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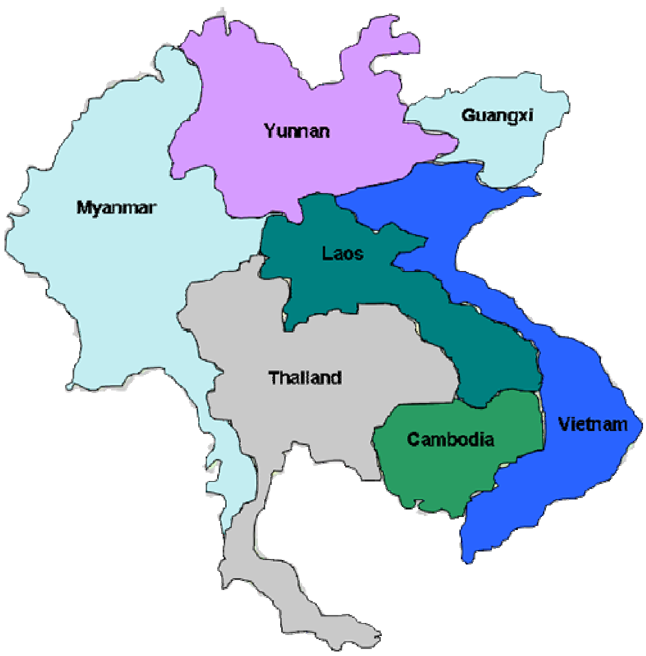

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The Greater Mekong Subregion Academic and Research Network (GMSARN) was founded followed an agreement among the founding GMS country institutions signed on 26 January 2001, based on resolutions reached at the Greater Mekong Subregional Development Workshop held in Bangkok, Thailand, on 10 - 11 November 1999. GMSARN was composed of eleven of the region's top-ranking academic and research institutions. GMSARN carries out activities in the following areas: human resources development, joint research, and dissemination of information and intellectual assets generated in the GMS. GMSARN seeks to ensure that the holistic intellectual knowledge and assets generated, developed and maintained are shared by organizations within the region. Primary emphasis is placed on complementary linkages between technological and socio-economic development issues. Currently, GMSARN is sponsored by Royal Thai Government.

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CONTENTS

Economic Rent from Hydropower Development in the Case of Lao PDR

Chansaveng Boungnong and Daovong Phonekeo

Abstract— *Like any other natural resources, hydro resources that are capable of generating electricity at cheaper cost give rise to economic rent. Lao PDR possesses huge amount of such cheaper hydro resources which is far in excess of the domestic demand. The existing rents levied by the governments are not found to address the potential value of resources. In this study hydro rent is calculated for two types of hydropower projects: (i) domestic demand oriented project and (ii) large and export oriented project including the Dams located in Mekong Mainstream. In doing so, the study uses the concept of hydro rent as a measure of cost savings achievable by the use of hydro resources over the least cost alternatives. The software "EVALS" was developed by Lahmeyer International to facilitate evaluation of a large number of hydro-electric projects and their corresponding alternatives and has been used to derive two least cost generation expansion plans i.e. one with and the other without the nominated hydro resource. The difference in the costs of two plans gives the rent of the hydro resource.*

Keywords— **Hydropower, opportunity cost, economic rent, generation expansion plans, least cost.**

1. INTRODUCTION

Definition of **'Economic Rent'**: Economic rent is the minimum amount of money that some owner must receive in order to use an asset for a given purpose. In labor terms, it is the reservation wage of the individual, which is the minimum amount of wages that the person must receive in order to work. In capital and land terms, economic rent is the amount of money needed to breakeven when either land or capital is used for any given purpose.

The concept of rent has evolved considerably since David Ricardo's classic examination in his Principles of Political Economy and Taxation, first published in 1817. Building on the work of the late seventeenth-century mercantilists, the physiocrats, Adam Smith, David Hume and others, Ricardo espoused a notion of land rent that has been expanded and refined into the modem concept of economic rent. [1]

Economic rent is the surplus return (earnings or profit) that some factors of production generate when they vary in quality and are limited in supply. Surplus means that the return is more than what the factor could earn in its next best occupation. In other words, the return is greater than needed to keep the factor in that use or a reward in excess of that required to bring forth a desired effort or function. If all factors of production were of the same quality, none could earn a surplus return since factors could be interchanged. Furthermore, if the factors were available in limitless quantities, they would earn no return at all.[2]

The exploitation of water in the hydropower sector can generate significant economic rents. These rents –the so-called resource rents - are defined by the surplus return above the value of capital, labor, materials and energy used to exploit water resources. States and regulators have different methods of procuring these rents, for instance through a fixed water fee system or a resource rent tax system. The latter is usually employed in the oil extraction industry. [3]

The rise in the oil price globally has increased the significance of other energy resources such as coal or hydropower. However, unlike the oil producing countries that are benefited by earning higher revenues arising from the increase in oil prices, the owner of hydro resources are not able to generate similar revenues out of it [4]. So, [5] argued that it is necessary to base public water resources development or reallocation decisions on estimated synthetic market price or shadow prices. The principal concept underlying the estimation of shadow prices is the amount a rational user of publicly supplied goods would be willing to pay.

For hydro sites, the prices obtained from the developers through the competitive auction would be the proper measure of the present value of all future annual hydro rents [5, 6]. In fact hydro sites would be developed to the extent that they allow the producers of electricity to reduce costs. It is this cost saving that represents the rent that would be attributable to a particular site if it has no other alternative use [6]. Export price could also be a measure for a true opportunity cost [6],[7].

When there is no competitive auction of hydro resources or component export price, an estimate of the economic rent of hydropower should be made based on its opportunity cost and on the basis of the surplus generated by it. According to [7] in a long run efficient equilibrium condition, opportunity cost of a hydropower resource would be equal to the marginal cost of obtaining additional electricity (for instance from new hydropower

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Chansaveng Boungnong (corresponding author) is PhD Candidate of Joint Doctor Degree program On Management Science and Engineering, National University of Laos (NUOL) and Kunming University of Science and Technology, China. Email: cboungnong@yahoo.com.

Daovong Phonekeo is Director General, Department of Energy Policy and Planning, Ministry of Energy and Mines, Nong Bone Road, Vientiane, Lao PDR. Email: daovongph@yahoo.com.

plants, or gas power plants or import etc). This is a long run marginal cost approach and the economic rent is determined as the residual value i.e. long run marginal cost of electricity less the cost of hydroelectricity.

The studies on the evaluation of hydropower rent for the Canadian utilities vary widely in terms of the assumptions on the costs of alternative technologies to the hydro resources, which gave rise to different values of hydro rents. Further, the methodologies used by these studies are not designed to capture the dynamic nature of the value of the hydro resources. Rather, they are based on least cost alternatives within a static framework. Clearly, these assumptions ultimately do not lead to the optimal results [9].

2. POWER SECTOR IN LAO PDR

Lao People Democratic Republic (Lao PDR) as figure 1.1 has several potential hydropower sites. These hydro sites are said to have the combined potential of generating 23,000MW of hydroelectricity a large part of which can be used mainly for meeting the export demand.

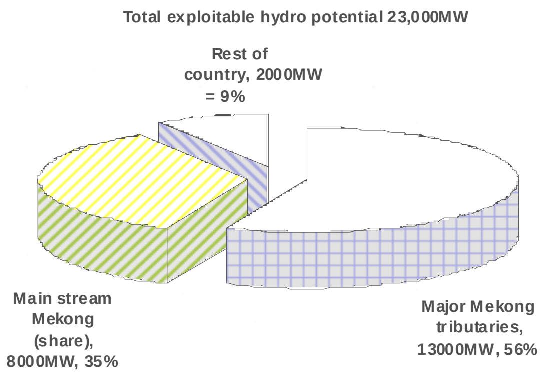


Fig. 1.1. The installed capacity of Lao PDR

However, the installed capacity of Lao PDR as yet is just over 2540MW about 11% of the exploitable potential has been implemented. Only around 73% of the population has access to grid electricity. As the demand of energy is rising at about 10% per annum, National Plan (2010-2020) aims to increase the installed capacity to 4216 MW by the end of the plan period serving 98% of the population and raising the per capita consumption to 2480 kWh.[10-11].

3. METHODOLOGY

In this study the hydro rent is measured by the difference in the total cost of two generation expansion plans, a ‘base plan’ (with ‘an identified hydro project’) and ‘alternative plan’ (without a hydro project). The difference of the two is the cost saving in the presence of low cost hydro resource, defined here as the ‘economic surplus’ or the ‘economic rent’ arising from hydro production. This methodology is also defined as a ‘detailed method’ or ‘system expansion method’ to calculate ‘avoided cost’ of the system [12].

Total system cost and corresponding generation capacity additions for the generation expansion plan of Laos Power System for the planning horizon are optimized with Develop and investigate alternatives for the most important power export candidate, and determine the technical, economic, financial, environmental, social and institutional consequences by using software program “EVALS” as described shown in figure 1.2 as below:

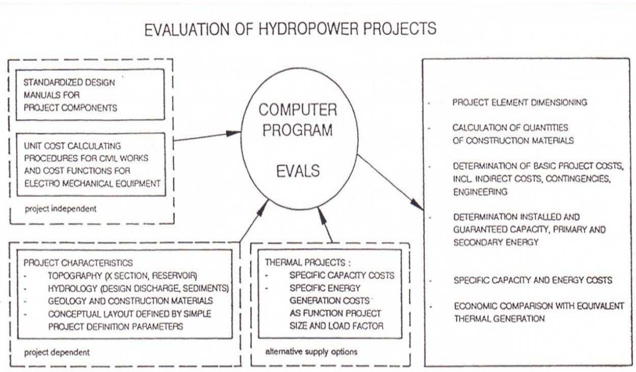


Fig. 1.2. Procedure of program “EVALS”

Program EVALS was developed to facilitate the rapid evaluation of a large number of hydro-electric projects and their corresponding alternatives.

Once the planning engineer has established the basic project layout and has defined the project element composition, program EVALS will carry out all further, usually elaborate calculations.

For a given set of simple project definition parameters (such as tunnel length, crest level of the dam, type of dam, etc.) and hydrologic as well as reservoir characteristics, EVALS performs the following computations for a range of project alternatives and variation of installed capacities:

- Dimensioning and partial optimization of principal project elements (such as dam, tunnel, powerhouse, etc.).
- Determination of installed and guaranteed capacity as well as primary and secondary energy production
- Calculation of the total basic project costs, including indirect costs, contingencies, engineering, administration and clients' own costs: as well as estimation of the annual costs for operation, maintenance and repairs
- Computation of the specific capacity (kW) and energy (MWh) costs as well as assessment of the benefit-cost ratio of the project when compared to an equivalent thermal power plant.

For each project up 20 project alternatives (project layouts, i.e. alternative dam heights, other type of power house etc.) can be defined.

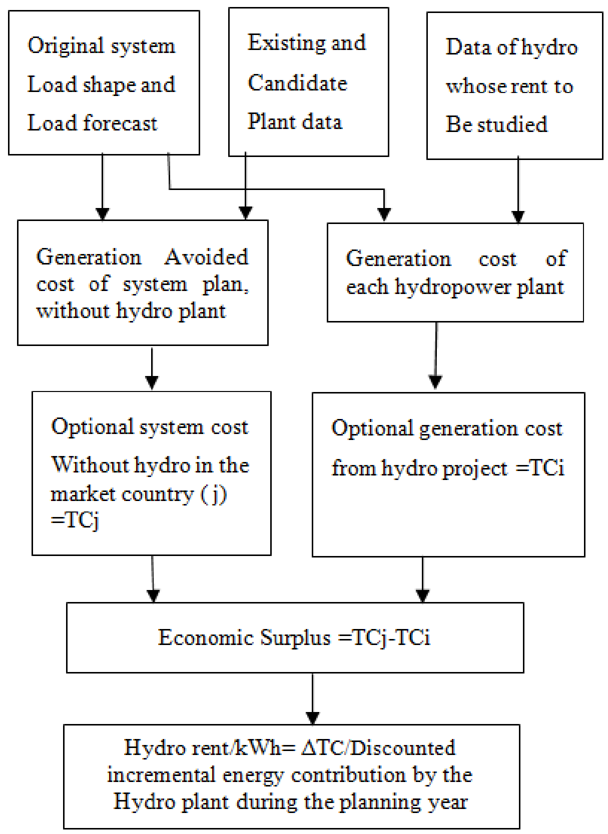
For each project alternative the computations can be carried out for up to 11 variants of the installed capacity, which are defined by the so called installed capacity factor. This factor defines the discharge capacity of all power related project components in terms of the mean stream flow available to the project.

The program produces a detailed description of the entire cost estimating and evaluation process. Data pertinent to river development, project screening a power systems analysis studies can automatically be stored in disk files for further processing.

Cost estimates made with program EVALS are on pre-feasibility level provided that the input match that level.

The results of program EVALS represent a decision base for the planning engineer with respect to the range of attractive dam heights and installed capacities. Definite decisions on dam height, installed capacity and project construction sequences can only be taken after thorough river development and power system expansion studies, in which interaction of the individual project with other generating plants of the interconnected system is considered.

3.1 Methodology to Calculate Hydro Rent



3.2 Total Cost Function

Objective functions of optimal expansion plan for a power generating system over a period of up to thirty years, within constrains given by the planner is ation

$$Bj = \sum_{t=1}^{T} \left[I_{jt} - S_{jt} + F_{jt} + M_{jt} + O_{jt} \right] \qquad (1)$$

where:

I Capital investment cost
S Salvage value of investment cost
F Fuel cost
M Operation & Maintenance costs
O Cost of the energy not served
J expansion plan,
T the length of the study period

Note: All costs are discounted net present values

Capital Investment cost on Hydropower Project is function as following :

$$I = \int (EPC, Tw, O\&M, Rc, Cc, Ef) \qquad (2)$$

where

I Capital Investment cost on Hydropower Project,
EPC Engineering Procurement Cost
Dc Development Cost
Tw Transmission line wheeling charge
O&MR Operation & maintenance cost
Rc Resettlement Cost
Cc Compensation Cost
Ef Environmental and social development fund

Hydropower Generation Cost is calculated as follow:

$$Ac = \frac{R*(R+1)^T}{(R+1)^T - 1}(\%) \qquad (3)$$

$$Gc = \frac{Pc*(Ac + O\&M)}{E}(c/kWh) \qquad (4)$$

where:

Ac Average discount rate
R Discount rate (%)
Pc Hydropower Project cost(m$)
O&MR Operation & Maintenance cost
E Energy Generation (GWh)
Gc Generation Cost (c/kWh)

Generation Cost of other resources are calculated as follow:

	Laos	Thailand	Cambodia	Vietnam
Generation Technology	Small coal fired	Combined cycle	Diesel	Coal fired steam
Capacity Cost ($/kW)	325.4	193.45	69.12	285.77
Energy Cost ($/MWh)	105	61.29	289.58	68.48

3.2 Regional Power Context

The economic value of hydropower is very different between the producing countries (Lao PDR and Cambodia) and the large power systems of Vietnam and Thailand. These large systems have several large-scale thermal generation options, including coal fired steam technology, gas fired combined cycle technology, and nuclear power. These large-scale thermal generation options can offer, on average, thermal energy costs (**TC_j** for Thailand and Vietnam) of the order of 75 $/MWh. Large-scale thermal options are not practical or economic for the scale of demands in Lao PDR and Cambodia which, in the absence of hydropower, would depend on oil or small scale fired thermal technologies (**TC_j** for Laos and Cambodia) that have costs in the order of 120 to 300 $/MWh.

The large sample of projects in the database offers the opportunity to examine the statistical characteristics of different cost indicators, such as the cost per unit of capacity and the cost per unit of mean annual energy. The results are compared against certain cost drivers, such as the scale of the project and the capacity factor of the projects. It was observed that for projects under 100 MW (Megawatt) the unit capacity cost is between 2 M$/MW (million US dollars per Megawatt) and 3.5 M$/MW, while most projects above 100 MW have unit costs around 1,5 M$/MW. The majority of projects have capacity factors in the 0.40 to 0.60 range, resulting in energy costs (**TC_i**) of 50 to 60 $/MWh (US dollars per Megawatt-hour) for projects under 100 MW and 40 $/MWh for projects over 100 MW. The national hydro development plans correlate reasonably well with the calculated energy costs. The average energy cost of projects not yet under operation or construction is 55 $/MWh.

3.3 Calculation of Hydro Rent (USc/kWh)

Domestic Case:

The ratio of the present value of the system cost saved by the selected hydro project to the present value of the energy contributed by the plant gives the per unit surplus due to the project and is termed as per unit rent of the project.

Let the total cost or objective function value of the '**base case plan**' with hydro plant, discounted to the year 2010 (base year of study) is **TC_j** and the total discounted cost of the alternative plan (i.e., the one without the hydro plant), is **TC_i**. Let **r** be the discount rate and total energy contributed by the hydro plant to the system in year 'i' be ΔEi.

Then, the average per unit surplus generated = Present value of the cost difference of expansion plans/ Present value of energy contributed by the hydro plant during the planning horizon. Or; Average rent/kWh=$(\sum TCj-\sum TCi)/\sum \Delta E/(1+r)^i = \Delta TC/\Delta E/(1+r)^i$

3.4 Input Data and Assumptions

Planning horizon of 30 years i.e., 2010 to 2040 is considered in the study. The base year of study being 2010, all the input costs are converted to 2010 based, and all costs are discounted to this year at the annual rate of 10%(which is the opportunity cost of capital in Lao PDR) in the base case. The LOLP value of 10 days/year and minimum reserve margin of 10% is taken. No more energy purchase from nebouring countries after year 2015 is assumed in the 'base case'. Cost of energy not served is assumed USc 50/kWh. Similarly, the foreign cost component escalation is supposed to take place at the rate of 2 % per annum. The Load forecast for the Nepal Power system used in the study is as given in Appendix-1.

3.5 Resource Rent in the Domestic Market

The hydro project considered in the domestic market scenario is small and medium scale hydropower projects and some of take from export project. In the expansion plan (6268 MW, 23,679 GWh), which is including from thermal power plant 2x300MW at Kalum Distric, of take 100MW from Hongsa Lignite and a least cost candidate of hydropower projects in the generation expansion plan inventory for domestic demand.

In the "base case" or "business as usual" case, all the existing and committed hydro of the inventory (Appendix-2) is considered available.

3.6 Resource Rent in the Export Market

To evaluate the hydro rent with powerexport scenario, optimisations of generation expansion plans are made with and without Mekong mainstream projects.

Table 1. Descriptions of Case Studies:

Cases	Descriptions
Case-I	The 'business as usual case for domestic' where hydro and thermal candidates are considered to obtain expansions plans with assuming no fuel price escalation during the planning horizon.
Case-II	The 'business as usual case for domestic and export' where hydro and thermal candidates are considered to obtain expansions plans with assuming no fuel price escalation during the planning horizon.
Case-III	The 'business as usual case for domestic and export' where hydro and thermal candidates are considered to obtain expansions plans with assuming with out Mekong mainstream projects.

4. RESULT AND DISCUSSION

In this study, hydro rent of two projects, one for domestic market and another for the export market are calculated separately as the opportunity costs are different in the two markets.

4.1 Results Domestic Hydro thermal Cases

Table 2. Domestic Hydro thermal Cases:

S.No	Descriptions	Case-I
1	SystemCost for only domestic used with out Hydropower	1,019,958,82 0
2	Total cost for hydropower project suppling domestic market	628,974,606
3	Saving due to	390,984,214
4	Incremental energy (2010) GWh	8499.657
5	Specific Rent of the Project =ΔTC/ΔE (USc/kWh)	4.6

4.2 Results Domestic & Export Hydro thermal Cases

Table 3. Domestic & Export Hydro thermal Cases including Mekong mainstream dams

S.No	Descriptions	Case-II
1	SystemCost for only domestic used with out Hydropower	3,053,655,542
2	Total cost for hydropower project suppling domestic market	1,905,085,588
3	Saving due to	1,148,569,955
4	Incremental energy (2010) GWh	34637.920
5	Specific Rent of the Project =ΔTC/ΔE (USc/kWh)	3.31

4.3 Results Domestic & Export Hydro thermal Cases

Table 4. Domestic & Export Hydro thermal Cases excluding Mekong mainstream dams

S.No	Descriptions	Case-III
1	SystemCost for only domestic used with out Hydropower	2,399,469,855
2	Total cost for hydropower project suppling domestic market	1,724,775,057
3	Saving due to	674,694,798
4	Incremental energy (2010) GWh	24639.644
5	Specific Rent of the Project =ΔTC/ΔE (USc/kWh)	2.73

5. CONCLUSIONS

This Paper study hydro rent is calculated for two types of hydropower projects: (i) domestic demand oriented project and (ii) large and export oriented project including the Dams located in Mekong Mainstream. In the study uses the concept of hydro rent as a measure of cost savings achievable by the use of hydro resources over the least cost alternatives.

In Case-I the rent of the hydropower is evaluated at its opportunity of providing electricity from optimal mix of new hydropower or coal fired (600 MW at Kaleum and of take 100MW from Hongsa Lignite) plants or imports. The value of hydro rent in the Case-I is found to be 4.6 USc/kWh, which is 3% of the cost of energy generation from oil.

Similarly, in Case-II, when we consider to power export The rent in this Case is found to be USc 3.31/kWh.

In the Case-III without Mekong mainstream projects. The rents would be USc 2.73/kWh

The economic benefit of projects is therefore very sensitive to where the power is targeted. The economic benefit is much lower for predominantly export projects than for predominantly domestic consumption projects. However, since this differential value of power is poorly represented by tariffs, having high economic performance does not mean that a project is easier to finance. Indeed, it is likely that the easiest projects to finance are those with high exports and hence low regional economic value. It is therefore relevant to explore how critical hydropower from the Mekong Basin is to the export markets of Vietnam and Thailand.

It is of course difficult to anticipate the impact of the current global financial crisis on the long term regional economic growth. If this impact can be ignored in the longer term, then by 2020 the electricity demand of Vietnam and Thailand will dwart the hydropower potential of the Lower Mekong Basin. The annual energy potential of all the hydropower projects in the Lower Mekong Basin that are not yet under operation or under construction will probably not exceed 12% of the combined electricity demand of Vietnam and Thailand in 2020. With an average energy cost of new Mekong mainstream hydro power of 55 $/MWh, and average replacement value of that power in these markets of 75 $/MWh, the margin is only 20 $/MWh. That means about 26% potential cost savings on 12% of the power supply, or only a 3.2 % overall saving in power supply cost.

Of course, on a case by case basis many projects will be more attractive than depicted by these average numbers. But the point is that the regional economics of hydropower development does not suggest a forecast of hydropower development of all sites. The prospect of delays, or environmental mitigation costs in controversial projects, could easily postpone the development of many projects until the value of alternative power is significantly higher than today.

As a final point, a reflection is made on the extent of hydropower export revenue that would effectively impact the economies of Lao PDR. It would appear that large export projects will largely be financed by exports. Furthermore, the export price that the importer (Thai and Vietnamese markets) can bear will be, on average, only marginally higher than the hydropower energy cost. It is therefore expected that only a small part of export revenue will actually impact the exporting country economy. The benefit for the exporting country will mostly be derived from the portion of the project energy that is targeted for domestic consumption.

It is nevertheless recognized that in South East Asia, as in other parts of the world, large export oriented projects offer feasibility of hydropower development that may not exist for smaller projects targeted solely for domestic consumption.

Limitations of Study

In the study of potential hydro resource rent above, no costs of externalities (in terms of timber, fish and recreational activity losses), implications to environment and nor the possible gains (interms of irrigation, flood control, navigation and outdoor activities) are considered.

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APPENDICES

Appendix: 1. System Load Forecastof Laos PDR

Year	Peak Load (MW)	Energy Forecast(GWh)
2010	583.80	2966.80
2011	786.40	4218.60
2012	1078.10	6023.70
2013	1369.70	7828.80
2014	1661.40	9633.90
2015	1953.00	11439.00
2016	2080.10	12198.00
2017	2207.20	12957.00
2018	2334.20	13716.00
2019	2461.30	14475.00
2020	2588.40	15234.00
2021	2717.80	15995.70
2022	2853.70	16795.50
2023	2996.40	17635.30
2024	3146.20	18517.00
2025	3303.50	19442.90
2026	3468.70	20415.00
2027	3642.10	21435.80
2028	3824.20	22507.60
2029	4015.50	23632.90
2030	4216.20	24814.60
2031	4416.90	25996.30
2032	4617.60	27178.00
2033	4818.30	28359.70
2034	5019.00	29541.40
2035	5219.70	30723.10
2036	5420.40	31904.80
2037	5621.10	33086.50
2038	5821.80	34268.20
2039	6022.50	35449.90
2040	6223.20	36631.60

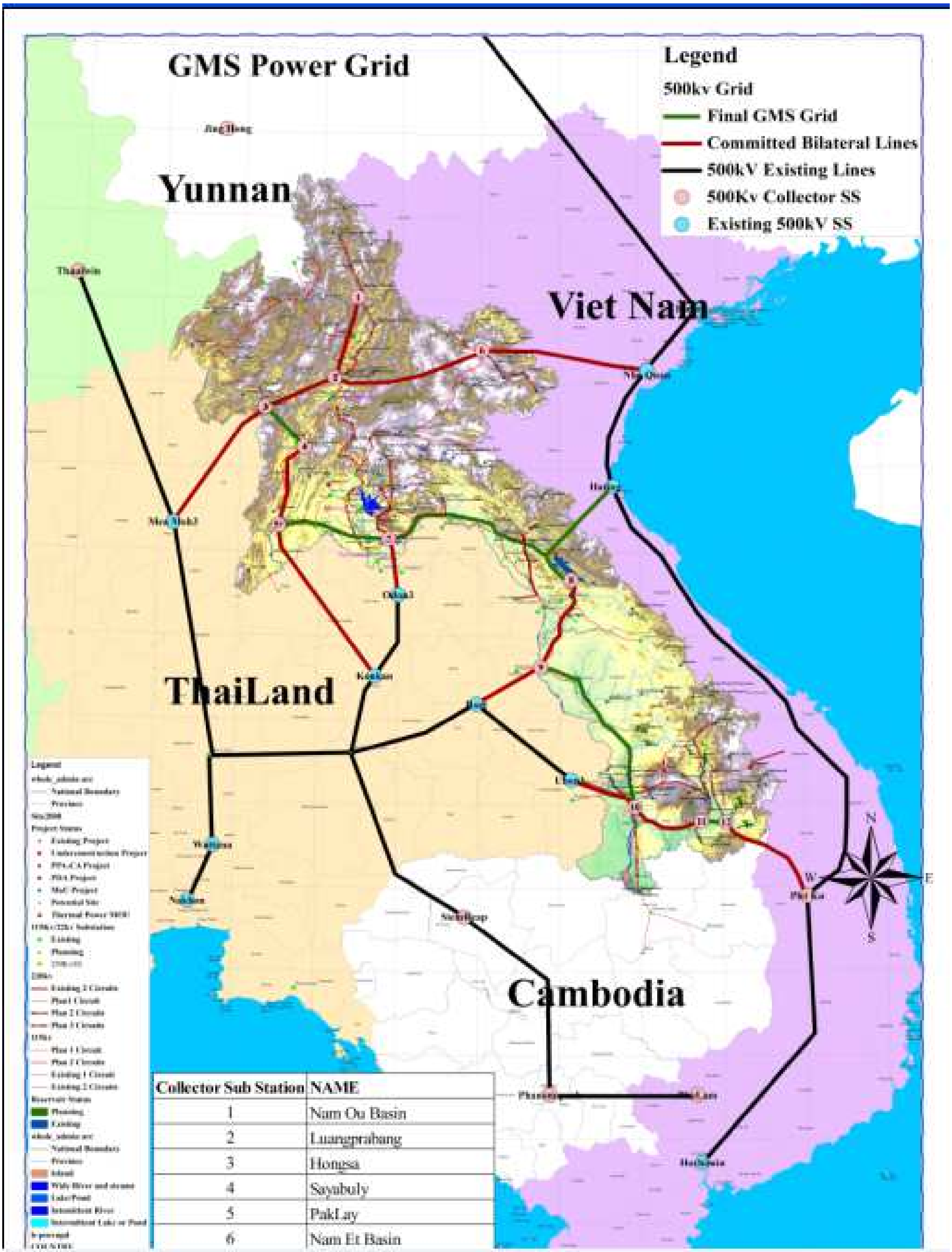
Appendix:2. Hydropower data

Project Name	Rated Head	Plant Design Discharge	Installed Capacity	Peaking Capability	Mean Annual Energy	Firm Annual Energy	Full Supply Level	Low Supply Level	Live Storage	Commission
	m	m3/s	MW	MW	GWh	GWh	mamsl	mamsl	mcm	year
Nam Ngum 1	38.5	414.4	148.7	148.7	1,006.0	846.0	212.0	196.0	4,700.0	1971
Nam Dong	136.5	1.0	1.0	0.9	4.8	4.0	605.0	603.3	0.0	1970
Xelabam	17.0	38.0	5.0	4.5	23.5	20.0	119.3	118.0	0.8	1969
Xeset 1	153.4	33.0	45.0	45.0	154.3	82.3	482.0	479.0	0.3	1994
Theun-Hinboun	225.5	106.0	210.0	186.0	1,327.0	1,300.0	400.0	395.0	15.0	1998
Houayho	748.3	23.0	150.0	144.0	487.0	397.0	883.0	860.0	649.0	1999
Nam Leuk	174.2	39.5	60.0	53.4	207.0	149.0	405.0	388.0	228.2	2000
Nam Mang 3	513.2	9.1	40.0	39.3	138.0	113.0	750.0	742.0	45.0	2004
Nam Ko	34.5	5.4	1.5	1.3	5.0	3.0	525.0	523.0	0.0	1996
Nam Ngay	17.0	8.5	1.2	1.2	3.5	2.8	455.5	452.5	0.7	2002
Nam Theun 2	356.6	334.0	1,075.0	1,080.0	5,936.0	5,339.0	538.0	525.5	3,378.4	2009
Xekaman 3	477.7	62.5	250.0	237.0	982.8	485.7	960.0	925.0	108.5	2009
Xeset 2	246.0	35.2	76.0	75.0	309.0	134.0	813.0	803.5	9.3	2009
Nam Ngum 2	146.5	448.0	615.0	554.0	1,976.0	1,387.0	375.0	345.0	2,994.0	2010
Nam Lik 2	74.5	187.0	100.0	71.0	460.0	334.0	305.0	270.0	826.0	2010
Nam Ngum 5	337.0	42.9	120.0	107.0	507.0	307.0	1,100.0	1,060.0	251.0	2012
Xekaman 1	99.0	336.6	290.0		1,096.0		230.0	218.0	1,683.0	2014
Xekaman-Sanxay	12.2	378.0	32.0	32.0	123.0	122.0	122.0	122.0	0.0	2014
Theun-Hinboun expansion	225.5	110.0	222.0	195.0	1,395.0	1,300.0	400.0	395.0	15.0	2012
Theun-Hinboun exp. (NG8)	47.0	134.0	60.0	20.0	294.0	161.0	455.0	420.0	2,262.0	2012
Nam Ngum 3	298.7	169.0	440.0	440.0	2,077.0	1,659.0	720.0	660.0	979.0	2018
Nam Theun1	140.0	404.0	523.0	388.0	1,840.0	1,424.0	292.0	260.0	2,549.2	2020
NamNgiep 1	136.2	230.0	260.0	252.0	1,327.0	1,300.0	320.0	296.0	1,191.8	2018
Nam Ngiep-regulating dam	12.0	160.0	16.8	16.0	108.0	100.0	181.0	176.0	4.7	2018
Nam Tha 1	65.5	289.5	168.0	168.0	759.4	530.0	455.0	442.5	675.5	2020
Nam Long	245.0	2.6	5.0	5.0	37.0	33.7	1,016.0	1,013.5	0.1	2013
Xepian-Xenamnoy	642.0	70.0	390.0	390.0	1,748.0	1,730.0	786.5	760.0	885.0	2017
Xe Katam	450.0	16.0	60.8	60.8	380.0	284.0	910.0	890.0	115.0	2016
Xekong 4	140.0	240.0	300.0	300.0	1,901.0	1,760.0	290.0	270.0	3,100.0	2020
Nam Kong 1	186.0	44.5	75.0	75.0	469.0	408.0	320.0	287.0	505.0	2018
Xe Kong 3up	33.7	460.0	144.6	144.6	598.7	50.1	160.0	155.0	95.1	2019
Xe Kong 3d	17.2	568.0	91.1	91.1	375.7	25.9	117.0	111.0	168.4	2019
Xe Kong 5	188.1	146.0	248.0	248.0	1,201.0	1,017.0	500.0	470.0	1,355.5	2022
Don sahong	17.0	2,400.0	360.0	359.7	2,375.0	1,988.7	74.5	72.0	115.0	2017
Nam Ou 1	20.5	1,045.0	180.0	180.0	829.0	500.2	305.0	300.0	10.0	2018
Nam Ou 2	11.0	932.0	90.0	90.0	413.0	254.9	320.0	316.0	8.4	2015
Nam Ou 3	43.0	831.0	300.0	300.0	1,337.0	838.3	375.0	370.0	13.5	2018
Nam Ou 4	16.0	558.0	75.0	75.0	337.0	237.4	400.0	395.0	9.2	2018
Nam Ou 5	25.0	514.0	108.0	108.0	496.0	358.3	430.0	425.0	11.2	2015
Nam Ou 6	68.0	368.0	210.0	210.0	840.0	717.4	510.0	490.0	363.0	2015
Nam Ou 7	90.0	238.0	180.0	180.0	725.0	702.6	630.0	600.0	1,134.0	2018
Nam Lik 1	19.5	300.0	54.0	54.0	255.0	219.0	195.0	191.0	6.8	2017
Nam San 3	877.0	6.7	48.0	48.0	366.0	274.0	1,470.0	1,445.0	121.7	2016
Nam Pha	111.0	142.3	147.2	147.2	577.0	444.0	550.0	515.0	2,738.0	2016
Nam suang 1	35.7	130.0	40.0	40.0	187.0	163.4	325.0	314.5	87.6	2021
Nam Suang 2	122.8	119.6	134.0	134.0	617.6	525.6	460.0	435.0	2,014.7	2024
Nam Nga	97.3	107.9	97.8	97.8	434.3	315.4	440.0	407.0	1,565.1	2025
Nam Beng	75.4	43.2	30.0	30.0	120.0	77.4	430.0	410.0	97.9	2016
Nam Feuang 1	57.0	57.1	28.0	28.0	113.2	26.7	340.0	334.0	30.0	2026
Nam Feuang 2	130.0	22.9	25.0	25.0	110.6	27.8	570.0	565.0	5.0	2026
Nam Feuang 3	211.0	11.3	20.0	20.0	88.5	21.8	820.0	815.0	4.8	2027
Mekong at Pakbeng	31.4	4,362.0	1,230.0	1,230.0	5,268.1	4,073.0	345.0	340.0	442.4	2022
Mekong at Luangprabang	40.0	3,812.0	1,410.0	1,412.0	5,437.3	4,205.0	310.0	300.0	734.0	2030
Mekong at Xayabuly	24.4	6,018.0	1,260.0	1,260.0	6,035.3	5,139.4	275.0	270.0	224.7	2019
Mekong at Paklay	25.7	5,782.0	1,320.0	1,320.0	5,420.7	4,251.7	240.0	235.0	383.5	2024
Mekong at Sanakham	25.0	5,918.0	1,200.0	1,200.0	5,015.0	3,978.2	215.0	210.0	106.1	2020
Mekong at Sangthong-Pakchom	22.0	5,720.0	1,079.0	1,079.0	5,318.0	5,052.0	192.0	190.0	11.8	2030
Mekong at Ban Kum	18.6	11,700.0	1,872.0	1,872.0	8,434.0	8,012.0	115.0	115.0	0.0	2034
Mekong at Latsua	10.0	9,600.0	800.0	800.0	3,504.0	2,452.0	100.0	100.0	0.0	2035
Xe Pon 3	277.2	30.4	75.0	75.0	338.9	328.5	580.0	560.0	368.0	2018
Xe Kaman 2A	48.6	155.0	64.0	64.0	241.6	175.0	280.0	275.0	3.7	2018
Xe Kaman 2B	78.8	90.0	100.0	100.0	380.5	202.0	370.0	340.0	216.8	2018
Xe Kaman 4A	423.6	26.0	96.0	96.0	375.0	262.5	860.0	840.0	16.5	2018
Xe Kaman 4B	459.1	18.4	74.0	74.0	301.0	195.7	865.0	850.0	21.2	2018
Dak E Mule	433.8	27.4	105.0	105.0	506.0	415.0	780.0	756.0	154.0	2026
Nam Khan 1	56.0	195.0	101.8	101.8	458.5	422.0	340.0	320.0	805.0	2019
Nam Khan 2	138.7	109.5	140.0	136.3	578.6	493.0	470.0	450.0	528.0	2018
Nam Khan 3	79.2	70.1	47.0	32.5	222.4	205.8	560.0	532.0	860.5	2018
Nam Ngum 4A	158.4	39.7	54.0	54.0	267.7	236.5	1,040.0	1,010.0	332.3	2023
Nam Ngum 4B	158.0	38.7	54.0	54.0	267.0	236.5	880.0	870.0	1.7	2024
Nam Ngum, Lower dam	13.6	776.4	90.0	90.0	526.0	498.0	160.0	155.0	243.0	2028
Nam Pay	714.7	10.0	62.0	62.0	242.6	168.3	1,120.0	1,100.0	52.3	2019
Nam Mang 1	115.8	50.8	51.0	51.0	235.3	182.9	360.0	330.0	551.4	2019
Nam Pouy	78.2	60.0	43.7	43.7	172.0	143.0	340.0	320.0	498.6	2019
Nam Poun	61.2	148.8	84.9	84.9	342.0	281.0	300.0	280.0	339.0	2019
Nam Ngao	347.6	6.6	20.0	20.0	155.0	108.4	880.0	855.0	434.0	2019
Nam Chian	656.2	26.3	148.0	148.0	627.2	480.0	1,040.0	1,020.0	8.3	2019
Nam Ngieu	189.5	18.7	30.4	30.4	132.3	105.4	1,060.0	1,050.0	18.8	2020
Nam Pot	703.3	3.5	22.0	22.0	99.5	96.4	1,145.0	1,127.0	45.1	2018
Nam San 3B	257.4	16.7	38.0	38.0	141.0	141.0	520.0	500.0	11.7	2020
Nam San 2	74.3	94.3	60.0	60.0	290.7	262.8	240.0	220.0	1,946.4	2020
Nam Pok	59.4	4.9	2.6	2.6	14.4	11.1	460.0	455.0	5.1	2020
Nam Phak	99.0	5.8	5.1	5.1	28.3	21.7	700.0	693.0	1.9	2018
Nam Hinboun 1	17.1	311.0	45.0	45.0	173.0	140.0	160.0	150.0	1,224.0	2020
Nam Hinboun 2	848.0	1.7	13.0	13.0	58.5	56.9	1,093.0	1,081.0	25.6	2019
Xe Bang Fai	16.0	756.8	107.0	103.8	564.2	486.0	155.0	150.0		2019
Xe Neua	94.0	40.8	34.0	34.0	230.0	196.0	370.0	330.0	624.0	2032
Nam Theun 4	157.2	20.5	30.0	30.0	130.5	125.1	720.0	680.0	806.5	2034
Nam Mouan	115.3	105.7	110.0	107.3	452.2	305.0	380.0	360.0	1,960.0	2035
Xe Bang Hieng 2	44.6	42.6	16.0	16.0	73.5	70.0	280.0	263.0	642.9	2027
Xedon 2	39.6	152.5	54.0	54.0	319.0	221.0	170.0	159.0	1,743.0	2036
Xe Set 3	164.1	13.6	20.0	20.0	74.0	50.0	1,022.0	1,018.0	3.5	2020
Xe Bang Nouan	118.8	19.0	18.0	18.0	79.1	78.8	260.0	230.0	1,477.0	2037
Xe Lanong 1	64.4	55.9	30.0	30.0	153.5	131.4	350.0	330.0	373.7	2021
Xe Lanong 2	178.2	12.9	20.0	20.0	103.5	87.6	580.0	560.0	79.2	2018
Nam Phak	669.5	13.0	75.0	75.0	307.0	279.0	920.0	910.0	35.0	2018
Xe Nam Noy 5	572.3	3.9	20.0	20.0	124.0	102.0	800.0	780.0	8.8	2022
Houay Lamphan	592.0	11.4	60.0	60.0	264.4	227.0	840.0	800.0	128.2	2018
Nam Kong 2	106.5	76.5	74.0	74.0	309.5	256.0	460.0	437.0	139.6	2021
Xe Xou	51.8	131.3	63.4	63.4	286.2	227.0	180.0	160.0	1,714.0	2022

Generation Cost of other resources are calculated as follow:

COMMON ECONOMIC DATA					
CURRENT YEAR	2010		Auxiliary Calculation		117.3909
DISCOUNT RATE %	10.00%	>>>>>>>>>>>>>>	Capital Recovery Factor for 50 year Life		
CONSTRUCTION COST ESCALATION %	2.00%				
DEVELOPMENT COSTS %	12.00%		Reference Power Trade Price must be Consistent with		
REFERENCE POWER TRADE PRICE (MONOMIC) US$/MWH	76.0	<<<<<<<<<<<<<<	Average Value of Power in Thailand and Vitenam		
REFERENCE PEAK PERIOD DURATION (HOURS/WEEK)	50.0		at a Load Factor of 0.70. From Line 47 th		101.4
POWER MARKET DATA		**LAOS**	**THAILAND**	**CAMBODIA**	**VIETNAM**
THERMAL REFERENCE COSTS					
GENERATION TECHNOLOGY		coal fired steam	combined cycle&	diesel	coal fired steam
FIXED COST CALCULATION					
UNIT EPC	$/kW	2200.00	1200.00	400.00	2000.00
IDC	%	18.00%	15.00%	7.00%	18.00%
UNIT IDC	$/kW	396.00	180.00	28.00	360.00
UNIT CAPITAL COST	$/kW	2596.18	1380.15	428.07	2360.18
ECONOMIC LIFE	years	30	25	15	30
CAPITAL RECOVERY FACTOR		0.106	0.110	0.131	0.106
UNIT ANNUAL CAPITAL COST	$/kW	275.40	152.05	56.28	250.37
FIXED OPERATION AND MAINTENANCE COST	% of Capital per Year	3.00%	3.00%	3.00%	1.50%
UNIT FIXED OPERATION AND MAINTENANCE COST	$/kW	50.00	41.40	12.84	35.40
UNIT ANNUAL FIXED COST	**$/kW**	**325.40**	**193.45**	**69.12**	**285.77**
CAPACITY FACTOR	%	80.00%	60.00%	80.00%	80.00%
EQUIVALENT FULL CAPACITY UTILIZATION	hours per year	7,008	5,256	7,008	7,008
EQUIVALENT ENERGY COST	$/kWh	0.046	0.037	0.010	0.041
EQUIVALENT ENERGY COST	$/MWh	46.43	36.81	9.86	40.78
VARIABLE COST CALCULATION					
FUEL TYPE		coal	natural gas	diesel	coal
UNIT FUEL COST	$/Mbtu	10.00	8.50	27.58	8.00
HEAT RATE	btu/kwh	10,000	7,000	10,000	8,000
VARIABLE COST FUEL	$/MWh	100.00	59.50	275.79	64.00
VARIABLE OPERATION AND MAINTENANCE	% of fuel cost	5.00%	3.00%	5.00%	7.00%
VARIABLE OPERATION AND MAINTENANCE	$/MWh	5.00	1.79	13.79	4.48
TOTAL VARIABLE COST	**$/MWh**	**105.00**	**61.29**	**289.58**	**68.48**
REFERENCE VALUE OF POWER					
CAPACITY VALUE	**$/kW-year**	**325.40**	**193.45**	**69.12**	**285.77**
ENERGY VALUE	**$/MWh**	**105.00**	**61.29**	**289.58**	**68.48**

Appendix: 3. Power network interconnection of Laos



Case Study of Ground Potential Rise on Two Neighboring Substations

W. Pobporn, D. Rerkpreedapong, and A. Phayomhom

Abstract— *This paper presents the effects of constructions of a new permanent substation while the existing substation has not yet been removed. the Isolation of ground grids of the two substations creates ground potential rise (GPR) to be steep between the ground grids of two neighboring substations. Modeling and simulation are performed on the Current Distribution Electromagnetic interference Grounding and Soil structure (CDEGS) program. It is found that the percentage of GPR ratio between the auxiliary grounding system and the main ground grid in uniform or homogenous soil is constant while the percentages of GPR ratio are different in the two layer soils. If the top layer soil resistivity is higher than the fixed bottom layer soil resistivity, the percentage of GPR ratio will decrease. However if the bottom layer soil resistivity is higher than the fixed top layer soil resistivity, the percentage of GPR ratio will increase. This implies that only a risky case can be considered in substation design, although the condition of soil is varied by season. Moreover, the case studies are analyzed by varying the thickness of top layer and distance between the main ground grid system and auxiliary grounding system, which affect the percentage of GPR ratio. The more distance between main ground grid system and auxiliary grounding system is, the less the percentage of GPR ratio is, as GPR return of the auxiliary grounding system is lower. This will make the touch voltage higher due to the steepness of GPR, which increases the risk of hazard.*

Keywords— **Ground potential rise, Safety criteria, Step voltage, Touch voltage.**

1. INTRODUCTION

This paper presents a construction procedure for a new permanent substation while the existing substation has not yet been removed. While the ground grids of the two distribution substations are isolated, the effect of the auxiliary grounding system of the de-energized electrical power site will exist. This creates ground potential rise (GPR) to be steep between the ground grids of two neighboring substations. It is a concern for safety issues because a short circuit can generate a large current that flows through the aboveground structures and grounding system and dissipates in the soil, which the high potential may cause a hazard to personnel working nearby or in the area of distribution substations.

The ground grid design for distribution substations of the Provincial Electricity Authority of Thailand (PEA) is examined with the main objective to assess grounding grid system conditions in terms of ground potential rise, maximum touch voltage and step voltage. These three values are analyzed to ensure that they comply with the safety criteria defined in the IEEE Std. 80- 2000. Modeling and simulation are carried out on the Current Distribution Electromagnetic interference Grounding and Soil structure (CDEGS) program. The results are found that ground grid isolation should not be allowed during the time of construction because the auxiliary grounding system of the de-energized substation can create steep ground potential rise and therefore the large voltage difference can harm personnel working nearby and cause a damage to equipment in the vicinity of faults, particularly when the ground grid of the two neighboring substations are not connected.

2. DIFFINITION OF TOLERABLE VOLTAGE

In the process of designing the ground grid system, safety criteria is firstly calculated to specify a tolerable level, then the maximum touch and step voltage are calculated to compare with the safety criteria to define whether it is safe to work on the area of substation. This part will show a calculation of safety criteria, touch and step voltages.

Touch Voltage Criteria

The potential difference between the ground potential rise (*GPR*) and the surface potential at the point where a person is standing while having a hand in contact with a grounded structure.

The tolerable touch voltage in volts is defined in (1).

$$E_{touch} = I_B \times \left(R_B + 1.5\rho_S\right) \qquad (1)$$

W. Pobporn (corresponding author) is with the Department of Electrical Engineering, Faculty of Engineering, Kasetsart University and with Engineering & Maintenance Division, Provincial Electricity Authority (PEA), Area 1 Central, Asia Rd., Hantra, Phranakorn Si Ayutthaya 13000, Thailand. Phone: +66-35-241-142 ext. 31413; Fax: +66-35-323-867; E-mail: watcharapob@hotmail.com, watchara.pob@pea.co.th.

D. Rerkpreedapong is with the Department of Electrical Engineering, Faculty of Engineering, Kasetsart University, 50 Ngam Wong Wan Rd., Ladyao, Chatuchak, Bangkok, 10900, Thailand. Phone: +66-2-942-8555 ext.1543; E-mail: dulpichet.r@ku.ac.th.

A. Phayomhom is with Power System Planning Department, Metropolitan Electricity Authority (MEA), 1192 Rama IV Rd., Klong Toey, Bangkok, 10110, Thailand. Phone: +66-2-348-5549; Fax: +66-2-348-5133; E-mail: att_powermea@hotmail.com.

where E_{touch} = tolerable touch voltage for human (V)
R_B = resistance of the human body (Ω)
ρ_s = surface layer resistivity ($\Omega \cdot$ m)

The current through the body is determined by (2)

$$I_B = \frac{k}{\sqrt{t_s}} \quad (2)$$

where I_B = current through the body (A)
k = 0.116 for 50 kg body weight
0.157 for 70 kg body weight
t_s = duration of current expose (s)

The safety of a person depends on preventing the critical amount of shock energy from being absorbed before the fault is cleared and the system is de-energized. To ensure safety, the magnitude and duration of the current conducted through a human body should be less than the value that can cause ventricular fibrillation of the heart. Fibrillation current is assumed to be a function of individual body weight. The tolerable body current limits for body weights of 50kg and 70kg can be found in [1],[2].

Step Voltage Criteria

The difference in surface potential experienced by a person bridging a distance of 1 m with the feet without contacting any other grounded object.

The tolerable step voltage in volts is defined in (3) [1]

$$E_{step} = I_B \times \left(R_B + 6\rho_S\right) \quad (3)$$

where E_{step} = tolerable step voltage for human (V)

3. MAXIMUM OF MESH AND STEP VOLTAGE

The maximum touch voltage within a mesh of a ground grid [1] is calculated by (4)

$$E_m = \frac{\rho_a K_m \cdot K_i \cdot I_G}{L_m} \quad (4)$$

where E_m = mesh voltage (V)
ρ_a = apparent resistivity of soil (Ω-m)
K_m = mesh factor defined for n parallel conductors
K_i = corrective factor for current irregularity
I_G = maximum rms current flowing between ground grid and earth (A)
L_m = effective length of $L_C + L_R$ for mesh voltage (m)

For grids with or without ground rods, the effective buried conductor length, L_s, can be determined by (5)

$$L_s = 0.75 \cdot L_C + 0.85 \cdot L_R \quad (5)$$

where L_s = effective length of $L_C + L_R$ for step voltage (m)
L_C = total length of grid conductor (m)
L_R = total length of ground rods (m)

Then, the step voltage is determined from (6)

$$E_s = \frac{\rho_a \cdot K_s \cdot K_i \cdot I_G}{L_s} \quad (6)$$

where E_s = step voltage (V)
K_s = mesh factor defined for n parallel conductors

4. NEARBY DISTRIBUTION SUBSTATION

For, a new distribution substation grounding grid close to the existing substation whose ground grid is depicted as a mesh of rebar conductor, safety considerations require that the new and existing distribution substation grids are interconnected and thus the de-energized electrical power site of ground grid acts as an auxiliary grounding system of the substation. However, if the effect of the existing is taken into account for a grounding design so as to reduce the performance requirements of the substation grounding system, the copper conductors must be connected in a reliable manner to the substation grid [3].

5. CASE STUDY

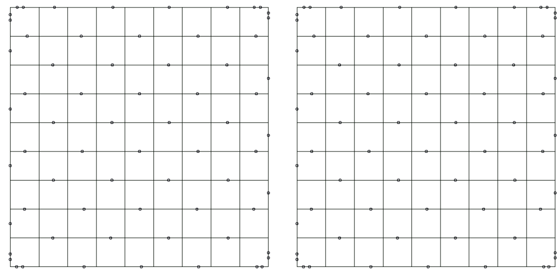
In this paper, case studies use the cross section of the ground grid conductor with size of 95 mm^2, and the ground rod is 3.0 m long with 15.875 mm in diameter. All the grid conductors are buried 0.5 m deep in the top layer soil. The figure of an installation of ground rod will be spread out. The dimension of ground grid which presents the status of return will be categorized into 45 m x 45 m. The main one is of medium size 45 m x45 m. Furthermore, the value of soil resistivity is chosen to be 1, 50, 100 and 1,000 $\Omega \cdot$m for both top and bottom layers of soil. In case studies, the top and bottom layers has difference resistivity due to a number of factors such as moisture content of the soil, chemical composition, concentration of salts dissolved in the contained water, and grain size [4]. Thus, the short circuit current of 25 kA is specified. This study is separated into 3 cases as follows:

<u>Case 1</u> The distance between main ground grid and auxiliary grounding system is 5 m as shown in Fig. 1. The thickness of the top layer soil is 1 m.

<u>Case 2</u> Configuration is shown in Fig. 1. The thickness of the top layer soil is 4 m. Distance between 2 ground grids is the same as case 1.

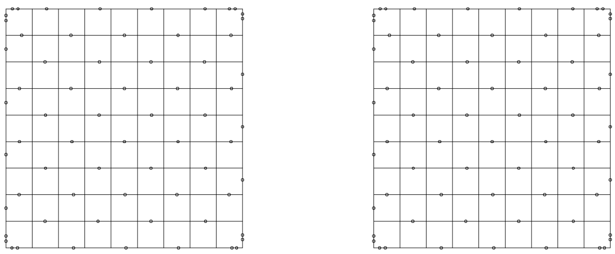
<u>Case 3</u> The distance between main ground grid and

auxiliary grounding system is 25 m as shown in Fig. 2. The thickness of the top layer soil is 1 m.



Main 45mx45m **Auxiliary 45mx45m**

Fig. 1. Ground Grid Configuration for Cases 1 and 2.



Main 45mx45m **Auxiliary 45mx45m**

Fig. 2. Ground Grid Configuration for Case 3.

The cases are of interest as follows:

Case 1: GPR, touch voltage and step voltage from the study of grounding system installation in various soil resistivity, the results are shown in Table 1. % GPR ratio between auxiliary grounding system and main ground grid is determined as percentage displayed in Table 2. For detailed consideration, it can be divided into 2 cases.

5.1.1 ***Top layer resistivity (ρ_1) is higher than the bottom layer resistivity (ρ_2)***

GPR of main ground grid, maximum touch voltage and step voltage will be increased when ρ_1 or ρ_2 increases. % GPR ratio between auxiliary grounding system and main ground grid is found lower than the uniform soil case. Therefore, the safety is also worse than the uniform soil.

*5.1.2 **Top layer resistivity (($\rho 1$) is lower than the bottom layer resistivity ($\rho 2$)***

GPR of main ground grid, maximum touch voltage and step voltage will be increased when ρ_1 or ρ_2 increases. % GPR ratio between auxiliary grounding system and main ground grid is found higher than uniform soil case. Therefore the safety is also higher than uniform soil.

For example, 3-dimension *GPR* of ground grid design in case 1 is shown in Fig. 3. Fig. 4 and 5 are the graphs of touch and step voltages, which illustrate the 2-dimension view to help determine the safe and unsafe contour areas**.** Between 2 substations, the touch voltage in Fig. 4 around the junction or the edge is very high. The step voltage in Fig. 5 is also high at the edge but lower than the touch voltage.

Table 1. GPR, Touch Voltage and Step Voltage for Case 1

Type of voltage		ρ_1 ($\Omega \cdot m$)	Voltage level (V) ρ_2 ($\Omega \cdot m$) 1	50	100	1,000
GPR	M	1	229.07	4,262.9	6,049.6	12,628
		50	326.93	11,454	20,185	123,330
		100	332.64	12,919	22,907	152,950
		1,000	338.37	15,645	29,664.0	229,070
	Au	1	92.567	3,281.2	4,981.6	11,494
		50	91.913	4,628.4	8,887	83,528
		100	92.015	4,851.3	9,256.7	91,264
		1,000	92.134	4,583.8	9,164.6	92,567
Touch		1	85.55	552.4	588.3	2,395
		50	168.12	4,277.5	6,899.4	22,262
		100	172.93	5,059.6	8,555	34,830
		1,000	177.72	7,820.4	14,180	85,550
Step		1	28.19	178.5	264.9	3,379
		50	56.60	1,409.4	2,230.5	7,529
		100	58.34	1,628.3	2,818.7	11,470
		1,000	60.02	2,619.8	4,710.5	28,190

ρ_1 resistivity of top layer soil

ρ_2 resistivity of bottom layer soil

M main ground grid system

Au auxiliary grounding system

Table 2. GPR Ratio between Auxiliary and Main Ground Grid Configuration for Case 1

Type of voltage	ρ_1 ($\Omega \cdot m$)	GPR (%) ρ_2 ($\Omega \cdot m$) 1	50	100	1,000
GPR	1	40.41	76.97	82.35	91.02
	50	28.11	40.41	44.03	67.73
	100	27.66	37.55	40.41	59.67
	1,000	27.23	29.30	30.89	40.41

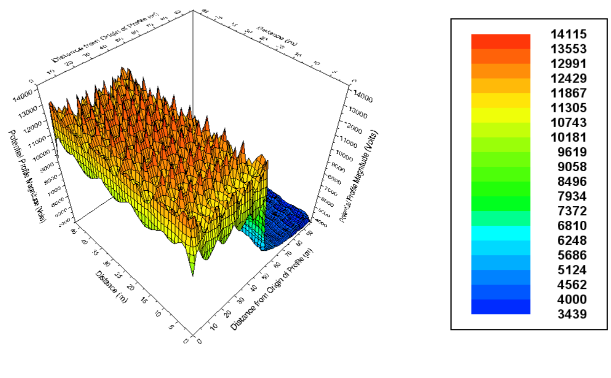


Fig. 3. Ground Potential Rise on 1000/50 $\Omega \cdot m$ for Case 1.

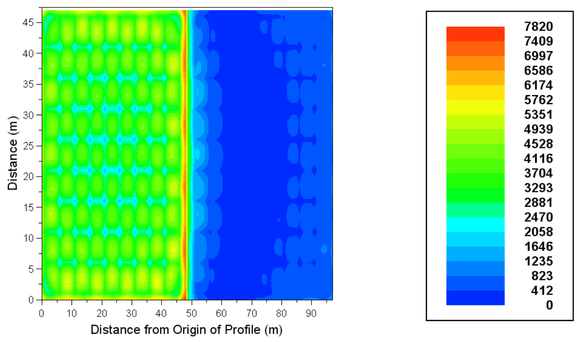


Fig. 4. Touch Voltage on 1000/50 $\Omega \cdot m$ for Case 1.

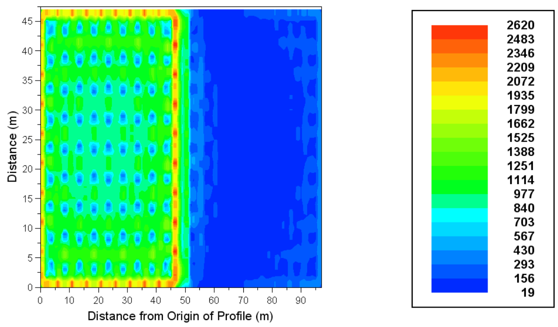


Fig. 5. Step Voltage on 1000/50 $\Omega \cdot m$ for Case 1.

Case 2: The results are shown in Table 3 and Table 4. For detailed consideration, it can be divided into 2 cases.

5.2.1 Top layer resistivity (ρ_1) is higher than the bottom layer resistivity (ρ_2)

The GPR of the main ground grid, maximum touch voltage and step voltage have the same trend as in case1, but these 3 voltages in case 2 are higher than those in case 1. This is because the ground rods of case 2 are still in the top layer soil with higher soil resistivity. Consideration of % GPR ratio between auxiliary grounding system and main ground grid at the same soil resistivity found that % GPR ratio in case 2 is lower than in that in case 1. This means that safety of case 2 is worse than case 1 because the maximum touch voltage is higher.

5.2.2 *Top layer resistivity (ρ1) is lower than the bottom layer resistivity (ρ2)*

The GPR of the main ground grid, maximum touch voltage and step voltage have the same trend as in case 1 but these 3 voltages in case 2 are lower than in the case 1. This is because the ground rods of case2 are still in the top layer soil with lower soil resistivity. Consideration of % GPR ratio between the auxiliary grounding system and main ground grid at the same soil resistivity found that % GPR ratio of case 2 is higher than that in case 1. This means that safety of case 2 is lower than in case 1 from the reason that the tolerable touch voltage is lower.

For example, 3-dimension *GPR* of ground grid design in case 2 is shown in Fig. 6. Fig. 7 and 8 are the graphs of the touch and step voltages, which illustrate the 2-dimension view to help determine the safe and unsafe contour areas.

Table 3. GPR, Touch Voltage and Step Voltage for Case 2

Type of voltage		ρ_1 ($\Omega \cdot m$)	Voltage level (V) ρ_2 ($\Omega \cdot m$) 1	50	100	1,000
GPR	M	1	229.07	2,111.2	2,695.3	4,465.4
		50	2,531	11,454	17,814	71,074
		100	4,837	15,213	22,907	98,655
		1000	46,333	57,292	68,331	229,000
	Au	1	92.57	1,756.2	2,334.9	4,120.9
		50	111.79	4,628.4	8,642.4	54,487
		100	132.62	5,070.4	9,256.7	69,647
		1000	509.62	4,988.3	9,833.8	92,576
Touch		1	85.55	200.3	204.0	948.6
		50	1,921	4,277	5,519	9,378
		100	3,771	6,683	8,555	17,200
		1000	37,055	40,520	43,830	85,550
Step		1	28.19	69.6	74.4	1,279.9
		50	646	1,409	1,822	3,155
		100	1,271	2,199	2,819	5,703
		1000	12,526	13,520	14,490	28,190

Table 4. GPR Ratio between Auxiliary and Main Ground Grid Configuration for Case 2

Type of voltage	ρ_1 ($\Omega \cdot m$)	GPR (%) ρ_2 ($\Omega \cdot m$) 1	50	100	1,000
GPR	1	40.41	83.18	86.63	92.29
	50	4.42	40.41	48.51	76.66
	100	2.74	33.33	40.41	70.60
	1,000	1.10	8.71	14.39	40.43

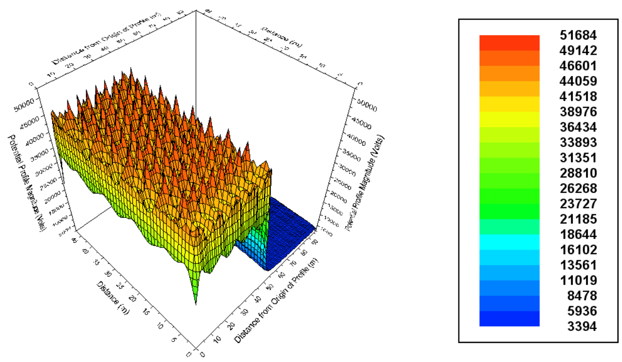


Fig. 6 Ground Potential Rise on 1000/50 $\Omega \cdot m$ for Case 2.

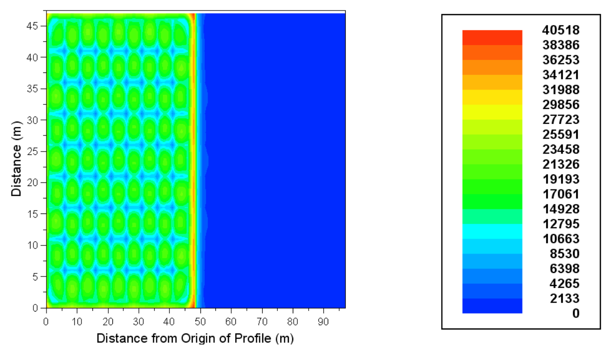


Fig. 7. Touch Voltage on 1000/50 $\Omega \cdot m$ for Case 2.

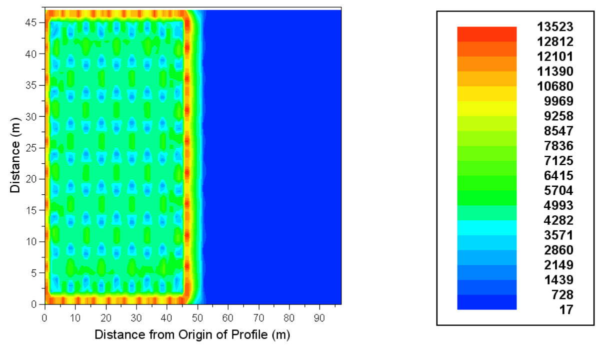


Fig. 8. Step Voltage on 1000/50 $\Omega \cdot \mathrm{m}$ for Case 2.

Case 3: The results are shown in Table 3 and 4. For detailed consideration, it can be divided into 2 cases.

5.3.1 Top layer resistivity (ρ_1) is higher than the bottom layer resistivity (ρ_2)

The GPR of main ground grid, maximum touch voltage and step voltage have the same trend as in case1 but these 3 voltages in case 3 are higher than those in case 1. This is because the difference between GPR of the main ground grid and auxiliary grounding system is significantly higher than that in case1. % GPR ratio between the auxiliary grounding system and main ground grid for the same soil resistivity in case 3 is found lower than that in case1. This means that safety of case 3 is lower than case 1 because the maximum touch voltage is higher than that in case1.

5.3.2 Top layer resistivity (ρ_1) is lower than the upper ayer resistivity (ρ_2)

The GPR of the main ground grid, maximum touch voltage, step voltage and % GPR ratio between the auxiliary grounding system and main ground grid at different soil resistivity have the same trend as in 3.1.

Table 5. GPR, Touch Voltage and Step Voltage for Case 3

Type of voltage		ρ_1 ($\Omega \cdot \mathrm{m}$)	Voltage level (V) ρ_2 ($\Omega \cdot \mathrm{m}$) 1	50	100	1,000
GPR	M	1	237.44	4,644.6	6,508.7	13,151
		50	331.49	11,872	21,130	134,670
		100	337.12	13,299	23,744	165,860
		1,000	342.78	15,885	30,182	237,440
	Au	1	237.44	4,644.6	6,508.7	101,470
		50	331.49	11,872	21,130	134,670
		100	337.12	13,299	23,744	165,860
		1,000	342.78	15,885	30,182	237,440
Touch		1	134.81	1,374.13	1,582	1,844.66
		50	226.7	6,740.1	11,453	50,100
		100	232.26	7,747.2	13,480	71,380
		1,000	237.81	10,660	19,720	134,810
Step		1	24.59	175.02	237.14	1,105.97
		50	54.11	1,229.62	1,898.98	6,398.23
		100	56.12	1,430.79	2,459.24	9,602.98
		1,000	58.10	2,475.33	4,380.68	24,592

Table 6. GPR Ratio between Auxiliary and Main Ground Grid Configuration for Case 3

Type of voltage	ρ_1 ($\Omega \cdot \mathrm{m}$)	GPR (%) ρ_2 ($\Omega \cdot \mathrm{m}$) 1	50	100	1000
GPR	1	25.29	52.09	59.70	77.16
	50	18.16	25.29	27.05	42.25
	100	17.86	23.83	25.29	35.83
	1000	17.58	18.93	19.92	25.29

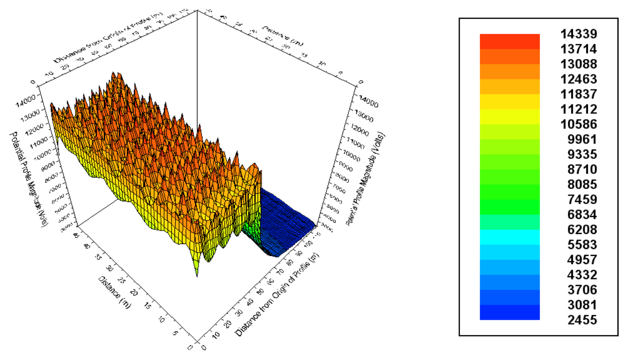


Fig.9. Ground Potential Rise on 1000/50 $\Omega \cdot \mathrm{m}$ for Case 3.

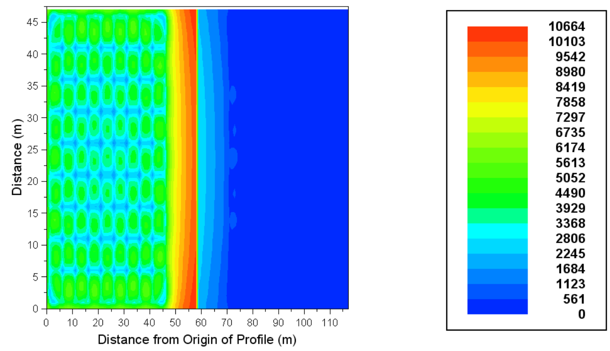


Fig. 10. Touch Voltage on 1000/50 $\Omega \cdot \mathrm{m}$ for Case 3.

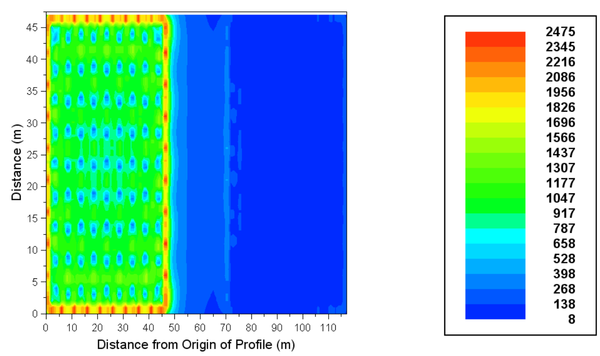


Fig. 11. Step Voltage on 1000/50 $\Omega \cdot \mathrm{m}$ for Case 3.

For example, 3-dimension *GPR* of the ground grid design in case 3 is shown in Fig. 9. Fig. 10 and 11 are the graph of touch and step voltages, which illustrate the 2-dimension view to help determine the safe and unsafe contour areas.

Table 7. Safety Criteria for 50 kg Body Weight, 1000/50 $\Omega \cdot m$

Surface Layer Resistivity ($\Omega \cdot m$)	Fault Clearing Time 0.1 sec		Foot Resistance: 1 Foot (Ω)
	Touch Voltage (V)	Step Voltage (V)	
None	741	2,096	3,125
1,500	936.2	2,877.3	4,475
3,000	1,508.3	5,165.8	8,431.9
4,000	1,863	6,588	10,891
8,000	3,335	12,472	21,066
1,2000	4,802	18,342	31,215
1,6000	6,268	24,208	41,356
20,000	7,734	30,072	51,495
24,000	9,200	35,935	61,633

Table 7 is the safety criteria of 1000/50 $\Omega \cdot m$ soil structure by material surface covering with 20 cm thick. For the base case, it is found that at the same soil resistivity, the maximum touch voltage is equal to 7,802.4 V and step voltage is 2,619.8 V. To comply with the safety criteria, it must be covered by 20,000 $\Omega \cdot m$ resistivity material. The touch voltage also meets the safety criteria. The step voltage does not violate the safety criteria and it can be easily solved. . Generally, PEA will spread the ground with crushed rock No.2 (Resistivity of crushed rock No.2 is about 3,000 $\Omega \cdot m$). The step voltage can be solved. From Table 7, spreading with 3,000 $\Omega \cdot m$ material, the step voltage criteria is 5,165.8 $\Omega \cdot m$, which can be met.

The study found that the danger may occur at the edge of ground grid, so the study concentrates at ground grid connections between the 2 substations. It is found that GPR, maximum touch voltage and step voltage are equal to 10,112 V, 3,846.36 V and 1,408 V respectively. The decrease is obtained by the reduction of resistance of electrode system.

6. CONCLUSION

The ground grid design for the distribution substation is examined with the main objective to assess its grounding system condition in terms of ground potential rise, touch voltage, step voltage and % GPR ratio between the auxiliary grounding system and main ground grid. These values are analyzed to ensure that they comply with the safety criteria defined in the IEEE Std. 80-2000 with three cases classified by 25 kA Power's Distribution in PEA. It is found that when the ground grid is separated or two neighboring substations are disconnected, the safety issue must be taken into account.

In case of ground grids of two neighboring distribution substations, connecting ground grids between two distribution substations can reduce the voltages to meet the safety criteria.

In the procedure of renovation of the existing distribution substation that requires a small distribution substation in order to supply temporary electricity, a large ground potential difference between two separate ground grids of the distribution substations can occur when the ground grids of two neighboring distribution substations are not connected together. This high GPR can damage intelligent electronic devices (IED), which will be used in distribution substations in the future or electronic controllers which are currently used. This incident can occur after a fault or lightning in a distribution system. Moreover, this high GPR is also dangerous to personnel operating in the distribution substation or nearby. The connection between ground grids of two neighboring distribution substations is a simple and economical method with effectiveness to reduce the damage of devices and danger to personnel that can lead to power supply outage in industrial zones or densely populated areas. Therefore, this method has more advantages compared with other methods e.g. installing more protection devices which needs more investment cost but it cannot completely solve the problem.

As far as installation costs and other necessary expenses in grounding system planning are concerned, the length of ground rods, the size of conductors, the short circuit current should financially reflect incremental cost and worth for various alternatives while respecting the established safety criteria [5].

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Effects of Nearby Auxiliary Grounding Imposed on Main Square and Rectangle Ground Grids of Distribution Substation

A. Phayomhom, T. Kasirawat, W. Pobporn, C. Pongsriwat, and A. Puttarach

Abstract— *The case study presents touch voltage reduction for uniform or two-layer soil by applying compression ratio technique to square or rectangle ground grid. Current Distribution Electromagnetic interference Grounding and Soil structure (CDEGS) program is used for the study purpose. The ground grid design is examined with the aim to assess its performance in terms of ground potential rise (GPR), maximum touch and step voltage. The parameters are analyzed to ensure that they are safe conforming to the IEEE 80-2000. It is found that in uniform or two-layer soil, the soil resistivity of top layer is lower than the bottom's, for a given GPR, the maximum touch and step voltage of the rectangle ground grid, regardless its compression ratio, are lower than that of the square one. This means rectangle grid is safer than square one. So, one should not ignore the shape of ground grid in the design, especially when they are placed close together. This is the case when a new substation is under construction near the old one which is still energized. The grounding system of the old substation can create steep ground potential rise to the other, therefore, the GPR can harm personnel working nearby and cause damage to equipment particularly when the two ground grids are isolated.*

Keywords— **Distribution substation, Ground potential rise, Optimum compression ratio, Step voltage, Touch voltage.**

1. INTRODUCTION

Metropolitan Electricity Authority (MEA) is an electric utility that is responsible for power distribution covering an area of 3,192 square kilometers in Bangkok, Nonthaburi, and Samutprakarn provinces of Thailand. MEA serves approximately 35.32 % of the whole country power demand in 2010. MEA's networks consist of transmission, subtransmission and distribution systems. The transmission line voltage is 230 kV, while the 69 and 115kV used in subtransmission systems and 12 and 24 kV in the distribution feeders.

Based on MEA's experience, one of the main causes of a sustainable fault is the short circuit fault right at the substation itself. The short circuit generates large amount of currents that flow in the aboveground structures to the grounding system and finally dissipate in the soil. The high currents may cause damage to equipment and may be dangerous to personnel working nearby. It is therefore important for the substation designer to take into account the safety issue pertaining to step and touch voltage limit that may exceed the safety criteria. [1, 2].

Talking about the grounding system design, people tend to familiar with ground grid that its conductors are laid equally apart, while pay little attention to the one with unequal separation. One of the reasons for this may be owing to the fact that many grounding system standards focus on ground grid designs with regularly spaced conductors [3] and put little emphasis on alternative design options based on unequal conductor spacing. The most likely reason should blame the lack of adequate information concerning the most promising, efficient grounding system configuration as a starter to avoid lengthy trials in the ground grid design process. In others words, there is a need of suitable reference containing necessary guidelines so that a grounding system designer can focus quickly on the most efficient design. This is exactly the main purpose of this paper [4].

2. EFFECTS OF NEARBY AUXILIARY GROUNDING SYSTEM OF SUBSTATION

Many a time, the new temporary (small) or permanent distribution substation is under construction while the existing substation is still in operation and not yet removed. There are two grounding systems for each substation that is not connected each other. The ground grid of the main substation is called main ground grid (energized electrical power site) whereas that of the other distribution substation (temporary or permanent) distribution substation) is called auxiliary ground grid. During the time of disconnecting of ground grid, the small or permanent distribution substation is de-energized, its auxiliary grounding system however

A. Phayomhom (corresponding author) is with Power System Planning Department, Metropolitan Electricity Authority (MEA), 1192 Rama IV Rd., Klong Toey, Bangkok, 10110, Thailand. Phone: +66-2-348-5549; Fax: +66-2-348-5549; E-mail: att_powermea@hotmail.com, attp@mea.or.th.

T. Kasirawat is with Operation Network Department, Provincial Electricity Authority (PEA), Northern Region1, Chiangmai, Thailand. Phone: +66-53-241-486; Fax: +66-53-246-743; E-mail: tirapong.kas@pea.co.th.

W. Pobporn is with the Department of Electrical Engineering, Faculty of Engineering, Kasetsart University and with Engineering & Maintenance Division, Provincial Electricity Authority (PEA), Central Region1, Asia rd., Hantra, Phranakorn Si Ayutthaya 13000, Thailand. Phone: +66-35-241-142 ext. 31413; Fax: +66-35-323-867; E-mail: watcharapob@hotmail.com, watchara.pob@pea.co.th.

C. Pongsriwat is with Power Quality Section, Service Department, Provincial Electricity Authority (PEA), Northern Region1, Chiangmai, Thailand. Phone: +66-53-241-018; E-mail: chotepong@gmail.com.

A. Puttarach is with Rajamangala University of Technology Lanna (RMUTL), Chiang Mai, Thailand; E-mail: a.puttarach@gmail.com.

exposes to the risk of high GPR caused by the main distribution substation which is still in operation. The GPR's steepness is located between the main and auxiliary ground grid.

3. OPTIMUM COMPRESSION RATIO (OCR)

The proper design of grounding system can ensure the personnel safety in the distribution substation while maintain reliable operation of the power system. This calls for the optimum compression ratio (OCR) be applied in the design together with the target to keep the touch voltage its minimum value [5].

Figure 1 shows the configuration of a ground grid the grounding conductors of which are of exponent regularity arrangement. This arrangement cannot only decrease the potential gradient of the ground surface, but also regarded as a safe and economic design model. The problem is how this exponent regularity be defined. As one can notice, the grounding conductors arranged according to an exponent regularity, its conductor span decreases exponentially from its centre to the edge of the grounding grid. The i th conductor span from the centre is given in Eq. (1) [4, 6].

$$d_i = d_{\max} C^i, \ (i = 0 \text{ to } m) \quad (1)$$

where d_i is the i^{th} conductor span from the center (m)

$d_{\max}$ is maximum conductor span (m)

c^i is the i^{th} compression ratios

where C is the compression ratio, whose value ranges from zero to 1 ($0 \le C \le 1$), if C = 1, then the grounding grid is of equal conductor span design. Let N denotes the number of (perpendicular) conductors to the side of interest of the grounding grid, if N is an even number; m = N/2-1; if N is an odd number; then m = (N-1)/2-1. The 1 th conductor span was counted from the centre of the grounding grid, not from the edge [6, 7].

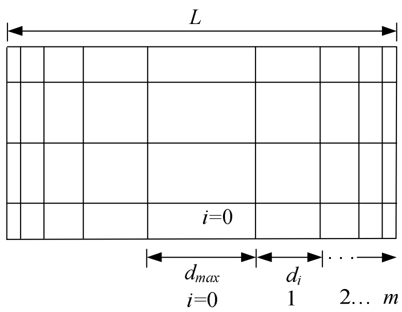

Fig. 1. Grounding Grid Scheme Arranged with Exponential Rule.

The conductors are perpendicular to the side, then the central span(s) is defined by equation either Eq. (2) or (3).

$$d_{\max} = \frac{L(1-C)}{1 + C - 2C^{(N/2)}} \quad , N \text{ is even} \quad (2)$$

$$d_{\max} = \frac{L(1-C)}{2(1-C^{(N-1)/2})} \quad , N \text{ is odd} \quad (3)$$

where N is the number of conductor perpendicular to the side of grounding grid

L is is the length of the side (m)

4. CASE STUDY

This paper studies the effects of nearby auxiliary grounding system of substation by comparing the configuration of main ground grid between square main ground grid and rectangle main ground grid as shown in Figures 2 and 3. The compression ratio is varied from 0 to 1.0 to notice the different of GPR ,touch voltage and step voltage. Auxiliary ground grid is determined as the square ground grid at 1.0 constant compression ratio.The distance between main ground grid and auxiliary grounding system is 25 m.

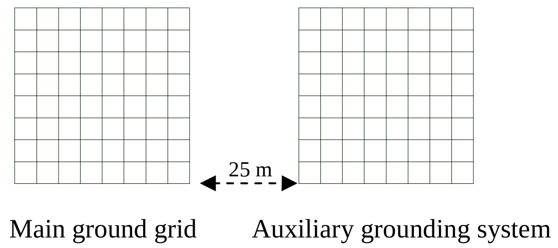

Fig. 2. Two Neighbouring Distribution Substation with Main Square Ground Grid.

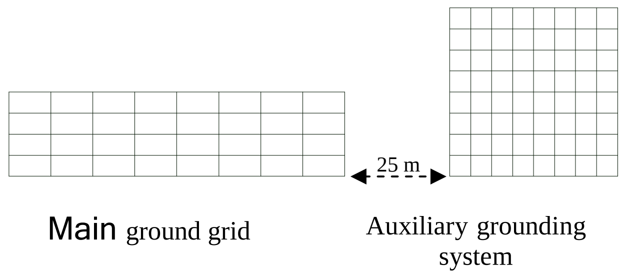

Fig. 3. Two Neighbouring Distribution Substation with Main Rectangle Ground Grid.

This research presents compression ratio technique which its values are varied from 0 to 1.0 with different dimension (square and rectangle) but the same of ground grid.

MEA's permanent distribution substation's ground grid is approximately 40 m x 40 m. This paper then studies the 40 m x 40 m (1,600 m^2) square ground grid while varying the compression ratio from 0 to 1.0 as shown in Fig 2. All ground grid conductors are 95 mm^2 (0.54979 cm. in radius) and buried at a depth of 0.5 m. The number of conductor in width and long side are 9 conductors. Total buried length of main electrode is 720 m. Top views of ground grid configuration are shown in Figure 4.

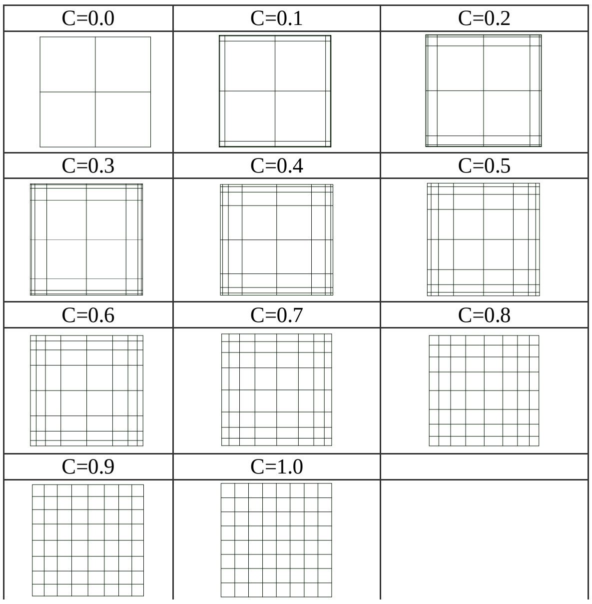

Fig. 4. Grounding Grid with Various Conductor Compression Ratio with 40 m x 40 m.

If we compare the resulted GPR, maximum touch voltage and step voltage of the square ground grid with a rectangle one 20 m x 80 m (1,600 m^2) ground grid. The ground grid configurations with compression ratio varied from 0 to 1.0. All ground grid conductors are 95 mm^2 (0.54979 cm in radius) and buried at a depth of 0.5 m. The number of conductors in width and long side are 9 and 5 conductors respectively. Total buried length of main electrode is 580 m. Top views of ground grid configuration are shown in Figure 5.

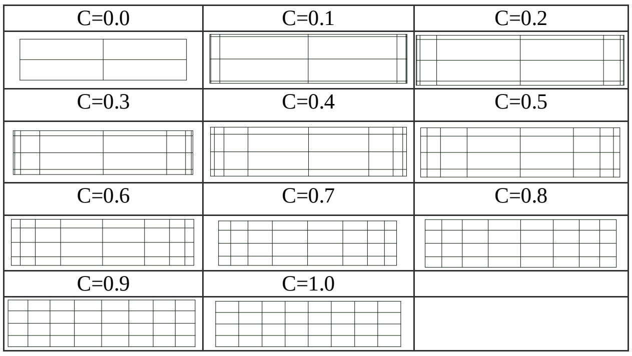

Fig 5. Grounding grids with various conductor compression ratios with 20 m x 80 m dimension.

The top layer has a more resistivity than the bottom layer (deep layer) or on the other hand due to a number of factors such as moisture content of the soil, chemical composition, concentration of salts dissolved in the contained water, and grain size [8, 9].

There are 3 cases of configuration studied.

Case 1: the conductors of square and rectangle ground grid are buried in the 10 Ω.m soil resistivity.

Case 2: the conductors of square and rectangle ground grid are buried in 100/10 Ω.m soil resistivity and.

Case 3: the conductors of square and rectangle ground grid are buried in 10/100 Ω.m soil resistivity.

The details of each case are as follows:

Case 1

The result in case1 shown in Table 1 are from the square main ground grid installation and from rectangle main ground grid in Table 2. The comparison of touch voltage graph is shown in Figure 6.

Table 1. GPR, GPR Ratio Touch and Step Voltage with 40 m x 40 m for Case 1

C	Square 40x40(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	3,447.7	643.9	18.68	2,818.0	512.8
0.1	2,992.7	644.6	21.54	2,362.7	433.7
0.2	2,888.6	644.1	22.30	2,259.4	416.5
0.3	2,840.1	643.7	22.67	2,211.3	395.3
0.4	2,816.3	642.9	22.83	2,187.6	377.0
0.5	2,804.7	642.3	22.90	2,176.3	360.1
0.55	2,803.6	642.1	22.90	2,175.4	343.0
0.6	2,804.1	642.0	22.89	2,176.0	343.8
0.7	2,808.4	641.7	22.85	2,180.5	320.3
0.8	2,815.1	641.5	22.79	2,187.4	320.7
0.9	2,817.7	641.3	22.76	2,190.2	324.6
1.0	2,827.1	641.2	22.68	2,199.7	325.1

Table 2. GPR, GPR Ratio Touch and Step Voltage with 20 m x 80 m for Case 1

C	Rectangle 20x80(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	2,999.5	523.7	17.46	2,184.2	456.8
0.1	2,693.6	526.6	19.55	1,874.8	418.8
0.2	2,649.3	526.5	19.87	1,830.8	386.8
0.3	2,631.1	523.3	19.89	1,816.5	332.2
0.4	2,624.4	525.3	20.02	1,807.5	333.9
0.5	2,626.0	524.6	19.98	1,809.7	326.6
0.55	2,627.0	524.3	19.96	1,811.1	317.0
0.6	2,628.5	524.0	19.93	1,813.0	320.3
0.7	2,631.1	523.3	19.89	1,816.5	332.2
0.8	2,635.6	522.8	19.84	1,821.7	320.9
0.9	2,640.2	522.4	19.79	1,826.9	322.2
1.0	2,650.0	522.3	19.71	1,836.9	341.8

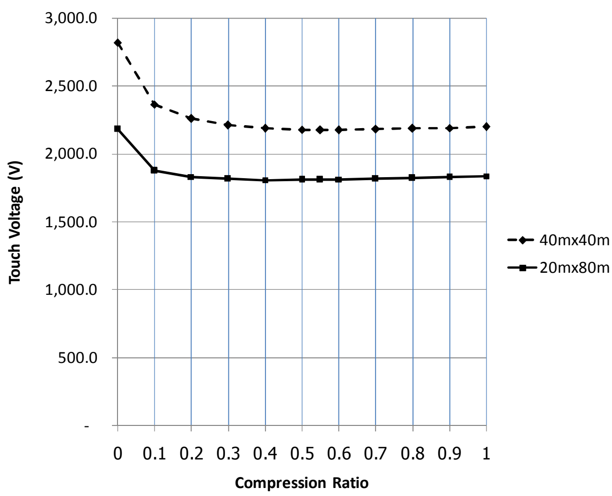

Fig. 6. Touch Voltage as A Function of Conductor Compression Ratios for Cases 1.

The result found that all voltage at every value of compression ratio of square main ground grid are lower than rectangle main ground grid. At 0.55 OCR, GRP, touch voltage and step voltage are equal to 2803.6 V, 2,175.4 V and 343 V respectively. The study also found that at the worst case, compression ratio is equal to 0. When the configuration of OCR is used instead, touch voltage can be reduced for 22.80% (from 2,818 V to 2,175.4V). At 0.55 OCR, %GPR ratio is 22.90%. More GPR cause more reduction of voltage. The safety is also increased.

For the rectangular main ground grid at 0.4 OCR, GPR, touch voltage and step voltage are 2624.4 V, 1807.5V and 333.9 V respectively. Comparison touch voltage at 0 compression ratio found that touch voltage can be reduced for 17.25% (from 2,184.2 V to 1,807.5 V). For rectangle ground grid with OCR 0.4, 3-dimension GPR touch and step voltage are in Figures 7 to 9 respectively.

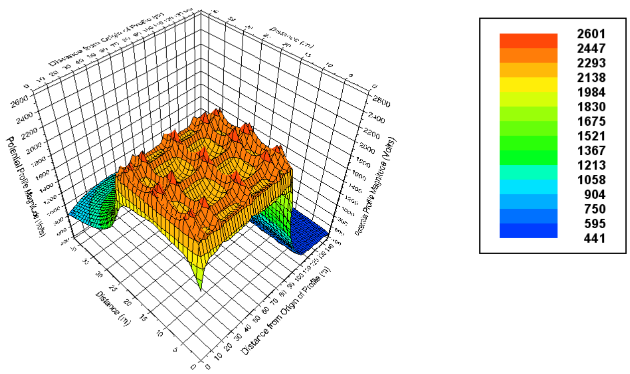

Fig. 7. 3-Dimension GPR for Case 1 with Rectangle Main Ground Grid at OCR 0.4.

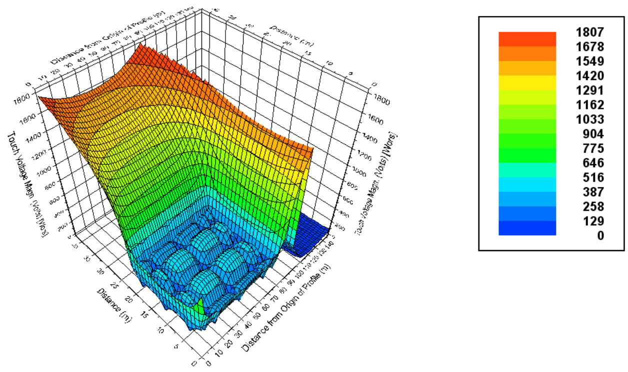

Fig. 8. 3-Dimension Touch Voltage for Case 1 with Rectangle Main Ground Grid at OCR 0.4.

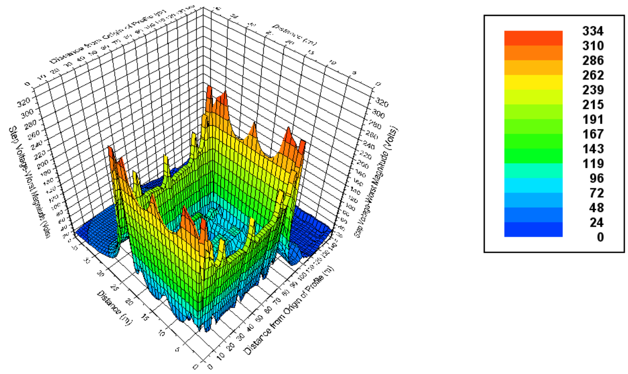

Fig.9. 3-Dimension Step Voltage for Case 1 with Rectangle Main Ground Grid at OCR 0.4.

Case 2

The study of case 2 is shown in Tables 3 and 4. Touch voltage graph is in Figure 10.

Table 3. GPR, GPR Ratio Touch and Step Voltage with 40 m x 40 m for Case 2

C	Square 40x40(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	14,198.0	654.7	4.61	13,553.0	4,429.9
0.1	9,575.2	646.0	6.75	8,939.4	2,980.1
0.2	8,484.4	644.5	7.60	7,849.3	32,619.5
0.3	7,963.8	654.6	8.22	7,319.3	2,317.7
0.4	7,576.5	643.8	8.50	6,942.4	2,095.4
0.5	7,384.6	653.0	8.84	6,741.3	1,902.4
0.6	7,269.1	652.4	8.97	6,626.2	1,833.4
0.7	7,209.9	651.8	9.04	6,567.5	1,719.7
0.8	7,130.4	641.1	8.99	6,498.1	1,700.0
0.87	7,054.3	641.4	9.09	6,422.4	1,757.1
0.9	7,059.9	641.3	9.08	6,428.1	1,713.3
1.0	7,078.4	641.0	9.06	6,446.8	1,781.4

Table 4. GPR, GPR Ratio Touch and Step Voltage with 20 m x 80 m for Case 2

C	Rectangle 20x80(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	11,600.0	525.5	4.53	10,775.0	3,599.6
0.1	8,602.1	530.1	6.16	7,771.8	2,796.5
0.2	8,053.7	529.2	6.57	7,223.0	2,459.3
0.3	7,504.7	522.4	6.96	6,680.7	1,996.9
0.4	7,637.2	526.1	6.89	6,809.0	2,052.1
0.5	7,577.1	524.5	6.92	6,750.2	1,978.6
0.6	7,535.9	523.2	6.94	6,710.3	1,980.3
0.7	7,504.7	522.4	6.96	6,680.7	1,996.9
0.8	7,499.5	522.0	6.96	6,676.7	2,012.6
0.87	7,543.7	523.5	6.94	6,699.3	2,025.6
0.9	7,505.0	522.1	6.96	6,683.4	2,023.1
1.0	7,575.7	518.7	6.85	6,755.6	2,069.5

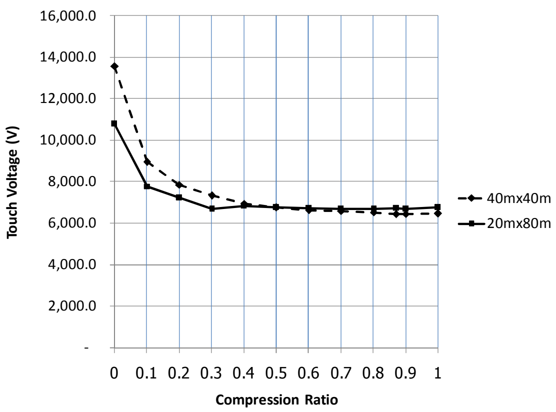

Fig. 10. Touch Voltage as A Function of Conductor Compression Ratios for Cases 2.

The result found that at 0.87 OCR , GRP ,touch voltage and step voltage are equal to 7,054.3 V, 6,422.4 V and 1,757.1 V respectively. The study also found that at the worst case ,compression ratio is equal to 0. When the configuration of OCR is used instead ,touch voltage can be reduced for 52.61% (from 13,553 V to 6,422.4V) . At 0.87 OCR, %GPR ratio is 9.09%.

For the rectangle main ground grid at 0.8 OCR, GPR, touch voltage and step voltage are 7,499.5 V, 6,676.7 V and 2,012.6 V respectively. Comparison touch voltage at 0 compression ratio found that touch voltage can be reduced for 42.44% (from 11,600 V to 6,676.7 V).

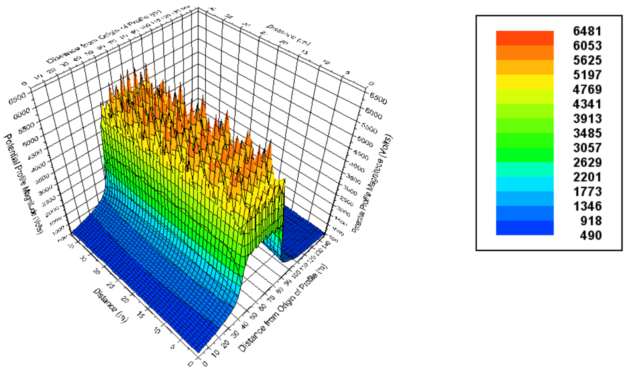

Fig. 11 3-Dimension GPR for Case 2 with Square Main Ground Grid at OCR 0.87.

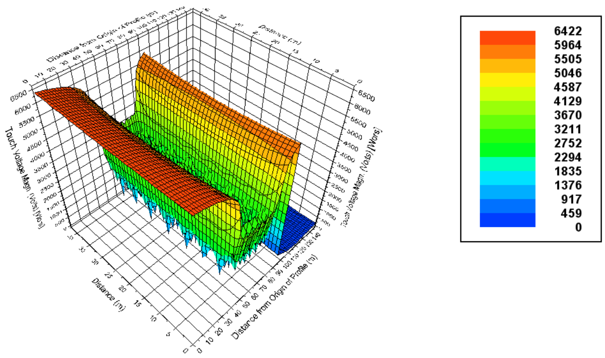

Fig.12. 3-Dimension Touch Voltage for Case 2 with Square Main Ground Grid at OCR 0.87

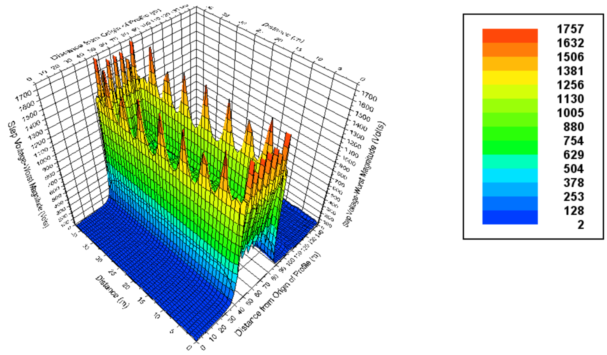

Fig.13. 3-Dimension Step Voltage for Case 2 with Square Main Ground Grid at OCR 0.87

As mention,at 0 to 0.4 compression ratio, GPR, touch voltage and step voltage of square ground grid are lower than rectangle square ground grid. For square ground grid with OCR 0.88, 3-dimension GPR touch and step voltage are in Figures 11 to 13 respectively.

Case 3

The results which is square main ground grid installation in case 3 are shown in Table 5. Table 6 is the results of rectangle main ground grid installation. Comparison of touch voltage graphs are shown in Figure 14.

Table 5. GPR, GPR Ratio Touch and Step Voltage with 40 m x 40 m for Case 3

C	Square 40x40(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	15,611.0	6,034.5	38.66	9,780.9	715.9
0.1	15,023.0	6,038.6	40.20	9,193.2	906.4
0.2	14,972.0	6,038.8	40.33	9,146.7	903.1
0.3	14,966.0	6,039.5	40.35	9,141.6	897.1
0.4	14,986.0	6,034.1	40.26	9,158.6	883.7
0.5	15,011.0	6,030.5	40.17	9,183.8	870.7
0.6	15,041.0	6,029.4	40.09	9,214.3	820.0
0.7	15,068.0	6,028.6	40.01	9,242.2	783.1
0.8	15,091.0	6,028.0	39.94	9,265.2	759.6
0.9	15,113.0	6,027.4	39.88	9,288.7	758.6
1.0	15,140.0	6,027.1	39.8	9,314.3	732.9

Table 6. GPR, GPR Ratio Touch and Step Voltage with 20 m x 80 m for Case 3

C	Rectangle 20x80(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	14,151.0	5,063.3	35.78	6,986.4	755.5
0.1	13,769.0	5,057.9	36.73	6,583.7	887.6
0.2	13,765.0	5,058.6	36.75	6,580.1	878.9
0.3	13,850.0	5,045.1	36.43	6,676.1	728.9
0.4	13,787.0	5,052.6	36.65	6,607.5	765.9
0.5	13,821.0	5,050.4	36.54	6,642.9	754.3
0.6	13,808.0	5,001.2	36.22	6,687.5	739.4
0.7	13,850.0	5,045.1	36.43	6,676.1	728.9
0.8	13,868.0	5,042.8	36.36	6,697.0	724.9
0.9	13,885.0	5,041.6	36.31	6,716.7	705.5
1.0	13,852.0	4,996.1	36.07	6,734.4	724.7

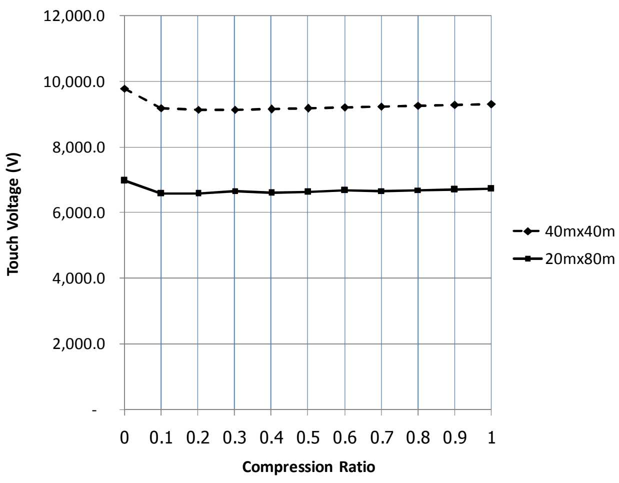

Fig. 14. Touch Voltage as A Function of Conductor Compression Ratios for Cases 3.

The study found that at various value of voltage at 0.3 OCR , GRP ,touch voltage and step voltage are equal to 14,966 V, 9,141.6 V and 897.1 V respectively. Comparison with 0 compression ratio touch voltage can be reduced for 6.54% (from 9,780.9 V to 9,141.6 V).

The study of various voltage value for the rectangle main ground grid at 0.2 OCR, GPR, touch voltage and step voltage are 13765 V, 6580.1 V and 878.9 V respectively. Comparison touch voltage at 0 compression ratio found that touch voltage can be reduced for 5.82% (from 6,986.4 V to 6,580.1 V).

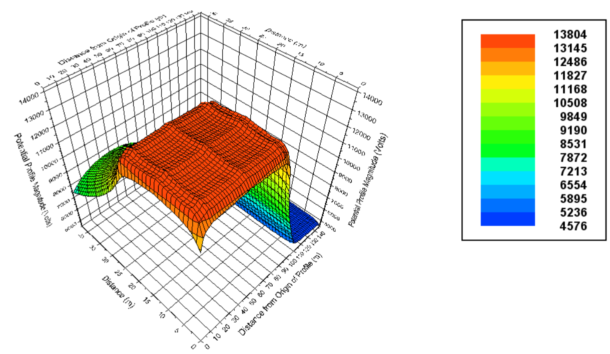

Fig. 15. 3-Dimension GPR for Case 3 with Rectangle Main Ground Grid at OCR 0.2.

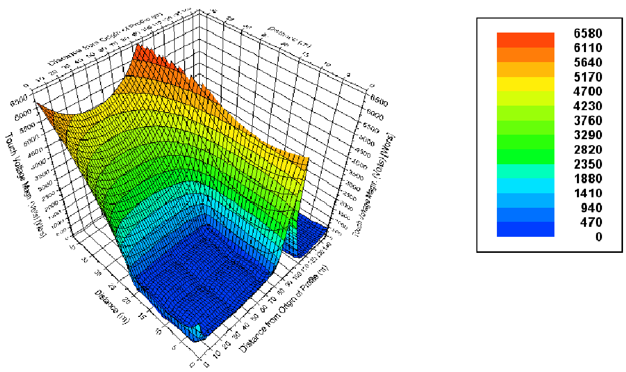

Fig.16. 3-Dimension Touch Voltage for Case 3 with Rectangle Main Ground Grid at OCR 0.2

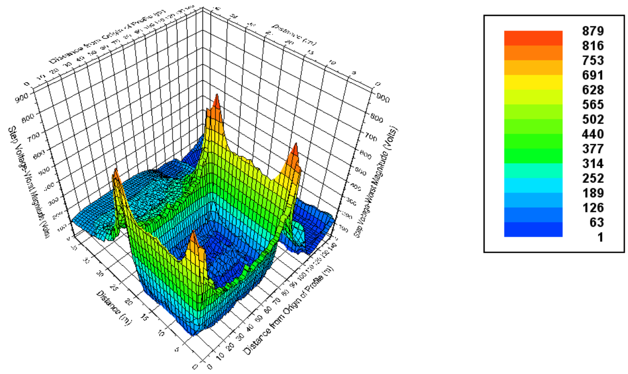

Fig. 17. 3-Dimension Step Voltage for Case 3 with Rectangle Main Ground Grid at OCR 0.2.

This research found that all voltage value at every compression ratio of rectangle main ground grid are lower than square main ground grid. For square ground grid with OCR 0.2, 3-dimension GPR touch and step voltage are in Figures 15 to 17 respectively.

5. CONCLUSION

The study of square and rectangle main ground grid shape without ground rod in different soil resistivity can be concluded as follows.

1. At uniform soil characteristic and soil resistivity of top layer soil is lower than bottom layer soil, GPR, maximum touch voltage and maximum step voltage at every value of compression ratio of rectangle main ground grid are lower than in square main ground grid. This mean rectangle main ground is more safety than square main ground.

2. When soil resistivity of top layer soil is more than lower bottom soil all voltage value of square main grid are more than rectangle main grid at 0 to 0.4 compression ratio. Whereas 0.4 to 1.0 interval, all value of voltage are lower than rectangle main ground grid.

3. The percentage value of GPR ratio of square main grid and rectangle main grid are safety indicator. More percentage value means higher safety. The comparison must only be in the same shape of ground grid configuration at various compression ratio. Between square and rectangle or same shape with different soil resistivity can not be compared. The comparison of the safety must consider maximum touch voltage and maximum step voltage whether all of these values exceed the determined safety criteria.

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The Optimal Energy Management of Hybrid Cooling System for Telephone Exchange in Thailand

Somkuan Rimsmutchai, Pornrapeepat Bhasaputra, Woraratana Pattaraprakorn, Natapongkorn Pawanawichien, Surasak Panjavaranont, Chaiyapat Kumpeerakupt, Kitti Tirawannavit, Wichit Krueasuk, and Kreingkrai Chongkhanpond

Abstract— *The existing cooling system of telephone exchange consumes more than 45% of overall energy consumption and generates the large amount of CO_2 that affect the global environment as well. Focusing on the energy conservation and expenditure, the hybrid cooling system using the air blowers integrated with the existing air conditioning system is proposed. The hybrid cooling system for telephone exchange in Thailand is proposed to enhance the energy management by integrating the conventional air conditioning system with air ventilation system. According to the complicated hybrid cooling system, the optimal energy management criteria are determined to minimize the energy consumption subject to security constraints for the different seasons. In additional, the energy consumption, life cycle costs, temperature and relative humidity profiles are compared with the conventional cooling system. The experiment demonstrated that the energy consumption of the cooling system decreased 91.54% and the overall energy consumption decreased 36.92% as compared to the convention cooling system. The annual cost of the proposed system can reduce up to 296,092 THB/Room with less than 1 year of return on investment. The proposed system can operate without any interruption under the temperature and relative humidity requirements. Finally, the report included important detail such as innovations, designs; preventive maintenance requirement and barriers of proposed system will be shown and described.*

Keywords— **Optimal, Energy, Hybrid, Exchange.**

1. INTRODUCTION

The telephone exchange is the back bone of the telecommunication system which consumes a significant amount of energy. However, the energy consumption of telephone exchange is concerned in term of significant operating cost. Figure 1 show proportions of energy consumption of telephone exchange, the proportions are 45% for air condition system, 40% for telephone equipments, 10% for lighting and 5% for the other.

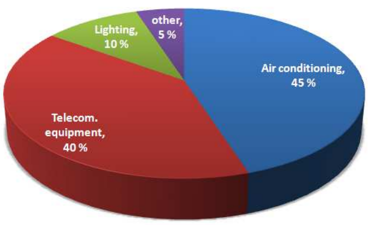

Fig. 1. Proportions of energy consumption of Telephone Exchange.

Somkuan Rimsmutchai (corresponding author), Pornrapeepat Bhasaputra, Natapongkorn Pawanawichien, Surasak Panjavaranont, Chaiyapat Kumpeerakupt, Kitti Tirawannavit, Wichit Krueasuk, and Kreingkrai Chongkhanpond are with Department of Electrical and Computer engineering, faculty of engineering, Thammasat University, 99 M18 Phaholyothin Road. Khlongluang, Pathumthani 12120, Thailand. E-mail address: somkuan_rim@hotmail.com.

Woraratana Pattaraprakorn is with Department of Chemical engineering, faculty of engineering, Thammasat University, 99 M18 Phaholyothin Road. Khlongluang, Pathumthani 12120, Thailand.

The traditional cooling system normally used the precision air condition for telephone exchange with many operation methods to enhance the energy management which is shown in Figure 2. Precision air-conditioning systems regulate temperature and relative humidity for sensitive and precisely purpose, the data centers and the telephone exchanges are typical principles used this kind of cooling system, its difference from air conditioning systen for resident which used in general household. In order to easy understand its can infer that the Precision air-conditioning systems have several special parts, the first part is the Heater Unit, both types included electric coils and hot refrigerant gas usually used for control room temperature within setting point, next part is Humidifier Unit, both types included infrared and electric coil usually used for controller room relative humidity within range, the last ones is Control Unit, it's improtant part used for controlled overall of air conditioning unit. Parts of conventional and precision air conditioning are shown in Figure 3. However, these types of air conditioning rather consume a lot of energy when comparing to air conditioning systen for resident.

This paper presents the optimal energy management of hybrid cooling system between precision air conditioning and air blowers to control the room environment for minimizing energy consumption and acceptable room conditions. Focusing on the energy conservation and expenditure, the hybrid cooling system using the air blowers integrated with the existing air conditioning system is proposed. Comparing the energy consumption, life cycle costs, temperature and relative humidity controls to the conventional cooling system control were done.

Fig. 2. Existing Cooling System of Telephone Exchange.

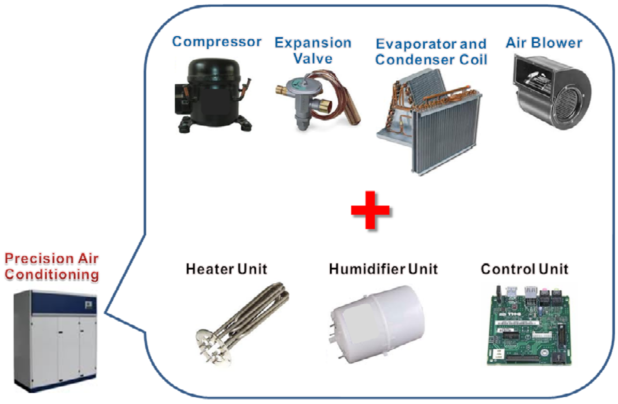

Fig. 3. Parts of conventional and precision air conditioning.

2. OPERATION STANDARD AND REGULATIONS OF COOLING SYSTEM FOR TELEPHONE EXCHANGE

Environmental Requirement

The basic environment requirements to operate the telephone exchange must meet three requirements including equipment operating temperature, relative humidity and air particle. Manufacturer's recommendation for environmental requirements of equipment is shown in Table 1.

Table 1. Equipment Environmental Requirement

Equipment	Environmental Requirements	
	Operating Temperature (°C)	Operating Humidity (%RH)
OSN-xxxx	0 - 45	10 - 90
DWDM-xxxx	0 - 45	10 - 90
NE-xx	0 - 45	10 - 90
MA-xxxx	0 - 45	10 - 90
NTU	0 - 40	10 - 90
PDH	0 - 45	5 - 95

Table 2 shows the average temperature and relative humidity of Bangkok, Thailand. The comparison of temperature and relative humidity in Table 1. and Table 2. seem that equipments will be able to operate without any control system, the telephone exchange can operate without the precision air conditioning system.

In fact, the generated heat from equipments may accumulate and increase the room temperature without the appropriate cooling system. The experimental results of various cases are illustrated in Figure 4, number two of graph: Inside room without air conditioning and ventilation, shows that the telephone exchange is need the ventilation system because temperature of telephone exchange without any ventilation system will be reached the upper limit in a short period.

Table 2. Average Temperature and Relative Humidity of Bangkok Thailand in 2010

Month	Temperature (oC)	Relative Humidity (%)
January 2010	32.00	86.65
Febuary 2010	33.53	90.32
March 2010	31.25	80.37
April 2010	33.38	63.70
May 2010	32.46	71.87
June 2010	32.99	76.60
July 2010	31.53	79.16
August 2010	31.20	79.39
September 2010	31.80	76.97
October 2010	31.57	71.71
November 2010	31.60	65.87
December 2010	30.07	61.49
Average	31.95	75.34

The various cases of relative humidity is recorded and shown in Figure 5. The relative humidity inside the room is lower than the outside. In addition, one blower may not maintain relative humidity of room; however three blowers cannot control relative humidity of room with significant additional controllability when compares with two blowers. According to experimental results, the optimal design of ventilation system is the hybrid two blowers with the existing precision air conditioning.

3. OPTIMAL ENERGY MANAGEMENT

Methodogy

From experimental results, only one blower can maintain the room temperature within the accepted range, however the room conditions are depend on many factors especially outside room temperature. The optimal design of ventilation system for temperature control is two criteria that are room temperature control by days and seasons.

Average temperature and relative humidity of Bangkok, Thailand, are shown in Table 2. which the out door ambient temperature is less than or equal 28.00°C is 3,730 of 8,760 hours in a year or 43% of the whole year as shown in Figure 6. During this period, only one blower can maintain the room temperature within the recommendation with less of energy consumption. The rest 5,030 of 8,760 hours or 57% is important periods needs for optimal energy management.

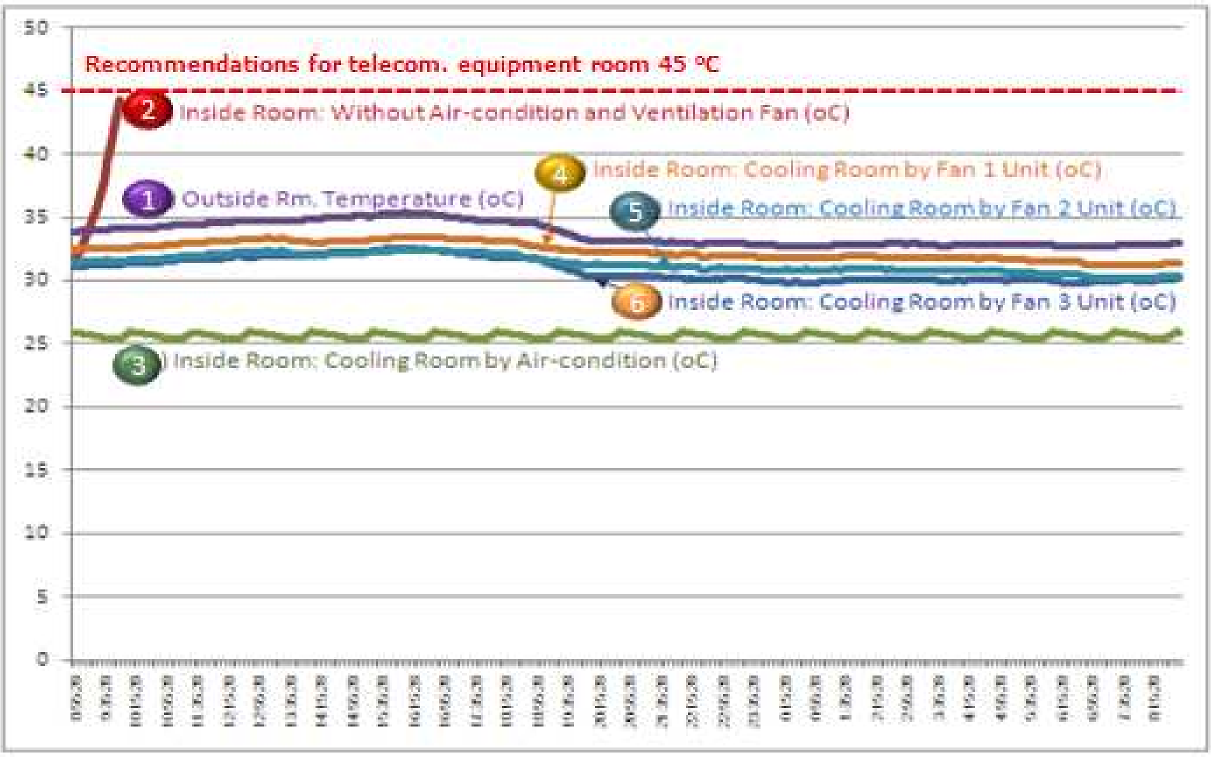

Fig.4. Comparison of Temperature with various cooling method and Recommendations for Telecommunication Equipment

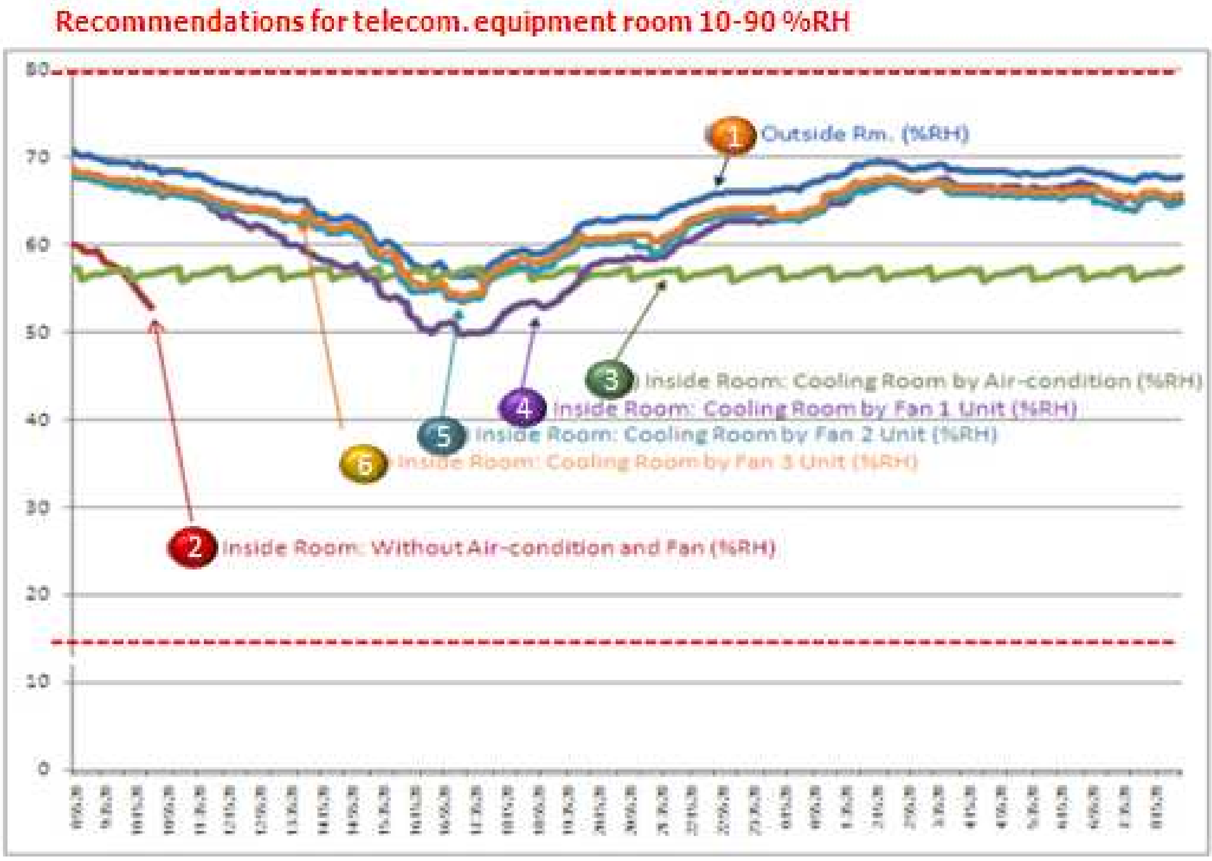

Fig.5. Comparison of Relative Humidity with various cooling method and Recommendations for Telecommunication Equipment.

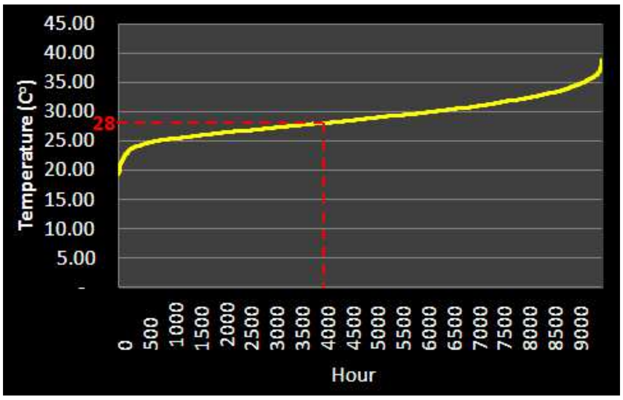

Fig.6. Temperature duration curve of Bangkok in 2010.

Design and Installations

The ventilation air volume is an important factor of generated heat for telecommunication equipment. If ventilation air volume is higher than generated heat the over need energy consumption is the waste of operating system. On the other hand, the ventilation air volume is under the standard may cause the damage of telecommunication equipment. The heat generated from telephone equipment is depending on many factors such as various ambient outside room temperature and load of telephone equipment operation. The first step of design and installations stage is data collection, this experiment used data logger to measures and records the room environment consists of temperature and relative humidity, both of inside and outside the room were done, details as shown in Figure 7.

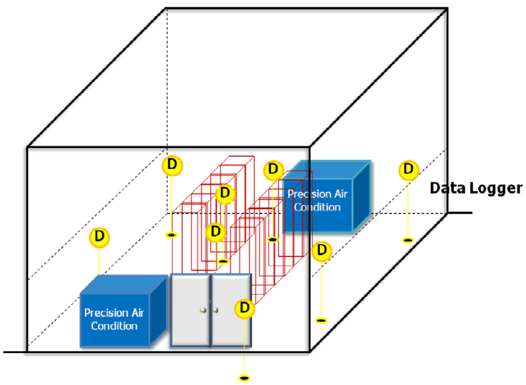

Fig. 7. Temperature and Relative Humidity Data Collection.

The airflow requirements are sometimes very difficult to evaluate for minimizing energy consumption. To avoid equipment shutdown caused by high temperature and to make sure that room temperature will be not excesses recommendation, the design of air flow rate and air change must be higher than normal design of ventilation system as shown in Eq.(1).

$$Q = Heat\ load \times \frac{(T_1 - T_2)}{1.108} \quad (1)$$

where:

Q air flow rate (ft^3/min),

T_1 the outdoor temperature (^{O}F),

T_2 the indoor temperature (^{O}F).

Air Changes

$$N = 60Q/V \quad (2)$$

where

N number of air changes per hour,

V volume of room (ft^3).

Air Change/h determined how many times of room volume would fill up with the air from the registers in one hour.

Installation

Three blowers with temperature sensor are installed as shown in Figure 8, the existing precision air conditioning and air blowers are used to control room conditions.

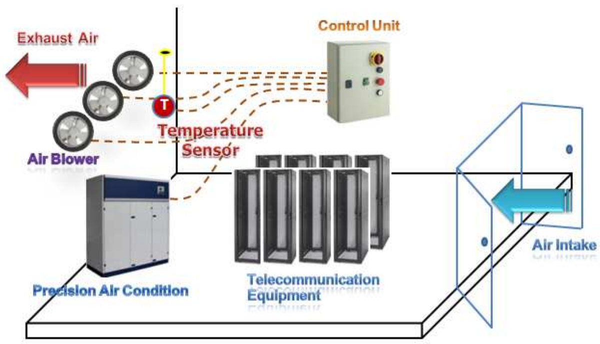

Fig. 8. Air Blowers, Temperature Sensor and Control Unit Installation.

Control Procedure

The temperature control procedures are shown in Figure 9, and operating procedures are as follow:

[a] When the room temperature is less than or equal 31 ^{o}C, one set of air blower is operated to control room temperature.

[b] When the room temperature is reached to 32 ^{o}C, two sets of air blower are operated to control room temperature.

[c] When the room temperature is reached to 33 ^{o}C, three sets of air blower are operated to control room temperature.

[d] When the room temperature is reached to 35 ^{o}C, the existing precision air conditioning is operated to control room temperature.

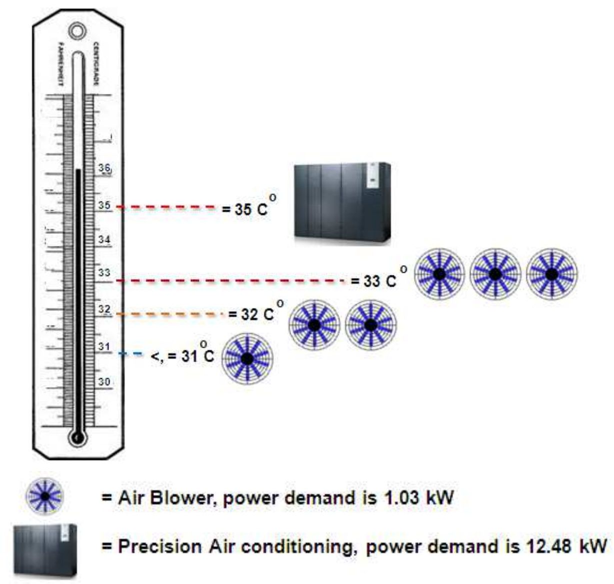

Fig. 9. Temperature Control Procedure.

Safety Preparations

However, a flexible working of controlled air blower by temperature is an optimum choice to maximize the energy saving. The design with automatic operate by use temperature sensor to control the number of blowers are required. This experiment utilized the existing doors for minimizing the installation cost. The fire rated steel doors of main entrance are used for air intakes to the room and in case of fire; function of the door is fire damper. Magnetic lock has been used to hold door to open, when normal situation and automatic relief door is to close in case of emergency situation.

In order to avoid accumulate of heat inside equipment rack, cover should be removed, the heat spread to room and remove to outside by ventilation system. The equipment rack is shown in Figure 10.

Fig. 10. Telephone equipment rack.

In addition, the safety design of fire detection system is need for safety and security conditions so the proposed system is redesigned the room conditions which gaseous suppression system to meet the recommended standard. Telephone exchanges must install fire detection and fire suppression system.

The automatic fire suppression system especially for the telephone exchange, is provided with total flooding gaseous system, as shown in Figure 11, when fire alarm persists, precision air conditioning and/or ventilation blowers have to shut off and every openings have to automatic close, each opening must equipped with fire resistance rated material with at least 2 hours. In case of fire and gaseous discharged the effective holding time to maintain the right concentration such as FM200 standard, at least 10 minute of holding time with 7% concentration is concerned.

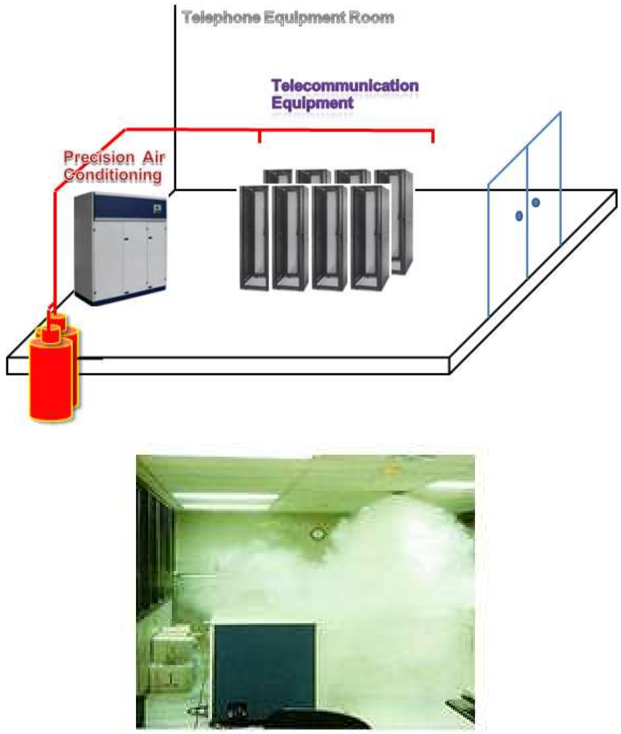

Fig. 11. Total flooding gaseous system in action.

Fig. 12. Fire damper electromagnetic locked type

In this design concept, when emergency situation and fire alarm persist, all of ventilation blowers shut off, fire damper with electromagnetic locked type is dropped to close the opening and magnetic lock at entrance door is relief, door automatic close to seal the room as shown in Figure 12 and Figure 13.

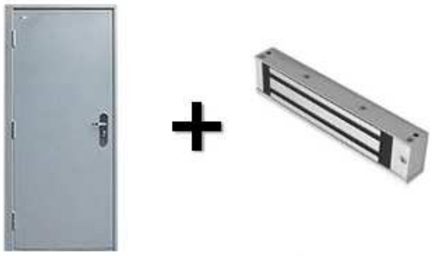

Fig.13. Door with magnetic lock.

This proposed experiment is not installed sensor to control relative humidity, during monitoring found that relative humidity of room is not over recommendation limit. The other control condition is air particle, the air filters are using to control air quality.

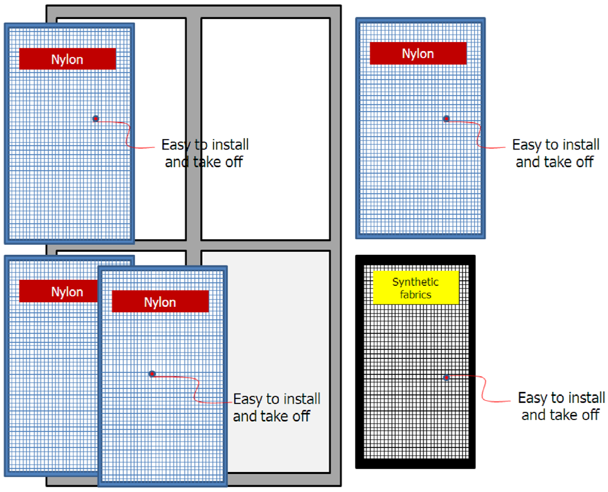

Fig. 14. Air Filter design for user friendly easy to take off.

Air filters are installed at air intakes point. The specification of air filter depends on volume of particle in the air, this experiment found that a lot of particle from outside air made air filter clog very quickly. The important issue is air flow, which is not only have to control air quality but also have to easy to preventive maintenance. Air filter shall be designed to easy to take off for cleaning and easy to install its back, quick lock basis are required. The double pre-filter is used two layers, first is nylon meshwork filter and second is polyester that normally used in air conditioning system as shown in Figure 14.

4. EXPERIMENTAL RESULTS

In this experiment, the details of designed ventilation blowers by using Eq. (1) and Eq. (2) are shown in Table 3, and selected air blower shown as Figure 15.

Financial Analysis

The Life Cycle Cost (LCC) of system is calculated by Eq. (3) that LCC of precision air conditioning system is 11,863,017 Baht. And LCC of the optimal energy management system is only 1,562,246 Baht. The proposed system can reduce LCC of environmental control system for telephone exchange up to 10,300,770 Baht or 7.6 times when compare with the conventional system.

Life Cycle Cost (LCC):

$$LCC = Cic+Cin+Ce+Co+Cm+Cd \quad (3)$$

where:

Cic initial costs,
Cin installation and commissioning costs,
Ce energy costs,
Co operating costs,
Cm maintenance and repair costs,
Cd decommissioning/disposal costs.

Table 3. Air Blower Selected Specification

Normal air displacement at 0 mm. WG.	20,640 cfm.
Electrical system	1 phase 220 volts.
Motor current	4.48 amps.
Absorbed power	1,029 watt.
Fan speed	388 rpm.
Efficiency	20.1cfm/w.
Noise level	64 dBA at 7 m.

Fig. 15. Ventilation fan.

In addition, the life cycle cost of precision air conditioning and optimal energy management system consists of electrical expense, preventive and corrective maintenance costs, i.e., the details are shown in Table 4. The Present Value of cost saving of the optimal energy management system which calculated by the discount rate technique is calculated by Eq. (4) the details are shown in Table 5.

Present Value (PV):

$$\sum_{i=0}^{N} PVi \quad (4)$$

where:

PV_i the present value of year *i*,
N the number of cycle year.

Furthermore, the proposed ventilation system with optimum design by the optimal energy management methods can enhance the energy efficiency for telephone exchange which can reduce the energy consumption up to 91.54% from existing precision air conditioning system. Figure 16 shows the energy consumption of proposed system and conventional cooling system.

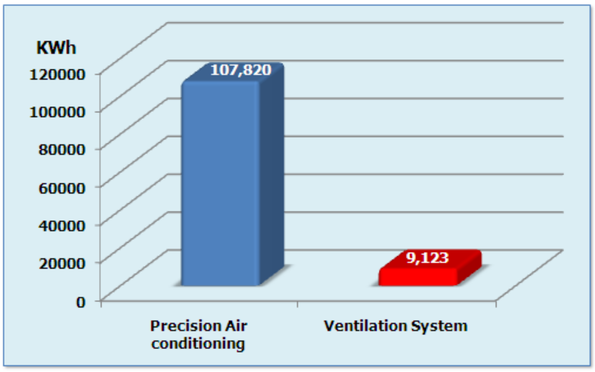

Fig. 16. Comparison of energy consumption with air conditioning and ventilation system.

The annual energy consumption for Precision Air conditioning system is 107,820 kWh/room and 9,123 kWh/room for conventional cooling system and proposed ventilation system respectively. The annual cost of the proposed system can reduce up to 296,092 THB/Room. The proposed optimal energy management of hybrid cooling system is able to greatly reduce energy consumption and operating cost, althoush, the cost saving depends on setting point of room temperature.

5. DISCUSSIONS

The results of experiment, during operated and monitored these hybrid cooling systems which using the air blowers integrated with the existing air conditioning system found that the system can be released heat that generated from equipments quite well and has ability to control temperature of telephone switching room within acceptable range with manufacturers recommend even though the raining day. The major concerned is air particle that come into the rooms and made air filter clog, obstruct the air flow and decreased volume of air intake to the room, rising of temperature which caused room high temperature. Some of air particle appeared on the wall, walk ways, some on the cabinets and switching board. At the first time, clean-up the air filter every 2 weeks, but it can't solved the room high temperature, so, in order to solve the problem its necessary to increase frequency of clean-up the air filter. At the next phase of experiment, additional air filter are required, two sets of air filter provided, twice day cleaned with alternate basis, under process to monitor the air particle.

Over one year operated didn't found damage of equipments which caused by heat or from collection of air particle. The factor affects to the proposed system should be mentioned as following, first of all, design and install the system should be considered of three requirements including equipment operating temperature, relative humidity and air particle. In addition, for flexibility and efficiency of operate and fixing the problems, the system shall be designed and installed with both automatic and manual mode basis, the watchdog system have to provide, alarm and warn when a trouble is brewing such as when ventilation fan is break down, the alarm should send to the responsible officer. Although the air ventilation system is the main system, the existing air conditioning system have to available for cooling the room for all time, especially need to be working automatically. Finally, from experiment results found that the hybrid cooling system by integrating the conventional air conditioning system with air ventilation system are suitably for reducing energy consumption for telephone exchange which installed equipment with circuit switch technology. IP base or package switch technology usually used in Data Center these devices generated high rate of heat and especially, its sensitive to heat can lead to unexpected problems with overheating, so, they might broke down. Until we have knowledge base about this system, advice that not to use with above-mentioned.

6. CONCLUSION

The proposed optimal energy management of hybrid cooling system for telephone exchange is redesigned the conventional system by considering equipment requirement, safety standard and energy management. From experimented results, the telephone exchange can operate without any effect but the energy consumption can reduce up to 91.54% and the overall energy consumption decreased 36.92% as compared to the convention cooling system. The annual cost of the proposed system can reduce up to 296,092 THB/Room with 1 year of return of investment. In additional, LCC of the optimal energy management system is only 13.47 % of conventional system, the proposed system can save up to 9,717,708 THB/Room, when compare with the conventional system. This hybrid cooling system have the potential for practical implementation, but, it's have to continued monitor and evaluated. Further study, when a fan driven by a fixed speed motor the airflow may sometimes be higher than it need to be, it is more efficient to regulate the airflow by regulating the speed of motor. Variable Speed Drives (VSD) with ventilation fan application is the way to enhance energy saving, it uses less energy than fixed speed mode of operations. The proposed temperature control method by used VSD application will be investigated in the future study.

Table 4. Comparison of Life Cycle of Air Conditioning and Ventilation System

LCC (life cycle cost)	Year												Total (Baht)
	1	3	5	7	9	10	11	13	15	17	19	20	
Precision Air condition 2 Unit													
Cic (initial costs/purchase price)	960,000	-	-	-	-	960,000	-	-	-	-	-	-	1,920,000
Cin (installation and commissioning costs)	720,000	-	-	-	-	720,000	-	-	-	-	-	-	1,440,000
Ce (energy costs)	327,953	327,953	327,953	327,953	327,953	327,953	344,350	379,646	327,953	327,953	327,953	327,953	6,822,039
Co (operating costs)	7,300	7,300	7,300	7,300	7,300	8,030	8,030	9,716	10,688	14,226	17,213	18,934	200,978
Cm (maintenance and repair costs)	30,000	40,000	120,000	40,000	40,000	30,000	30,000	40,000	30,000	40,000	40,000	120,000	1,080,000
Cs (downtime costs /loss of production)	-	-	-	-	-	-	-	-	-	-	-	-	-
Cenv (environmental costs)	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd (decommissioning/disposal costs)	-	-	-	-	-	200,000	-	-	-	-	-	200,000	400,000
Total	**2,045,253**	**375,253**	**455,253**	**375,253**	**375,253**	**655,253**	**382,380**	**429,362**	**368,640**	**382,178**	**385,166**	**666,887**	**11,863,017**

LCC (life cycle cost)	Year												Total (Baht)
	1	3	5	7	9	10	11	13	15	17	19	20	
Air Blower 3 Unit													
Cic (initial costs/purchase price)	164,400	-	-	-	-	-	164,400	-	-	-	-	-	328,800
Cin (installation and commissioning costs)	109,600	-	-	-	-	-	109,600	-	-	-	-	-	219,200
Ce (energy costs)	27,747	27,747	27,747	27,747	27,747	27,747	27,747	27,747	27,747	27,747	27,747	27,747	554,946
Co (operating costs)	7,300	7,300	7,300	7,300	7,300	7,300	8,030	8,030	8,030	8,030	8,030	8,030	153,300
Cm (maintenance and repair costs)	3,000	3,000	19,500	3,000	3,000	19,500	3,000	3,000	3,000	3,000	3,000	19,500	126,000
Cs (downtime costs /loss of production)	-	-	-	-	-	-	-	-	-	-	-	-	-
Cenv (environmental costs)	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd (decommissioning/disposal costs)	-	-	-	-	-	90,000	-	-	-	-	-	90,000	180,000
Total	**312,047**	**38,047**	**54,547**	**38,047**	**38,047**	**144,547**	**312,777**	**38,777**	**38,777**	**38,777**	**38,777**	**145,277**	**1,562,246**

Table 5. Present Value of Cost Saving which calculated by the Discount Rate Technique

Table 5. Present Value of Cost Saving of the Optimal Energy Management System which calculated by the Discount Rate Technique

Cost Saving	Year												Total (Baht)
	1	3	5	7	9	10	11	13	16	17	19	20	
LCC of Prec. Air cond. 2 Unit - LCC of Air Blower 3 Unit	1,733,205	337,205	400,705	337,205	337,205	510,705	69,603	390,585	2,012,108	343,401	346,388	521,610	**10,300,771**
Present Value calculate with Discount Rate (PV)	1,635,099	318,118	378,024	318,118	318,118	481,797	65,663	368,476	1,898,215	323,963	326,781	492,084	**9,717,708**
Net Present Value (NPV) in this design concept = 9,388,908 Baht.													

Remark: *r* is the rate of interate = 6%

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Thailand's Energy Conservation Policy for Industrial Sector Considering Government Incentive Measures

Rittirong Intarajinda and Pornrapeepat Bhasaputra

Abstract— *This paper presents the simulation results of energy conservation potential for designated factories under incentive measures from Thailand's energy conservation policy. Historical campaigns and projects established from the past energy conservation policies have been reviewed. The investment cost of government and performance of energy conservation including energy reduction, participation of designed factories and financial indices are also investigated. Since the achievement of energy conservation policy for designated factories depends on several factors, the simulation has been taken internal factors of designated factories and external factor affected from economic situation into the consideration. The fuzzy inference system and regression analysis approach have been introduced to develop a hybrid model for evaluating benefits of energy conservation measures. In this approach, the benefit to cost ratio with different project life cycle and percentage of government incentives are investigated. In addition, multi-scenarios of worth obtained from energy conservation implementation with various sequential investments are evaluated. Finally, key success factors for promoting sustainable energy conservation policy in Thailand have been given.*

Keywords— **Designated factory, energy conservation, energy efficiency, incentive measures.**

1. INTRODUCTION

At the present, Thailand is one of developing country of which nation economy growth is driven by high energy-intensive. In 2010, a total value of energy import into Thailand was accounted of 911 billion Baht mainly caused by imported crude oil (751 billion Baht) [1]. During 1987-1997, prior to the (Asian) economic crisis, Thailand's expenditure on energy import at an average rate of 3% of the GDP as energy prices was then relatively low. However, after the economic crisis, crude oil prices sharply increased, causing an increasing loss of foreign currency to Thai currency; particularly in 2008 when the crude oil price was exorbitantly high, Thailand had to spend on imported energy as high as 12.8% of the GDP. In 2010, Thailand's expenditure on energy import accounted for 9.0% of the GDP. A large portion of energy import value results the country to be an imported energy dependency. Considering Thailand energy policy in the present time, not only the strategies have focused on distribution of energy resources and fuels, but the reducing imported energy especially crude oil and petroleum also attempt to implement with renewable energy and energy efficiency projects [2]. In addition the renewable energy development, the energy saving, energy conservation, energy efficiency and energy management from both supply and demand side are common terms used in the energy policy planning. Recently, Thailand has been formulated the long term energy efficiency planning called "the 20-Year Energy Efficiency Development Plan (2011-2030) or EEDP [3]. As shown in Fig. 1, this plan was set the target to reduce energy intensity by 25% in 2030 compared to 2005, or equivalent to reduction of final energy consumption by 20%. In order to achieve the policy target, the potential assessment approach is necessary to evaluate energy conservation potential at the national level and at the individual economic sector level.

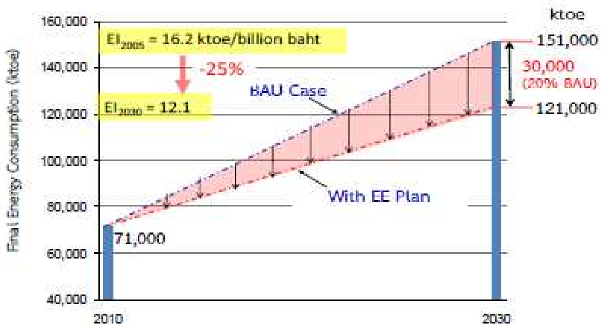

Fig. 1. Energy consumption in the past and future demand trend under business as usual case.

For industrial sector, the energy saving potential is divided into five main clusters, i.e. non-metal, food & beverage, basic metal, chemical and paper. These clusters account for the largest share of energy consumption, i.e. over 84% of the total energy consumption in the industrial sector in 2009. The energy conservation potential of each industrial cluster was roughly assessed by statistical and mathematical model. The approach can be made by comparing Thailand's current average specific energy consumption (SEC) with the best SEC or best practice in foreign countries or with the best practice in Thailand. The different value was set as the energy saving target for energy efficiency improvement in respective industrial cluster in the next

Rittirong Intarajinda (corresponding author) is the PhD student of Electrical Engineering, Department of Electrical and Computer Engineering, Thammasat University, 99 Moo 18 Klong Luang, Pathumthani 12120, Thailand. E-mail: 5210300140@student.tu.ac.th

Pornrapeepat Bhasaputra is with the Department of Electrical Engineering, Faculty of Engineering, Thammasat University. 99 Moo 18 Klong Luang, Pathumthani 12120, Thailand. E-mail: bporr@engr.tu.ac.th.

20 years. Despite the need for increasing industrial energy conservation and efficiency, there were studied results indicated that cost-efficient energy conservation measures were not always implemented according to the company's investment criteria [4]. The actual energy reduction implemented by individual factory depends on several conditions, for example, the external factors such as the government promotion campaigns, the enforcement of energy conservation law, energy efficiency technology development and price trends which can impact to the energy conservation and efficiency. In the public policy making, economic parameters have also affected a potential of factories to perform energy conservation activities [5]. In addition to the external factor, the investment potential, energy policy of each organization, awareness of people, characteristic of plant operation, aging of equipment and machines, quantity and value of products were significant factors and strongly related to the implementation of the energy conservation project in each factory. In general, barriers to the success of energy conservation and efficiency can be summarized in various aspects such as economic barriers, behavioral barriers, organizational barriers, social barriers and driving market barriers [6-9]. Therefore, the characteristics of factories and driving forces from external factors should be taken into the energy saving potential assessment.

This paper presents the stochastic model using the hybrid fuzzy-regression method for examining the energy conservation potential of industrial sector. This approach was considered external factors and internal factors of each factory and projected the energy saving to the next 20 years. The benefits from energy saving potential are converted to monetary value in order to compare with the government supports. The information required to develop to model was provided from surveyed 380 factories. The development of these aspects will concern the cost-effectiveness in the project investment as well as feasibility of participation from all sectors. This paper also examined multi-scenarios of energy conservation policy for industrial sector based on various economic situations.

This article is organized as following aspects; the overview of energy conservation policy in Thailand was reviewed in Section 2 in order to address energy conservation policy in each period. The activities related to energy conservation policy, support and incentive measures for industrial sector have been described in Section 3. In order to assess the effectiveness of incentive measures for designated factories, the conceptual framework of modeling development using hybrid fuzzy-regression approach was described in Section 4. Then, the simulation results represented by worth of energy saving was presented in Section 5. In this section, direct-subsidy and tax incentive measures were selected to demonstrate the optimal subsidy criteria for promoting the energy conservation implementation of factories. In addition, multi-scenarios of government subsidy with sequential investment were also presented. Finally, in Section 6, we presented recommendations and conclusion of this study.

2. OVERVIEW OF ENERGY CONSERVATION POLICY IN THAILAND INDUSTRIAL SECTOR

In the past experience, the energy policy in Thailand had mainly focused on the supply side in order to meet the level of requirement while energy policy related to the demand side was less attention to consider. Since 1970s, energy efficiency and conservation have become one of key components to address energy security. During the crude oil shortage in 1973, the direction of energy policy in Thailand was changed with more consideration in the energy saving and energy conservation projects. The energy policy at that time had launched several measures to prevent the oil shortage and saving electricity. Some measures were temporarily required such as: reducing the public lighting by 50%, restriction on engine capacity not over 1,300 cc for the new official vehicle procurement, etc. All measures from government announcements had then been eliminated after the crisis was in a better situation. During 1977-1982, the problems of high rate of oil consumption and imported petroleum for electricity generation lead the government at that time to re-establish the campaign for energy saving measures covered transportation, industry and public sectors. Most were also temporary measures emphasizing on resolving the current problems such as: limit a driving speed of cars and truck, impose the bus lanes, prohibit the car parking along the main roads, forbid the electricity use in large factories during a peak load period, impose the opening-closing time of the services and entertainment places, reduce the TV broadcasting time in the evening, etc. In fact, the implementations of government campaigns were not capable of effective reducing the oil consumption and imported petroleum dependency because these measures were promoted with encouragement from the government sector while end-users were act as the reactive players for responding to the energy policy. For this reason, the strategic energy policy during 1982-1986 was reviewed from the previous plan and replaced by using the concept of maximum benefit to a country development. The government at that time had implemented the National Energy Saving Project for improving energy efficiency as well as the adjustment energy production structure. Industrial sector is the first target sector for providing energy efficiency promotion measures including energy audit, training in energy conservation technology, tax incentives, low interest loans and etc. The success of energy conservation implementation in National Energy Saving Project was expanded from the industrial sector to the commercial and residential sectors during 1987-1991. In 1986, the rapid economic expansion as well as the higher growth of commercial energy demand impacted to the energy supply adequacy. In addition, the achievement in energy conservation campaigns in several countries including Japan, Germany, and Canada which had enacted the Energy Conservation Act as a tool in energy conservation promotion to private sector lead the Thai government to firstly establish the Energy Conservation Promotion (ECP) Act in 1992. The ECP Act was expected to be sustainable energy conservation policy which helps Thailand to maintain the energy security onwards.

The strategic of energy conservation policy in Thailand has been more attention over a past of two decades because of the competitive market mechanism, energy conservation law and regulations and worldwide environmental concerns. Since the first enactment of energy conservation law in 1992, the government sector plays important roles for establishing the sustainable energy conservation policy especially in large energy consumer. Based on a period of policy planning, Thailand has been considered the energy conservation policy from 1992-2011 under short term planning (5-year period). Since 1992, three phases of the Energy Conservation Program have been completed: Phase 1 (1995-1995), Phase 2 (2000-2004) and Phase 3 (2005-2011). Although the target of each plan had focused in the similar way, the details and programmatic activities were different depending on politic direction, economic situation, oil price, energy resources availability and energy efficiency indicator. For practical planning of energy conservation policy, the industrial manufacturing sector, the largest energy consumer and economic contributor, is normally the dominate target sector for implementing energy conservation program when consider a proportional of energy consumption and a number of operating industry.

3. THE IMPLEMENTATION OF ENERGY CONSERVATION PROGRAMS AND INCENTIVE MEASURES IN THAILAND

The energy conservation programs implemented in Thailand can be classified by three perspectives: compulsory program, voluntary program and complementary program. For the compulsory program, the energy conservation program, a part of the ECP Act, put mandates on so-called designated factories and building to perform the energy conservation activities. Mandatory tasks for designated factories are:

- Appoint at least one Personal Responsible for Energy (PRE) or energy manager to regular work related energy conservation activities in an organization;
- Report energy consumption and production capacity in half a year period (Form Bor Por Ror 1);
- Determine the Energy Conservation Plan and Target and submit to DEDE at every three years;
- Conduct the energy audit funded by the Energy Conservation Program.

The successful implementation activities at initial state were primary driven by the Energy Conservation Promotion Fund (ENCON Fund). It was used as working capital and as grants or subsidy for energy conservation investment and operations, promotion of renewable energy utilization, public relations work, energy-related research and development, information dissemination, public awareness campaigns and expenses for management and monitoring of the energy conservation program. However, some activities of the energy conservation program were stopped such as mandatory energy auditing. From the mandatory tasks of designated factories, major problem findings for implementation in practical are;

- Reports on PRE appointment were delayed since the qualifications of the persons to be responsible for energy consumption in the facilities did not meet the criteria specified by laws, or it was difficult to find a qualified person for the task. Also, when the PRE of a facility resigned, a new one had to be hired and the new appointment had to be reported to the DEDE. This process was often delayed.
- The delivery of production data was delayed. This was due to the fact that a number of PRE did not clearly understand the way to fill in the energy consumption information in the given form, or some of the required information was not available. The production data in some designated factories is not preferred to reveal from its confidential information.
- The plan and target of energy conservation program was not directed assessed because of a number of energy expertise or specialists is limited when compared to the total number of designated factories.

For the government supports, there were several incentive measures which provide to the private sectors and social community. In this study, activities for energy efficiency implementation in the first two phases (1995-2007) were:

- Grants designated factories and buildings for conducting preliminary and detailed audits;
- Promote cost-based tax incentive program (direct subsidy) to encourage private sectors and enterprises to invest in high energy efficiency equipment. In the pilot phase, the government provided 10 million Baht for 25 factories and resulted the saving of 1.96 GWh/year. This measure has been extended a government budgetary of 100 million Baht to encourage energy conservation programs of private sector.
- Promote performance-based tax incentive program with financial support from the Energy Conservation Promotion Fund. In this measure, there were 219 companies received the subsidy contributed energy saving by 37.68 ktoe/year or 857.19 million Baht. Total project investment cost was 1322.91 million Baht while government supported in term of tax deductible of 62.65 million Baht.
- Promote a new energy business model in term of an energy service company (ESCO) by giving tax incentives from Board of Investment. Although the ESCO industry has been continued to promote for energy conservation programs, it is a limited number of company in Thailand. The services of ESCO for energy conservation activities are still not widely known from private sector.
- Promote Board of Investment (BOI) incentives for energy conservation that include corporate income

tax exemptions and import duty exemptions for energy conservation equipment;

- Provide energy revolving fund offered low cost loans for energy conservation and renewable energy projects. This measure contributed investment in energy conservation projects by 13815 million Baht while the government subsidy was accounted by 6,820 million Baht. The benefits of saving approximate with 300.84 ktoe/year or 4,698 million Baht/year;
- Support ESCO fund by one billion Baht through six activities: equity investment, venture capital, equipment leasing, carbon credit market, technical assistance and credit guarantee facility. However, this campaign was preferred by renewable projects while energy conservation is less attention.

Develop participatory approach for energy conservation that provides funding support for technical advice (<100,000 Baht) to factories on value engineering (VE) and energy management. This measure has been promoted for designated factories since the past decade. The success of implementation leads to introducing this measure for small and medium factories (SME). During 2002-2008, there were 1,036 designated factories had participated this campaign and it contributes the saving of 1,716.4 million Baht or 72.12 ktoe/year. In addition, the VE program for 1,068 SME factories can contribute the energy saving value of 561.6 million Baht/year.

4. THE HYBRID FUZZY-REGRESSION MODEL FOR ASSESSMENT ENERGY CONSERVSTION POTENTIAL

In order to study the implementation of energy conservation projects, the survey approach with questionnaire related to energy conservation activities in factories is used as a tool to collect information. Responded factories operating inside and outside industrial estates are shown in Table 1. The number of survey sample is 377 factories or 10.5% of total designated factories. Most are classified as the designated factory, the large energy consumer, while approximate 15% is the medium scale industries and expected to be a designated factories in the next few year. When classify a sample into the nine industrial categories, the survey shows that the factories under fabricated metal, machines and equipment (TSIC 38) has a largest number of respondent (107 samples), followed by chemical, petrochemical and chemical products (TSIC 35) with a number of 82 samples and food, beverage and tobacco (TSIC 31) with 77 samples, respectively.

In order to evaluate the energy conservation potential of factories with consideration external and internal factor, two methodologies have been employed to develop the hybrid model: fuzzy inference system and regression analysis technique. For the fuzzy inference system concept, it is used in two perspectives. First aspect, it is proposed for decision a feasibility of participation for designated factories to implement energy conservation project which presented in the energy management report. Second, the degree of membership function is represented as a confidential level of designated factories to implement energy conservation measures under different economic situation. For the regression analysis technique, it is employed to construct the model with two independent variables: an investment cost of designated factories and a number of supports for implementing energy conservation programs. The framework of hybrid model development for assessing energy conservation potential is shown in Fig.2. The following provides description of two approaches for model development.

Table 1 A number of sample classified into nine categories

category	number of sample	total number of designated factory	% of sample
Food, beverage and tobacco	77	727	10.60
textile	31	364	8.50
Wood and wood products	13	105	12.38
Pulp and papers	10	109	9.20
Chemical, petrochemical and chemical products	82	756	10.80
Non-metallic mineral	19	164	11.60
Basic metal	19	215	8.80
Fabricated metal, machines and equipment	107	1,011	10.60
Other manufacturing	19	70	27.10
total	377	3,521	10.50

4.1 Fuzzy inference system

A concept of fuzzy had introduced by Lotfi Zadeh in the mid of sixties to deal with a reality problems which contain more or less uncertain, vague and ambiguous. In general, the fuzzy concept is represented by fuzzy set and fuzzy logic to extend classical sets and mathematical logic which normally define by yes or no, white or black, true or false. Fuzzy sets and fuzzy logic deal with objects by using a fuzzy numbers which describe grade or degree of membership function between (0 to1). More details on fuzzy logic theory and applications are outlined in References [10-11]. A concept of fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. In this study, a concept of fuzzy set is employed to develop the decision model using a fuzzy logic or fuzzy rule.

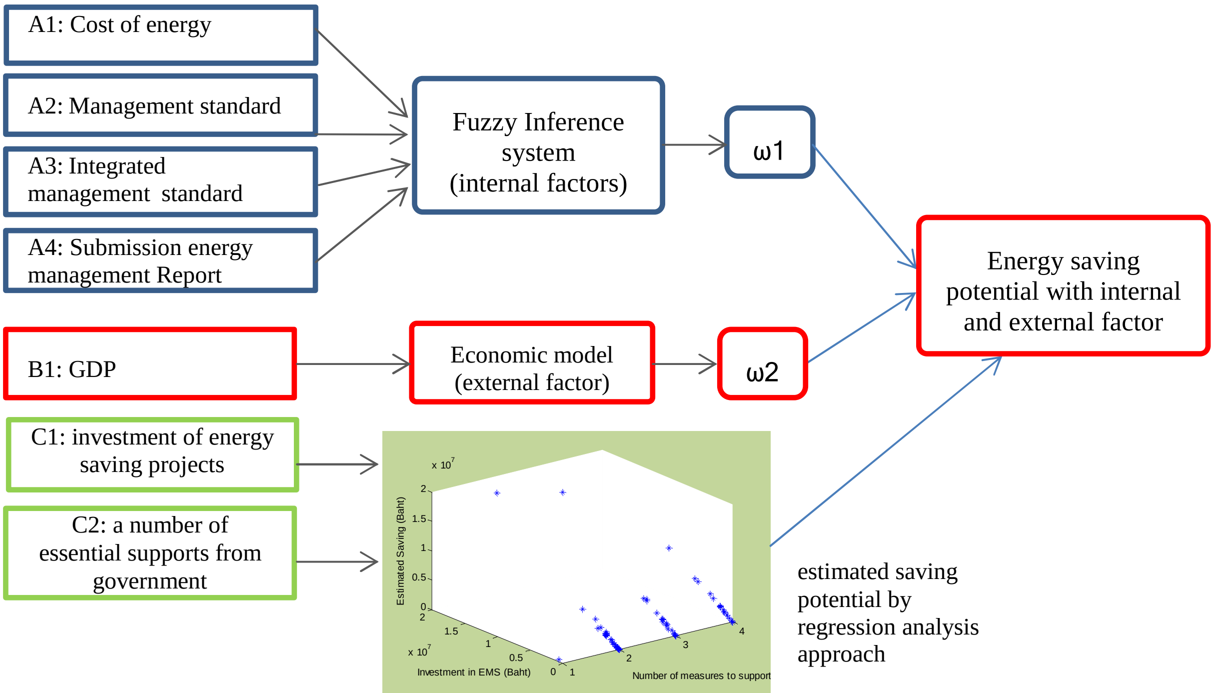

Fig. 2. Conceptual framework of the proposed model for estimating energy conservation potential.

4.2 Regression analysis technique

The regression analysis is a technique for modeling and analysing several variables, when the focus is on the relationship between a dependent variable and one or more independent variable. For this study, the multiple regression technique is used to develop for predicting the energy reduction target of nine industrial sectors with two independent variables: the cost of designated factories to invest in energy conservation projects and a number of support and measures which enhance the achievement of energy conservation project implementation.

4.3 Overview of the model development

4.3.1 Internal factor model

In general, industrial manufacturing sector intends to monitor and control business target based on company profits. The quantity and quality of products are the most important factors which impact to business growth. Without establishment energy conservation laws and regulations, the energy efficiency was expected to less attention by top management perspectives when compared to a quantity and quality of products. However, the energy conservation and energy efficiency projects have been more considered for large scale industries over a decade after the oil price crisis and energy conservation law enforcement. For this reason, internal factors of industry were strongly related to the success of energy conservation projects. In this study, four significant factors from large scale industrial survey were selected to be the input variables for the decision process with fuzzy inference system. The output of internal factor model in a range of 0 to 1 will indicate a level of confidential of an industry to achieve the energy reduction target as shown in the energy management report. For example, if an industry expected that annual energy reduction target by a project of high efficiency motor replacement to be 100,000 kWh. The proposed model will calculate a confidential level or participation factor of energy reduction target with input variables in FIS. Four significant variables for construction fuzzy inference system consist of energy cost (A_1), a number of management standards (A_2), integration of management standard (A_3) and energy management report submission (A_4). Assumption in each input variable can be described as following;

A1: the energy cost was derived from survey questionnaire. It consists of two cost elements including electricity and thermal energy. In fuzzy rule, a high energy cost industry was more expected to achieve energy reduction than a lower energy cost industry.

A2: a number of management standards were important factors for the success of energy conservation project implementation. In this study, the three worldwide standards (ISO 9001, ISO 14001 and OHSAS 18001) were considered. An industry with more standards was expected to achieve the energy conservation target higher than an industry without certified management standard.

A3: Not only a number of management standards, the integration of the existing standards was also expected to enhance the success of implementation of energy conservation projects.

A4: The submission of energy management report to the DEDE was expected to indicate the responsibility of an industry. In this report, the lists of investment plan and activities related to energy conservation project implementation were given.

Fig. 3 illustrates the model of participation factor estimated from internal factors of surveyed factories in TSIC 31 by FIS approach. Since a number of surveyed factories in TSIC 31 account by 10.6% of total designated factories in this sector, the boostrap technique, a statistical method for estimating the sampling distribution, was applied in order to represent to participation factor of all designated factories in each industrial category. Comparison the participation factor from FIS before and after resampling with boostrap technique is presented in Fig. 3. We can see that the a pattern of participation factor after using boostratp technique is normal distribution in a range of 0.91-0.97.

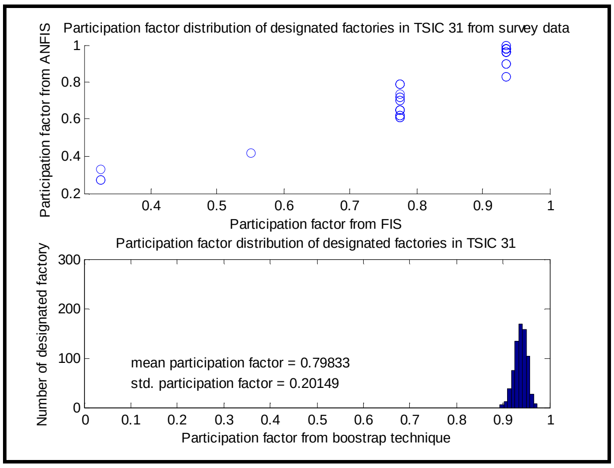

Fig. 3. Participation factor to implement the energy conservation programs of factory in TSIC 31.

4.3.2 External factor model

Manufacturing industry is the highest contributor for economic and social development in Thailand. The demand situation of global or local economy directly impact to the value added of industry which can be monitored by the growth rate of GDP. In this study, we formulated the participation factor of energy conservation implementation of factories under various conditions of national economy. The relationship between GDP growth rate and participation factor (B_1) of implementation was assumed as shown in Fig. 4.

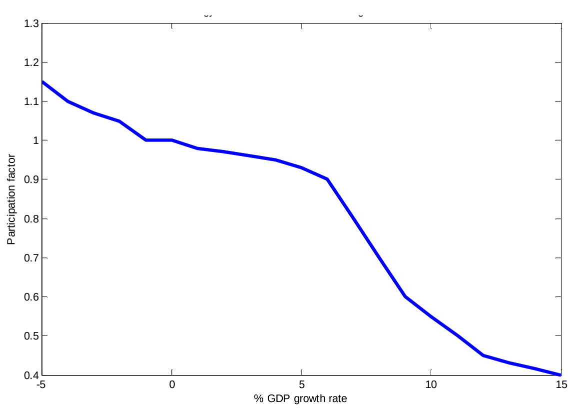

Fig. 4. Participation factor under economic situations.

4.3.3 Energy saving potential model

The model of energy saving potential (ES) has been developed by two input variables: the investment cost (C_1) of designated factories for implementing energy saving project and a number of measures (C_2) which factories requested a support from government sector. The data set of investment cost and a number of measures has been modelled by multiple regression technique to predict a potential of energy saving in each designated factory.

$$\log(\mathrm{ES}) = \log(\mathrm{C}_1) + \mathrm{C}_2 + \mathrm{k} \quad (1)$$

where k is constant number while ES is expressed in the unit of Baht/year. In this study, the ES was presented as the worth or benefits from energy conservation implementations in a year. The information of factory investment was based on the year of 2007-2009.

In the survey questionnaire, a number of measures and supports from government are limited by 5. Examples of measures from government support to enhance designated factories to implement energy conservation projects include technical expert assistance, financial assistance (soft loan), tax incentive with cost-based and performance-based, energy service company.

5 THE STUDY RESULTS

In this section, we provide the information related to the industrial preference for subsidy programs in order to implement energy conservation projects under presented in the energy management report. As is presented in Table 2, the percentage of respondent with seven options is significant to the benefits which factories can be obtained. In the industrial survey, the direct incentive, normally in range of 20-30% of investment cost for energy efficiency equipment, is the most preference option to obtain for implementing energy conservation project with 80.75% of total samples in this study. Then, the measure of tax incentive (cost based, performance-based) is also high level of preference by 63.06%, followed by the measure of soft loan financial assistance by 37.99% and ESCO program by 28.5%. It is also surprise that the measure of technical assistance is very low rate of preference which account by only 0.79%. In addition, there are significant portions by 20.05% of sample factories which not request for any supports from government sector. The feasible reasons to explain the option of expert and technical assistance is that the factories are not satisfy the previous performance of expert assistance from the past. The technical knowledge of factory's staff is sufficient to deal with the energy conservation project. The respondents are also indicated that this measure is non-monetary support directly. Furthermore, there are several reasons which factories not prefer measures and support from government to implement energy conservation projects. For examples, the quantity of production is more important than the energy saving aspect. The energy cost for some factories account by a small portion when compare with the labour and employee cost and raw material cost. Other possible reasons include the complex of subsidy procedure, unattractive rate of incentives and financial resource limitation to implement the energy conservation projects.

Table 2. Respondent related to the preference of supports

No	Subsidy programs	%
1	Not prefer	20.05
2	Tax incentive	63.06
3	Direct subsidy	80.75
4	Soft loan	37.99
5	ESCO	28.5
6	Expert, technical assistance	0.79
7	Other	1.85

Considering the incentive measures shown in Fig. 5 which classified energy cost of sample factories, the two incentives of tax incentive and direct subsidy programs are still most preference incenives for factories to implement energy conservation projects particularly industries with high energy cost. In contrast, an industry with low energy cost has less attention to consider energy conservation projects and the measure of expert/technical assistance not much prefers for all scales of factory. Therefore, the simulation of enery conservation potential assessed by the proposed hybrid model selected the measures of direct subsidy and tax incentives for investgating the optimal subsidy criteria from government sector. The project life cycle from 2 to 10 years has been varied in order to determine the sensitivity of financial performance as well as the rate of government subsidy.

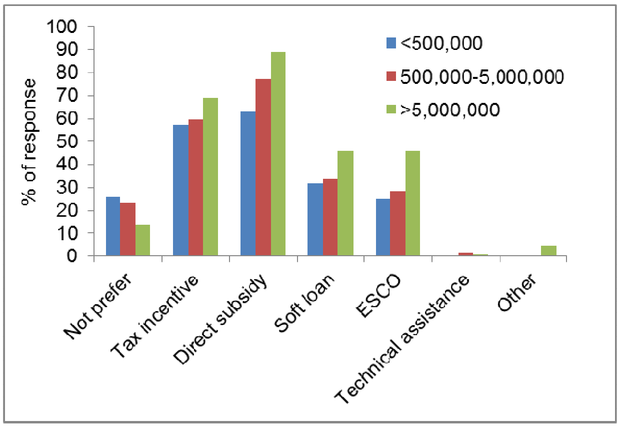

Fig. 5. Percentage of industrial response under subsidy programs preference considering energy costs.

Direct subsidy program

The energy conservation promotion with 30% direct subsidy incentive for industrial sector is one of the most successful programs in Thailand. The concept is based on the successful implementation in Denmark. The keypoint of this campaign is from the attractive rate of subsidy for industry to invest in a pre-approved list in high energy efficiency equipment. In the subsidy criteria, the government provides the 30% direct subsidy of equipment investment but not higher than 30% of standard price. The minimum subsidy is 15,000 Baht while the maximum support is limited at 2,000,000 Baht per factory. In the other word, the capital cost for investment in this project is in a range of 50,000-6,670,000 Baht. During the pilot project in 2000-2001, the 25 non-designated factories and buildings was selected as the target sector with project budgetary of 10 million Baht. In general approval criteria, the submited measure of energy conservation project should have a pay back period within 7 years. In general, this program is simple. The factories is not required to calculate financial or economic return and the procedures are not much complex for approval process. So, this campaign is attracted from many investors wich 11 standard measures are approved to receive the subsidy incentives: high frequency electronic ballast for lighting, variable speed drive on air compressor, insulation of pipes and surfaces, variable speed drive for pump, heat recovery equipment, controller of air supply for combustion, air to heat exchanger, high efficiency motors, luminaires reflectors, voltage regulator and power control for lighting system. However, the direct subsidy program was announced only in some periods and was stopped because from several reasons. The most important was the misperceptation that such a kind of subsidy is non macro-economically justifiable. In this study, the direct subsidy program is demonstrated for promotion in long term energy conservation policy which planned from 2011-2030. The project life cycle is expected in range 2-10 years. The variable of percentage for government subsidy to the industrial sector is varied from 20%-70%. The results of simulation in case of BAU scenario (GDP 3.5-6%), high economic growth rate situation (GDP >6%) and low economic growth situation (GDP <3.5%) are shown in Fig. 6 to Fig. 8, respectively.

The general results show that the benefit to cost ratio will be increased when the project life cycle is extended. Under the similar government budgetary, the benefit to cost ratio will be decreased if the percentage of government subsidy is increased because the investment from factories is minimized. As results of BAU scenario shown in Fig. 6, the optimal criteria for implementing energy conservation project is that the project life cycle must be longer than two years and the percentage government subsidy is lower than 50%.

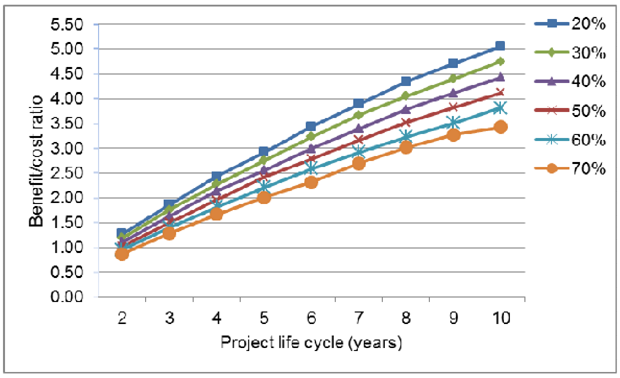

Fig. 6. Benefit to cost ratio for direct subsidy program with BAU scenario.

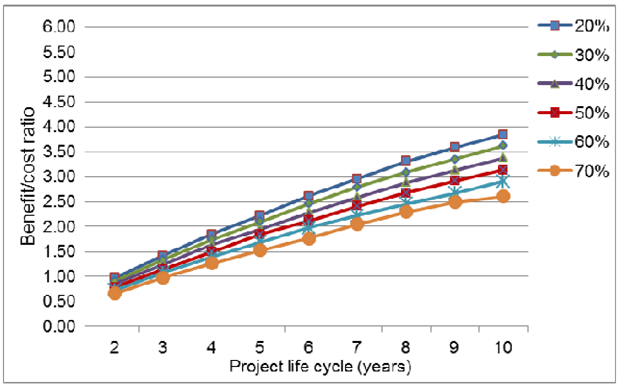

Fig. 7. Benefit to cost ratio for direct subsidy program with high economic growth rate scenario.

For the high economic growth rate, the energy conservation implementation is considered as the minor priority while the quantity of products is more important for factory profits. The government should provide the subsidy lower than 60% while the mimimum life time is expected with three years. The simulation results in this case is presented in Fig. 7. In the low economic growth rate or recesstion period, the energy conservation implementation is considered as the major policy for all factories in order to maintain their business operation profits. As the results shown in Fig. 8, the government should provide the subsidy lower than 70% while the mimimum life time is expected with two years. However, the results of this scenario may be reversed if factories counter a financial constraints from economic recession and result of investment capability for energy conservation project implementation. Therefore, the concept of value engineering with provision of enegy conservation experts or technical assistance is recommended. The low investment budgetary such as housekeeping measures are situated for this case.

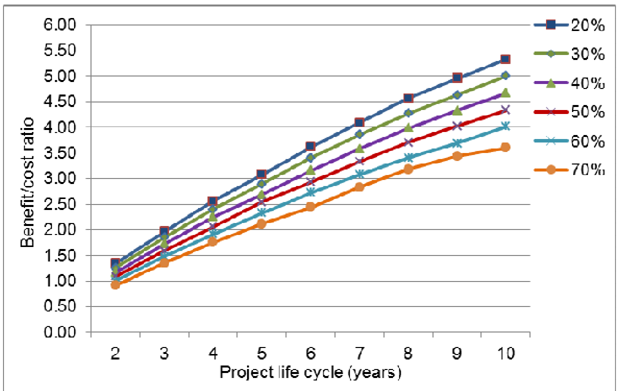

Fig. 8. Benefit to cost ratio for direct subsidy program with low economic growth rate scenario.

Tax incentive programs

For tax incentive measure, there are two programs considered in this study: cost-based tax incentive and performance based tax incentives. In the initial state, the campaign of cost-based tax incentive is firstly promoted because of government needs all energy intensive end-users invest in the proved energy efficiency technology. However, this measure leads to the large burden budgetary of government. Then, the performance-based tax incentive programs are introduced for reducing government constraint while the end-users are still received the incentive with acceptable value. For cost-based tax incentives, a 25% tax break is given to industrial sector for investing in projects that result in efficiency improvement. These tax breaks are applicable to the first 50 million Baht investment and spread over a 5-year period. In contrast to the cost-based consideration, the performance-based is introduced with 100% of tax deductible for all energy saving achieved. The maximum of this incentive measure is set at 2 million Baht. In this option, the procedure of pre and post energy saving audit is necessary to perform in order to certify the actual saving. Since two measures are related with tax, simulation results have been varied government subsidy from 15-85% while the project life cycle has a similar range with direct subsidy measure. The summary results of simulation obtained from the hybrid fuzzy-regression model for BAU, low growth rate GDP and high growth rate GDP are illustrated in Fig. 9-Fig. 11, respectively.

As shown in Fig. 9, we can investigate that overall results of benefit to cost ratio for the tax incentive measure are lower than direct subsidy program under the similar percentage of subsidy. If considering the case of BAU with the project life cycle of 2 years, the maximum percentage of subsidy for tax incentive measure should not higher than 25% in order to achieve the benefit to cost ratio at least 1.0. For the case of project life cycle is 3 years, maximum criteria of the tax incentive measure should not more than 55%. However, the economic situations can provide different results of cost-effectiveness for investment in energy conservation programs. Fig. 10 shows the simulation results of benefit to cost ratio for tax incentive measure in case of high growth rate of GDP. Our main finding results indicate that the tax incentive measure should not provide for the energy conservation projects with the life cycle less than 3 years in order to maintain the benefit to cost ratio at least 1.0. In addition, the optimal percentage of subsidy for the project life cycle between 5-7 years should not higher than 65% while the energy conservation projects with life cycle between 8-10 years should be received the incentives at maximum of 75%.

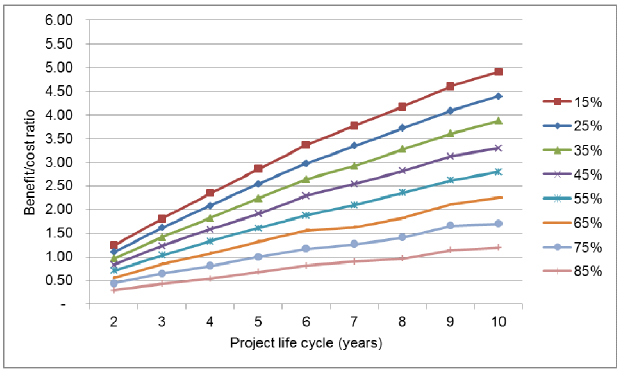

Fig. 9. Benefit to cost ratio for tax incentive program with BAU scenario.

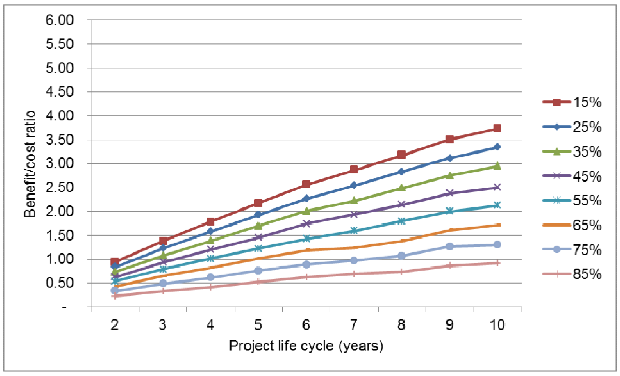

Fig. 10. Benefit to cost ratio for tax incentive program with high economic growth rate scenario.

For the situation of low economic growth rate, the trend of investment performance under various subsidy rates is shown in Fig. 11. The tax incetive measure has a maximum rate for subsidy by 25% if the project life cycle is at 2 years. The maximum subsidy of 75% is also possible if the project life time is at least 7 years. The simulatio results also indicate that the benefit to cost ratio in this case is more sensitive with the different rate of subsity and project life cycle.

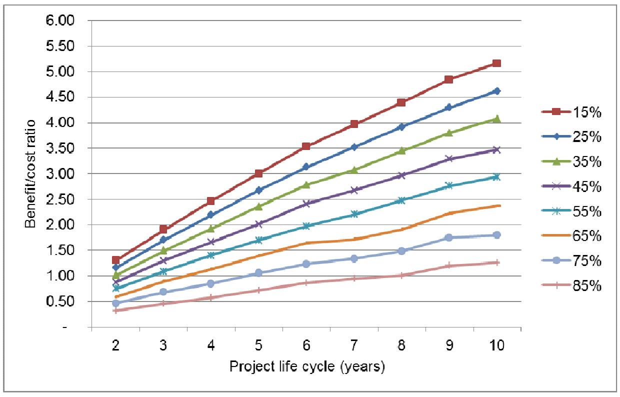

Fig. 11. Benefit to cost ratio for tax incentive program with low economic growth rate scenario.

The relationships between the investment performance index (benefit to cost ratio) under several conditions of economic situation, percentage of incentive subsidy and project life cycle have already presented. However, in fact, the decision making for implementing energy conservation project in industrial process are sequenctial investment. The factories need to choose the optimal timing for thier investment program based on thier specific industrial prioritie rather than the financial internal rate of return of the investment project alone. The multi-scenario of goverment investment with several time sequential for promoting energy conservation measures to the designated factories is presented in this section. The incentives of 30% direct-subsidy and 25% cost-based tax incentives are selected for comparison the results. In this calculation, the investment constraints of government budget for the 30% direct-subsidy program is 100 million Baht a year while the tax incentives is set the budget with 60 million Baht a year. In order to investgate the sensitivity of financial investment index, four scenarios with varying the time sequential of investment in each subsidy measure is assumed while the project life time is estimated in a range of 3-5 years. The annual worth of energy saving with the interest rate of 5% is ploted according to the sequential investment from government. The assumption in each scenario and simulation results are given as follow;

Scenario 1: promoting direct subsidy measure with 5-year period and the tax incentive measure with 2-year period.

This first scenario has been examined on the fact that 30% direct subsidy is the most attractive for designated factories. Therefore, the strategic planning for promoting this incentive is setting 30% direct subsidy program as the first priority, followed by 25% cost-based tax incentive. In this scenario, direct subsidy measure has been scheduled in the five years period while tax incentive has planned to promote in every two years. The time sequential of two subsidy programs within 20 years long term planning is shown in Fig. 12. The annual worth derived energy saving potential over 20 years with 5-year project life cycle is also illustrated. The net present value (NPV) of this scenario is calculated by 8,597.14 million Baht. However, the government investment is also high which accounted by 400 million Baht for direct-subsidy and 600 million Baht for tax incentive program.

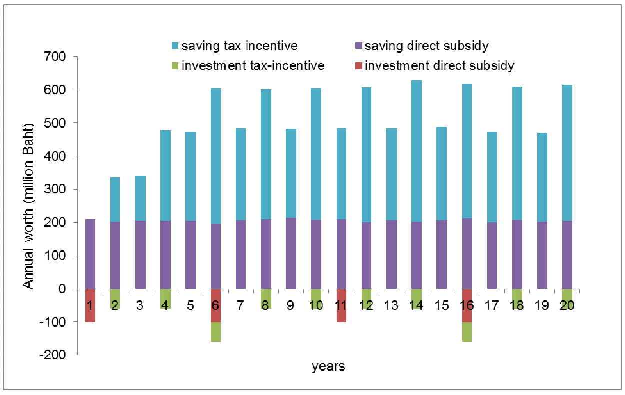

Fig. 12. Annual worth of scenario 1.

Scenario 2: promoting direct subsidy and tax incentive measures with 5-year period

This second scenario is based on the similar schedule for two incentive measure programs. The direct-subsidy and tax incentive is expexted to promote in every 5-year period. This scenario provides designated factories to have two options for energy conservation projects. The time sequenctial of government support over 20-year is shown in Fig. 13. The expected saving from two subsidy measure presented by annual worth have a similar trend. The NPV of this scenario is calculated by 5,873.09 million Baht and the government investment is lower than the first scenario. Overall investment burden from government subsidy is 640 million Baht which 400 million Baht is from direct subsidy and 240 million Baht from tax incentive measures.

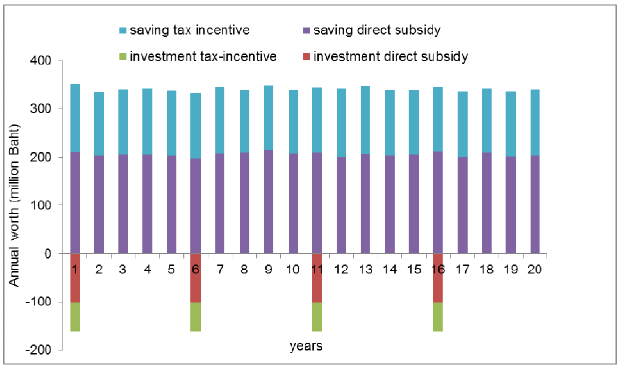

Fig. 13. Annual worth of scenario 2.

Scenario 3: promoting direct subsidy and tax incentive measure with 4-year period, the tax incentive measure lack the direct subsidy by 1 year

This third scenario is set the interval for subsivy shortter than the first scenario while the direct subsidy is still considered as the first priority for announcement. In this scenario, the direct-subsidy is placed on the order of 1st, 5th, 9th, 13th and 17th-year while tax incentive is set on the 2nd, 6th, 10th 14th and 18th-year. The sequential of subsidy programs and the saving potential is illustrated in Fig. 14. The NPV of this scenario is calculated by 6,878.06 million Baht. The government investment to promote this campaign is about 800 million Baht which the 500 million Baht is nessessary for direct subsidy and 300 Baht is required by tax incentive program.

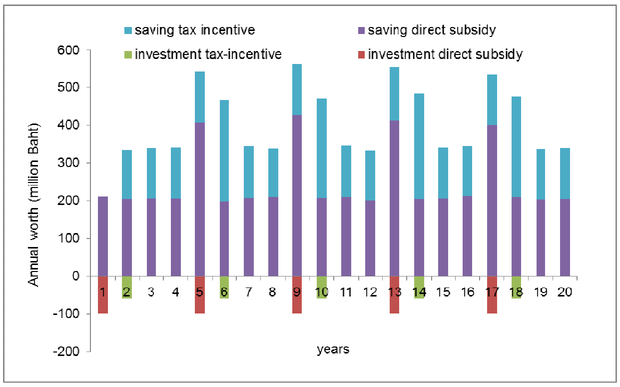

Fig. 14. Annual worth of scenario 3

Scenario 4: promoting direct subsidy and tax incentive measure with 3-year period, the tax incentive measure lack the direct subsidy by 1 year

This last scenario is established with the 3-year period of two subsidy programs. This scenario is based on the law enforcement for designated facories to performance the energy conservation projects and these require financial support from government frequently. Fig. 15 illustrates the government investment sequential over the 20-year planning period. The direct subsidy is still considered as the first priority for announcement and followed with the tax incentive measure program delayed by 1-year. In this scenario, the direct-subsidy is placed on the order of 1st, 4th, 7th, 10th, 13th,16th and 19th-year while tax incentive is set on the 2nd, 5th, 8th,11th 14th,17th and 20th-year. The NPV of this scenario is calculated by 9,019.26 million Baht. The government burden to promote this campaign is in the highest level compared to the onther scenarios. In this option, overall investment from government is about 1,120 million Baht which the first 700 million Baht is from direct subsidy program and 420 Baht is required by tax incentive program. It is noted that the simulation results is calculated based on the constant price of energy while the factory investment is obtained from survey. In case of energy prices is higher than the present situation, there are more opportunities for promoting the subsidy program with short sequential period of investment.

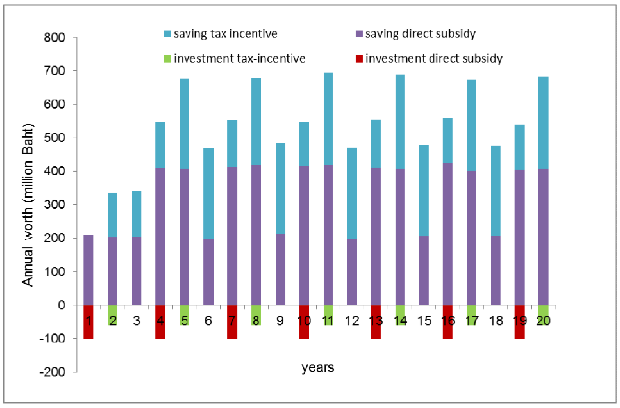

Fig. 15. Annual worth of scenario 4

In order to compare the cost-effectiveness of investment in each promotion campaign, Table 3 summarizes the NPV of four scenarios under the project life time of 3-5 years. This analysis considers both the NPV which derived from energy saving potential in a year and the burden from government investment. Thus, we define the cost-effective investment index with NPV and divided by government investment to represent the term of effectiveness. Based on the analytical results in Table 3, the results show that scenario 2 is the most efficient for promoting subsidy of energy conservation projects with the NPV/government investment of 9.18, followed by scenario 1 and scenario 3 with the NPV/government investment of 8.60. These imply that the effective promotion is from the announcement of two incentive measures in the similar period. In contrast, the scenario 4 provides the lowest feasibility for proposing the factories to implement the energy conservation projects although it contributes the result in term of highest energy saving return. In this case, the scenario 4 provides the NPV/government investment of 8.05.

The results of four scenarios imply that the strategy of investment to promote energy conservation programs based on long term period is strongly affected to the burden of government as well as the worth of energy saving. In practical, factory ability for replacement equipment from the existing system to the high efficiency technology is different from each other although they are classified within the similar category.

In this aspect, the large scale factory (large production volume or large energy consumption) has limitations higher than a small scale factory for investment in equipment with contributes a major impact of energy efficiency. Thus, our recommendation is that the percentage of subsidy should be considered the size of project investment. A factory required to change a major (major impact to the energy saving or energy efficiency) should be received more percentage of subsidy. Our further recommendation for sustainable and effective policy for energy conservation is that the person in an organization who is aggressive to energy conservation implementation should be received benefits from the worth of saving in order to encourage awareness and the responsibility of energy conservation in mind.

Table 3 Financial index from four investment scenarios

Scenario	Project life time	NPV ($x10^6$ Baht)	Investment	NPV /Investment
1	5	8,597.14	1000	8.60
	4	6,731.11		6.73
	3	5,008.91		5.01
2	5	5,873.09	640	9.18
	4	4,551.31		7.11
	3	3,402.79		5.32
3	5	6,878.06	800	8.60
	4	5,543.33		6.93
	3	4,096.78		5.12
4	5	9,019.26	1120	8.05
	4	7,158.64		6.39
	3	5,299.14		4.73

6 CONCLUSION

For the past decade, the investment for energy conservation policy in Thai industries has been promoted with several government measures. However, the uncertainty of manufacturing operation and investment limitations lead the actual energy reduction from energy conservation implementations to difficulty to assess in practical. This article presents the approach for estimating energy reduction potential using the hybrid fuzzy-regression model. The fuzzy concept is introduced to deal with the uncertainty of project implementation while the regression is used to describe the relationship of investment and energy reduction potential of factories. The internal factors of factories obtained from survey and various economic situations which significantly impact to the success of energy conservation projects are considered as the inputs for model development. After the model is already set up, the investment of factories related to energy conservation project with different subsidy options and project life time have been simulated. The benefit derived from energy saving to total cost of government investment is investigated. The simulation results indicate that the mechanism of direct subsidy measure can contribute the higher benefits than the tax incentive under the different government subsidy and project life time. In addition, the proposed model has been studied with the multi-scenario of government investment for promoting energy conservation policy. The sequential timing of government subsidy for direct subsidy and tax incentive programs results to the different investment performance index. Because of the factory can request the subsidy of energy conservation measure only one time per subsidy program, sustainable policy should be based on the project with long life time while the investment is in an acceptable range. Furthermore, our findings from survey clearly display that company policy and management understanding are the key driver for effective implementation of energy conservation activities. Finally, the direct subsidy and tax incentive are the most industrial preference for enhancing the energy conservation policy in Thailand.

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NOTES FOR AUTHORS

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In the Greater Mekong Subregion, home to about 250 million people, environmental degradation - including the decline of natural resources and ecosystems will definitely impact on the marginalized groups in society - the poor, the border communities especially women and children and indigenous peoples. The complexity of the challenges are revealed in the current trends in land and forest degradation and desertification, the numerous demands made on the Mekong river - to provide water for industrial and agricultural development, to sustain subsistence fishing, for transport, to maintain delicate ecological and hydrological balance, etc., the widespread loss of biological diversity due to economic activities, climate change and its impacts on the agricultural and river basin systems, and other forms of crises owning to conflicts over access to shared resources. The *GMSARN International Journal* is dedicated to advance knowledge in energy, environment, natural resource management and economical development by the vigorous examination and analysis of theories and good practices, and to encourage innovations needed to establish a successful approach to solve an identified problem.

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P.O. Box 4, Klong Luang
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Tel: (66-2) 524-5437; Fax: (66-2) 524-6589
E-mail: gmsarn@ait.asia
Website: http://www.gmsarn.org

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