and size of the ship and LNG export destinations
PI9	Discharge Rate from the ships to the terminal	Type and size of the ship
PI10	Maximum LNG-NG conversion rate	LNG-NG conversion technology
PI11	Minimum LNG storage at the terminal	Safety Stock
PI12	Physical resources which do not pass an impact assessment	Pipeline
PI13	Biological resources which do not pass an impact assessment	Pipeline
PI14	Human use values which do not pass an impact assessment	Pipeline
PI15	Quality of life value which does not pass an impact assessment	Pipeline
PI16	Minimum Attractive Rate of Return (MARR)	MARR
PI17	Capital expenditure (Capex)	Capex
PI18	Operation expenditure (Opex)	Opex

A. Control Measures of CSF of Establishment of a Terminal

The result of sorting out 13 CSFs and the amount of control measures which were developed are shown in Table 8.

TABLE 8
THE RESULT OF SORTING OUT 13 CSFS AND THE AMOUNT OF CONTROL MEASURES

No.	Critical Success Factor (*EN,**EX)	Measures for each factor
EX1	Water depth	EX1.1 ,EX1.2
EX2	Sea temperature	EX2.1 ,EX2.2
EX3	Wind speed	EX3.1 ,EX3.2
EX4	Wave	EX4.1 ,EX4.2
EX5	Tidal current	EX5.1 , EX5.2
EN1	Type and size of the ship	EN1.1 ,EN1.2 ,EN1.3
EN2	LNG export destinations	EN2.1 ,EN2.2 ,EN2.3 ,EN2.4
EN3	LNG-NG conversion technology	EN3.1
EN4	Minimum LNG storage at the terminal	EN4.1
EN5	Pipeline	EN5.1 ,EN5.2 ,EN5.3 ,EN5.4
EN6	Minimum Attractive Rate of Return (MARR)	EN6.1 ,EN6.2
EN7	Capital Expenditures (Capex)	EN7.1 ,EN7.2
EN8	Operating Expenditures (Opex)	EN8.1 ,EN8.2

*EN: Endogenous Factor **EX: Exogenous Factor

B. Control Measures Of CSF of Establishment of A Terminal

The result of sorting out 13 CSFs and the amount of control measures which were developed are shown in Table 8.

C. Control Measures of CSF of Establishment of a Terminal

The result of sorting out 13 CSFs and the amount of control measures which were developed are shown in Table 8. Nonetheless, the branches of relevant experts include metocean, logistics, environment and economics. There were 4 experts who accepted to evaluate the questionnaires in this research. The standard scores to divide the control measures are shown in Table 9, the compatibility results and the scores from experts' evaluations on each measure are shown in Table 10, and finally these are classified into 3 phases as previously stated in the methods section and shown in Table 11.

TABLE 9
THE STANDARD SCORES TO DIVIDE THE CONTROL MEASURES INTO 3 PHASES

Average score range	Description
5.00–3.68	Control measures which are highly critical to the establishment of the terminal (short-term measures)
3.67–2.34	Control measures which are moderately critical to the establishment of the terminal (intermediate measures)
1.00–2.33	Control measures which are slightly critical to the establishment of the terminal (long-term measures)

TABLE 10
THE COMPATIBILITY RESULTS AND THE SCORES FROM EXPERTS' EVALUATION

Score	5	5	5	5	4.75	4.5	4.5	4.5	4.25
Measure	EX1.2	EX3.1	EX3.2	EX5.1	EX4.2	EX1.1	EX4.1	EN5.4	EX5.2
Score	4.25	4	4	4	3.75	3.75	3.75	3.75	3.5
Measure	EN7.1	EN2.3	EN5.2	EN8.1	EN1.2	EN5.1	EN5.3	EN.6.2	EN2.4
Score	3.5	3.25	1.75	*0					
Measure	EN3.1	EN2.2	EN1.3	EX2.1, EX2.2,	EN1.1,	EN2.1,	EN3.2,	EN6.1,	EN7.2, EN8.2

*0 are measures which are not compatible

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TABLE 11
THE RESULT OF CLASSIFYING MEASURES INTO 3 PHASES

No.	Measure Description
	Short-term measures (5.00 – 3.68)
EX1.1	Avoid locations of the terminal with the water depth in the Gulf of Thailand which is less than 20 M
EX1.2	Dredge channels in the location of the terminal to have a water depth of greater than or equal to 20 M
EX3.1	Avoid locations of the terminal which are affected by wind speed by collecting previous data from weather stations
EX3.2	Schedule LNG unloading from carrier ships to avoid the time with Beaufort wind speed above level 4
EX4.1	Prepare a plan to support risks from natural disasters which may occur due to potential waves
EX4.2	Build coastal erosion defensive structures along natural gas pipelines on land
EX5.1	Avoid locations of the terminal which are affected by tidal currents by collecting previous data from water level stations
EX5.2	Schedule LNG unloading from carrier ships to avoid the time with tidal currents which cause sea level to be above the nominal value (Low. – High. ≤ 3 M)
EN1.2	Have plans to monitor and control emissions of SO_X, NO_X, and CO_2 from carrier ship to be within the legally acceptable values as well as preparing reports of results from the monitoring and controlling
EN2.3	Prepare a forward trading contract with exporters in the long run and plan to review the contract with exporters periodically
EN5.1	Prepare a plan for pipeline construction and a plan to reduce impacts on physical resources
	-Prepare a plan to monitor location, scope, and importance of physical resources by experts.
	-Determine the pipeline route and pipelining methodology to avoid impacts and damages
	-Design a construction which does not harm physical resources
EN5.2	Prepare an exploration plan and impact assessment to evaluate impacts on natural vegetation resources and aquatic ecology
	-Explore the natural vegetation and aquatic ecology of the areas along the pipeline.
	-Prepare pipeline construction and materials transportation control plans to control impact on natural vegetation and aquatic ecology
EN5.3	Prepare a plan to promote good relations with neighboring communities and support activities of communities or corporations along pipeline area
EN5.4	Prepare a public insurance system to cover potential damages to life and properties due to construction of NG pipelines
EN6.2	Prepare a restructuring plan to adjust the capital ratio periodically (debt/ equity)
EN7.1	Prepare a Work Breakdown Structure (WBS) Activity of the project and distribute investments to activities in WBS
EN8.1	Prepare a Master Production Schedule (MPS) and Manufacturing Resource Planning (MRP) for LNG-NG conversion and set required values for each plan
	Intermediate measures (3.67 – 2.34)
EN2.2	Prepare LNG monitoring and quality assurance plans on both side before the unloading
EN2.4	Prepare a transportation plan, transportation amount, and sea route for carrier ships to be sufficient for the power plant (1.692 billion tons per year)
EN3.1	Choose technology which can convert LNG into NG at a fast enough minimum rate to meet the needs of the power plant (≥ 270,000 m3/hour)
	Long-term measures (1.00 –2.33)
EN1.3	Set the discharge rate of LNG carrier to be ≥ 12,000 m3/hour

VI. CONCLUSION

The result of this research shows that with power production capacity of 1,300 MW of Phra Nakhon Tai power plant which will be built according to PDP 2015, the NG demand is 2.23×10^9 Nm^3/year and the LNG storage capacity is 108,467 m^3. With such demand and storage capacity as well as limitations of water depth in the Gulf of Thailand, the most suitable type of a LNG receiving terminal is an Offshore FSRU type.

The result of analyzing for CSFs which affect the establishment of a LNG receiving terminal of Phra Nakhon Tai power plant shows 13 factors. The control measures of each factor are classified into endogenous factor and exogenous factor which sum up to the total of 29 measures. After the process of compatibility assessment by experts, it was found that only 11 factors and 21 measures are compatible with an establishment of the LNG receiving terminal in the Gulf of Thailand by Phra Nakhon Tai power plant. With the average scores from criteria in 4 subjects, it was found that there are 17 short-term measures which include 8 measures for exogenous factors and 9 measures for endogenous factors. The next is the intermediate measures which include 3 measures for endogenous factors. Finally, long-term measure has only 1 measure to control an endogenous factor.

All of these are 3 phases of CSF control measures to establish a LNG receiving terminal in the Gulf of Thailand to supply NG to Phra Nakhon Tai power plant continuously.

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