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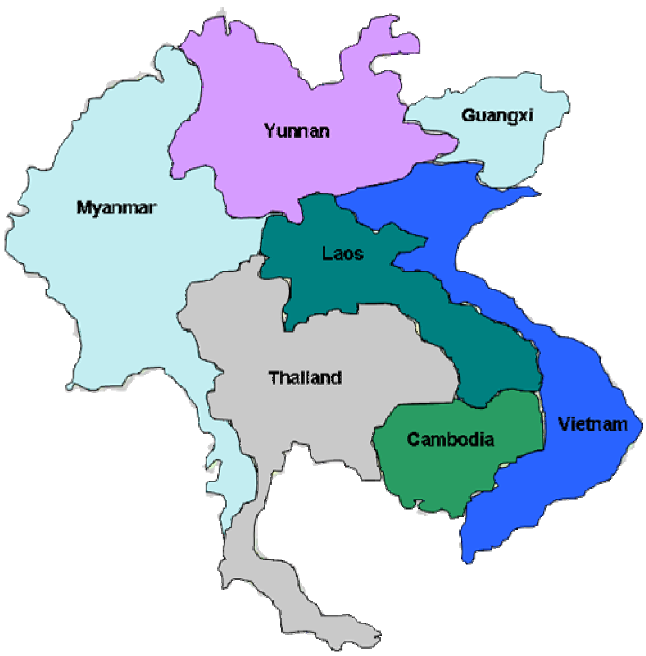

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CONTENTS

Performance and Durability Test of Diesel Engine Generator Using Hundred Percent of Jatropha Curcas L. Oil

Sovanna Pan, Romny Om, Norith Phol, Thavarith Chunhieng, Yoshihisa Shimizu, Yukimasa Yamamura, Keiji Oyama, Ichiro Uchiyama, Akifumi Nakamura, and Toshiki Yamasaki

Abstract— *The research paper aims to develop the process of generation technology using neat Jatropha Curcas Oil (JCO) as diesel engine fuel. In this paper, an experiment on a four-cylinder diesel engine generator is carried out. The research is started by development of fuel oil processing technology from Jatropha seed. The phosphorus, which is forming as phospholipids in Jatropha oil, was removed up to about 10 ppm by water degumming method. The development of power generation technology by straight use of Jatropha oil in diesel engine has been performed. The result is shown that operating conditions of medium size diesel engine with the Dephosphorized Jatropha Oil (DJO) were stable. The effects of DJO on the engine performance, durability and exhaust gas emission had been investigated. The Oxides of Nitrogen (NOx) and Carbon Monoxide (CO) concentrations in exhaust gas of diesel engine with Jatropha oil were lower and higher, respectively, than that of the light oil. The combustion has been improved by raising the fuel injection pressure. The result of the overhaul consideration after long time 300 hours durability test is shown that engine main parts related to the fuel combustion are still in normal functional conditions. Finally, this research experiment confirms that diesel engine generator can be operated by hundred percent of DJO with respect to some modifications of engine cooling system.*

Keywords— **Biofuel, Diesel engine, Generation technology, Jatropha Curcas L.**

1. INTRODUCTION

Due to the depletion of the world petroleum resource and the increasing of exhaust gas, further efforts on the research to seek for new energy and reduce the exhaust gas emission have been made to fulfill the huge energy demands today [1]-[3]. From this aspect, biofuel has been discovered as the most promising fuel for energy production and emission reduction.

Jatropha oil has various uses. Apart from its use as a liquid fuel, the oil has been used to produce soap and biocides (insecticide, molluscide, fungicide and nematicide). The oil can be directly used in older diesel engines or new big motors running at constant speed (e.g. pumps, generator), blending with fossil diesel and/or other fossil fuels belongs to options as well. The oil can be transesterified into Jatropha methyl esters that can be used in conventional diesel engines with adapted parameters.

In present experiment, Jatropha oil is a promising alternative fuel that can be used in diesel engine since its properties, except viscosity, are similar to those of diesel fuel. This viscous oil has been studied in various ways. Some researchers have investigated the viscosity of the light/Jatropha oil blends to be used in diesel engine [4]-[7]. It is shown that the viscosity of the blend is low as much proportion of diesel fuel is contained. Due to high viscosity and the present of wax and gum, raw jatropha oil as such cannot be used in diesel engine properly [8].

An approach to use it appropriately is considered that JCO must be de-gummed before it is supplied to a diesel engine so that why the simple dephosphorization processing technology was developed to remove gum in the oil through an examination test devices and was able to achieve an expected aim.

The objective of this research paper is to study the development of power generation technology utilizing hundred percent of JCO and to investigate behavior of an unsteady power of diesel engine. The research was covered the process of oil squeezing technology from the Jatropha seed, technology of removal phosphorus from Jatropha oil and the process of the generation technology in order to operate engine by neat JCO. In this case, preheating of the dephosphorous oil had been prevented before it supply to the engine fuel system to avoid the difficulty of pumping. Diesel engine had been modified to be used in dual fuel, light oil and neat DJO. The emissions, gum formation and injector deposits have been observed in standard condition and in the case that the injection pressure is increased about five percent to sixteen percent. Engine overhaul was checked after 300 hours running test to evaluate the effects of the phosphors remaining in utilized JCO. Diesel engine generator was also tested for performance comparison between light oil and DJO. Experimental results such as

This research is one of the international joint research projects funded by New Energy and Industrial Technology Development Organization (NEDO) for International Cooperation Research Program, which has been done with Chugoku Electric Power Co. Inc., Japan under the supervision of Ministry of Industry, Mines and Energy. Special thanks to NEDO for providing the fund and to the Chugoku EPCO team for the cooperative research during fiscal years 2009 and 2010.

Sovanna Pan (corresponding author), Romny Om, Norith Phol, and Thavarith Chunhieng are with Institute of Technology of Cambodia, P.O. Box 86, Russian Confederation Blvd, Phnom Penh, Cambodia. Phone: +855-12-552-556; Fax: +855-23-880-369; E-mail: pans@itc.edu.kh.

Yukimasa Yamamura, Keiji Oyama, Ichiro Uchiyama, Akifumi Nakamura, and Toshiki Yamasaki are with Energia Economic & Technical Research Institute, The Chugoku Electric Power Co., Inc., 3-9-1, Kagamiyama, Higashihiroshima-city, 739-0046, Hiroshima-prefecture, Japan.

limit of phosphorus content, brake specific fuel consumption (BSFC), thermal efficiency and also amount of exhaust gas composition during long term and performance tests will be reported in the next sections.
Finally, the research and development of performance and durability test of diesel engine generator using hundred percent of JCO had been applied and achieved at the Institute of Technology of Cambodia. Base on our research plan, the development of biomass gasification devices are under construction in objective to mix combustion between Jatropha oil and biogas produced from Jatropha squeezing cake and other mixtures consisting of agriculture wastes that are available in Cambodia.

2. EXPERIMENTAL SETUP

The pilot plant is composed from six units: oil pressing machine, de-phosphorizer, filter press machine, diesel engine generator, switch board and Jatropha seed roast machine. The new model of SP100 screw press machine was used for the oil pressing from Jatropha seed. The squeezing capacity is 80 to 100 kg seed/h. The de-phosphorizer type BDK-100S was used in research pilot plant with capacity of 130 L, powers supply AC200V with a 30A for heating resistance and together with 1.5 kW of agitator motor. Jatropha oil filter pressing machine was used to screen small debris and other undesired substances from oil before putting it as fuel into engine. The filtering capacity is 100 to 150 L/h.

A four-cylinder water-cooled turbo diesel engine generator developing 40 kW power at 1500 rpm was equipped in pilot plant. Power output from the unit that joining to the switch board unit are installed with main circuit breaker for supplying electricity to all devices and connected to four heating resistance loads of five kilowatt each. A several thermocouples are arranged to the generating sets for recording all necessary data values from the heat. These sensors are connected to the digital data acquisition interfaces “Data logger GL 800” for recording and documentation. An exhaust gas analyzer “Testo 350” is also interfaced to data logger for measurement of exhaust gas composition. Jatropha seed roasting device had been reserved for heating the seed by using an extra-heat from exhaust gas during diesel engine operation.

Experiments were initially carried out on dual fuel diesel engine generator. Light oil is used to start and warm engine for maintaining the temperature of cooling water about 80ºC. The last one is used like heat-exchanger for heating DJO as fuel before it switch on to fuel injection system. Light oil is also resupplied to the fuel injection system at the end of diesel engine operation for cleaning DJO from the fuel system to avoid any difficulty in starting process of the next operation.

3. DEVELOPMENT OF THE FUEL OIL PROCESSING TECHNOLOGY

The reference [9] had been reported the methodology for development of the fuel oil processing technology from Jatropha seed, development of removal technology of phosphorus from Jatropha oil and also development of power generation technology by using DJO.

Squeezing process

As reported hereinabove screw press machine SP-100 is used for the experiments. The Jatropha seed supplied from the seed hopper moves into the space of the screw and the screw casing, where capacity becomes small heading for exits, and Jatropha seed is compressed between its. The screw casing is a slit where tens of square sticks were combined like the cylinder, and the Jatropha oil is squeezed from this space. Jatropha crude oil squeezed contains fine residues of seed cake. It is naturally precipitated spending at least three days. The supernatant is filtered with the cloth while naturally precipitating. The Jatropha seed cake is defecated by small shape if the_frequency of squeezing oil increases. This cake contains various toxins and is therefore not usable as fodder. However it is useful as fertilizer. The seed cake can serve also as feed for biogas production in gasifier.

Seed heating before oil squeezing was conducted because it was reported that oil and the protein separate when the temperature of the seed is adjusted to 70ºC or more to which the protein denatures and oil pressing efficiency improves. The exhaust gas of the diesel engine passing through roasting unit was used for heating the seed.

It is noted that the efficiency of squeezing oil is in range of 80%. In average, for Cambodian Jatropha seed, oil yield in the seed is equal to 36% by weight. The seed roasting at 70ºC to 100ºC is effective to improve the oil press efficiency. The time squeezing is also reduced. Oil can be hardly squeezed at second or third time processing. But it is preferable to squeeze oil by one time at best seed condition from the viewpoint of the power consumption, in average 0.05 kWh/kg seed, for this type of oil pressing machine. Particularly, oil squeezing efficiency is depended also from the quality of the seed collected, from the types of squeezing machine and from qualification of the operator who managed this work.

Dephosphorization process

The phosphor removal process was examined using the water degumming method, basically by adding water to the Jatropha oil and exhausting phosphorus with drain. This method had been developed in laboratory scale by joint researchers from National Institute of Advanced Industrial Science and Technology, Japan and ITC.

In pilot project, the amount of JCO after first filtration was poured into dephosphorizer. Oil is preheated and stirred by machine agitator for about 20 minutes to reach a temperature 70ºC. After that, the amount of water (5% by weight regarding to JCO) must be added like shower into JCO. Afterward, the temperature of 70ºC was maintained and the process of agitation is continuing for 30 minutes at 180 rpm. During this time the emulsion of oil and water was formed immediately. For separation of waste water from oil the agitation was stopped and the mixture was left for 30 minutes at the room temperature. After that the drain water with soluble substances was drawn out from the bottom of dephosphorizer. Water was added three times for one dephosphorisation experiment. The second and third washing were done with the same process as the first one. The samples of DJO and drained water after each washing process were obtained for measuring its phosphor content. In pilot scale DJO is filtered second time by press filter before it use as diesel engine fuel.

Project experiments provided the results as following: crude oil after seed squeezing contained phosphor about 1328 ppm, then this amount is reduced to about 50 ppm and to around 10 ppm respectively for Jatropha oil before and after dephosphorization. The experiments were confirmed that the amount of around 10 ppm of phosphor remained in oil is satisfied to be used as fuel in diesel engine without any troubleshooting.

Production cost analysis

According to the quality of Jatropha seed for the whole process, in average, we need 4 kg seeds for producing 1 kg DJO. In Cambodian market the price of Jatropha seed is around 0.175US$/kg seed. The labor cost for producing DJO is estimated to 0.02US$/kg seed. As mentioned hereinabove we spends in average 0.05 kWh/kg seed, so electricity cost is equal to 0.0125 US$/kg seed. And for the mass production we count also for the equipment amortization that costs about 0.005US$/kg seed. Finally, including some other expenses (0.005 US$/kg seed) for producing 1 kg of DJO we spend around 0.87 US$. This price is considered high. We expect that it will be decreased in term when the price of the seed reduces with growing of Jatropha plantation against the price of fossil fuel.

4. DEVELOPMENT OF POWER GENERATION TECHNOLOGY USING DJO

In this experiment diesel engine generator was modified to be used dual fuel system. Light oil is supplied to diesel fuel system directly while DJO was oriented for passing by heat exchanger. A special faucet is installed for changing fuel supply from light oil to Jatropha oil and inverse. Cooling water with operational temperature varied from 70ºC to 85ºC exited from engine head cylinder is flown through heat exchanger and exchanged heat with DJO before entry back to radiator.

Experimental data records are shown that during diesel engine operation the temperature of DJO was in average 50ºC, when the temperature of cooling water in heat exchanger reached above 80ºC. In consequence, the kinematic viscosity of JCO at this time was less than 30 mm^2/s. The value of kinematic viscosity is considered decrease to around 20 mm^2/s in instant of fuel jet from injector nozzle into engine cylinders.

Engine combustion has been improved also by rising injection pressure. In experiments, we changed the injection pressure two times. Injection pressure is increased by adding the thickness of injector adjusting shim. Engine was operated using neat DJO by standard fuel injection pressure (21.6 MPa), then by 7% and 16% pressure rising respectively. New injectors with corresponding pressure adjustment were changed after every 40 hours engine review check. An engine head cylinder was disassembled to examine the situation of the fuel injector nozzle. The results showed that the abnormal carbon sedimentation inside of engine and obstruction of jet pressure of fuel injector nozzle were not recognized. For long term durability and performance tests a 16% of fuel injection pressure rise (25.0 MPa) was adjusted. This choice is done due to it good fog spray injection which improved the combustion of heating DJO.

5. DURABILITY TEST

From the result of the combustion improvement and the collection of the basic data in the JCO raising fuel injection pressure improved fuel injection characteristics inside of engine. It was confirmed that the CO density is fall down by the improvement of the incomplete combustion; the NOx density is increased by rising the combustion temperature.

The long term durability test was carried out in this pilot project. The duration of the test is 300 hours with proximately constant load equivalent to 20 kW of power generation. The purpose of the test is to investigate the effects of the fuel on exhaust gas emission and on engine components. Engine had been running consecutively from eight to ten hours per day. The test conditions were the same as mentioned hereinabove. Light oil is used for starting and ending the operation and in the remaining time engine was running by neat DJO.

Results and discussion

Table 1 shows the long term test result of exhaust gas temperature and four kinds of exhaust gas emission respectively such CO, NOx, carbon dioxide (CO_2) and oxygen (O_2). For comparison, in average the exhaust gas temperature of JCO measured at exhaust gas manifold increased around 39ºC regarding to which of light oil. It is reasonable, because the high viscosity and low cetane number of JCO provoke the late pre-ignition and main combustion. In consequence, the retardation of main combustion results to remain more fuel burnt at late combustion.

Table 1. Data of exhaust gas emission in average

Fuel type	CO, [ppm]	NOx, [ppm]	CO2, [%]	O2, [%]	Exhaust gas temperature
Light oil	225	499	5.54	14.32	250ºC
DJO	425.9	425.2	6.0	13.3	289ºC

The Figure 1 presented more details about evolution of exhaust gas emission during long term durability test. The amount of CO emission for engine running by DJO is higher than which of the light oil, but it is still limited under standard environmental requirement (500 ppm). We observed that the amount of CO became higher at the end of long time testing period. Some time it was closed to standard limit value. This explained the incomplete combustion due to some formation of the gums in injector nozzle and due to effect of viscosity of JCO. The NOx emission of DJO is decreased compared to light oil. The lower combustion temperature results the reduction of NOx emission. CO2 emission is an exhaust gas producing by the fuel oxidizing reaction. The amount of CO2 increases due to increasing of the mass of DJO consumed. Oxygen content in the exhaust gas is the rest of O2 in the combustion reaction. For this experiment, the amount of O2 contained in the exhaust gas of DJO is lower compared to the light oil.

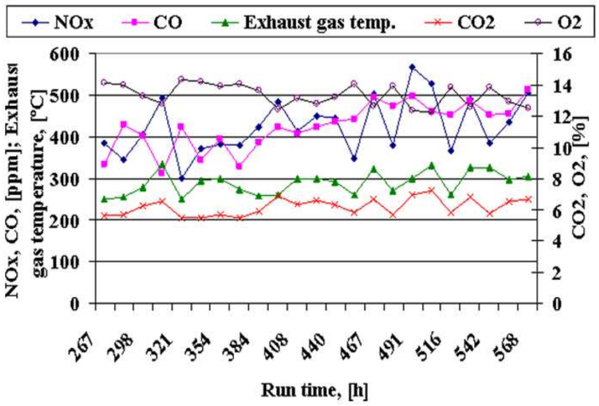

Fig.1. Evolution of exhaust gas emission during durability test.

Fig.2. State of injector nozzle after overhaul.

Fig.3. State of top side of pistons after overhaul.

During long time durability test engine was operated smoothly, no any troubleshooting was found. The overhaul of engine after long running time was allowed us to recognize the effect on inner engine components. Figure 2 shows that the gums were found only around injector nozzles in small quantity. Separated injectors were checked for injection spray by manual injection pump. Injection spray was in good condition for all injectors, obstruction of nozzle holes was not found. Besides that, as shown in Figure 3, the inner side of combustion chamber and top side of the pistons are still cleaned. That means the gums caused by phosphorus content in oil are reduced and the remaining was burnt by high combustion pressure. The other components related to combustion chamber were in normal conditions.

6. PERFORMANCE TEST

The long term durability test was surely confirmed that diesel engine can be operated by DJO. Performance and exhaust gas emission tests were pursued an experiment for comparing the results of engine performance and exhaust gas emission. Diesel engine generator was run on constant speed 1500 rpm using light oil and DJO with the variation of the power output. Four resistances heaters and one heating resistance of dephosphorizer were used as the engine loads corresponding respectively to 20, 35, 50, 65, and 80 percent of engine loads. The data of exhaust gas emission such as CO, NOx, Hydrocarbon (HC), CO2, and O2 were recorded by exhaust gas analyzer during performance test period.

The main properties of diesel and Jatropha oils are given in Table 2, as in [6]-[8]. The results show that the calorific value of the vegetable oil is comparable to the diesel oil and cetane number is slightly lower than the diesel fuel. However, the kinematic viscosity of JCO is several times higher than the light oil.

Table 2. Fuel properties

Properties	Light oil	Jatropha Curcas oil
Density at 40 °C, [g/cm^3]	0.8253	0.933
Kinematic viscosity at 40 °C, [mm^2/s]	3.15	34.4
Calorific value, [MJ/kg]	42.7	38.2
Cetane number	51.5	38

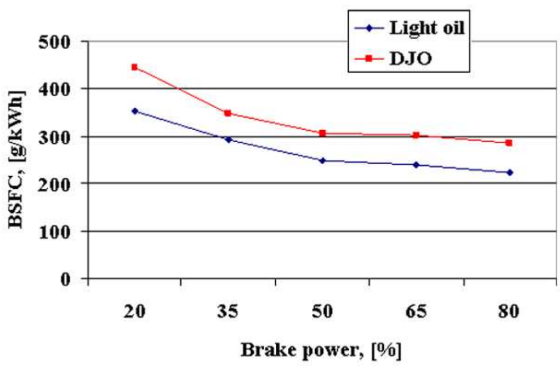

Fig.4. Evolution of brake specific fuel consumption.

Results and discussion of the performance test

The performance of the diesel engine was evaluated in term of brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature.

The figure 4 compares the BSFC of light oil and DJO at varying brake power loads in the range of 8 to 32 kW. It was observed that the specific fuel consumptions of the light oil as well as the DJO were decreased with increasing of the loads. The fuel consumptions for DJO were found higher for about 19% compared to light oil in the entire load range. This is mainly due to the combined effects of the relative fuel density, viscosity and heating value of the oils.

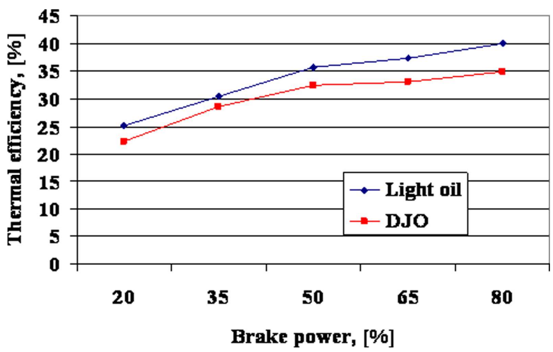

Fig.5. Evolution of brake thermal efficiency.

The variation of brake thermal efficiency of the engine running by light and Jatropha oils is shown in Figure 5. From the test results it was observed that initially with increasing of brake powers the thermal efficiencies of both fuels were increased. The efficiency of DJO is low for about 8% with large deviation at high load compared to light oil. This is because of it low heating value and its poor combustion which reduce the ability to convert the energy from the oil.

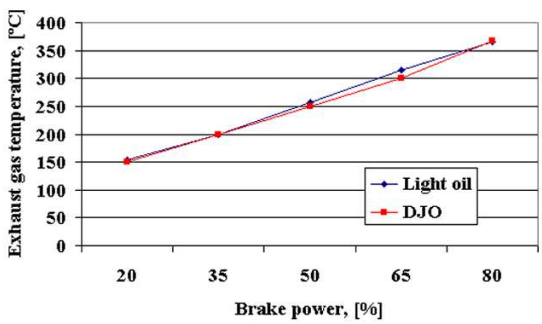

Fig.6. Evolution of exhaust gas temperature.

The Figure 6 shows the variation of exhaust gas temperature with loads in the range of 8 to 32 kW for light oil and DJO. The results show that the exhaust gas temperatures increased with increasing of brake power in all cases. Exhaust gas temperatures of each fuel are not so much different, this shows that most of the fuel burn in the main combustion and they have similar combustion temperatures. For records these values are started from 150ºC to 368ºC respectively for 20% to 80% loads.

Results and discussion of emission test

The Figure 7 shows that CO emission levels are higher with DJO as compared to light oil at all loads. The concentration of CO is become higher with increased load on the engine. It is noted that for the performance test the maximum value of CO emission is around 382 ppm. The amount of CO concentration for DJO is too high at low brake power load. It is due to low temperature of cooling water in this condition that effected to viscosity of DJO and in consequence the combustion was not complete.

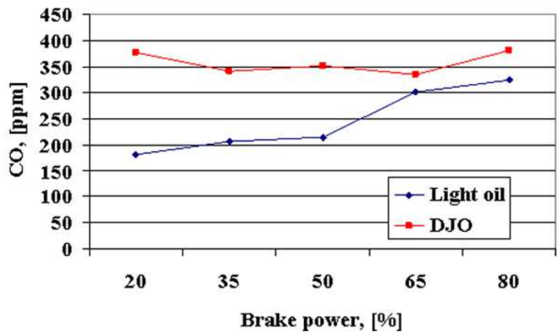

Fig.7. Evolution of CO emission.

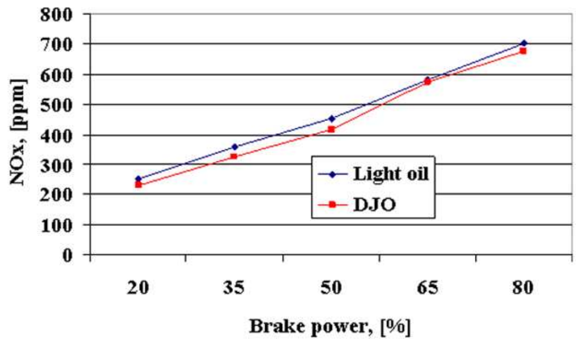

Fig.8. Evolution of NOx emission

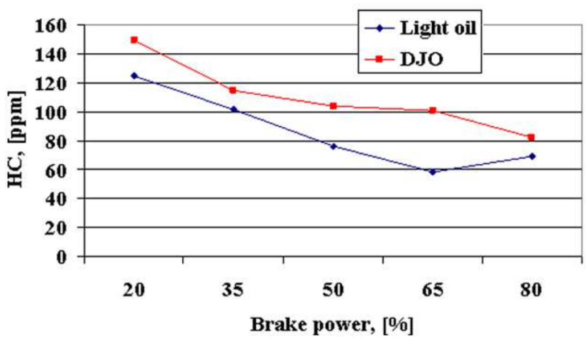

Fig.9. Evolution of HC emission

The NOx emission is related to the combustion temperature. Higher combustion temperature gives more NOx emission. The Figure 8 shows that the values of NOx emission for light oil and DJO are close each to other. These values are increased with increasing of the loads. The values of NOx were varied from 231 ppm to 701 ppm respectively for 20% and 80% loads.

The HC concentration found in exhaust gas is shown in the Figure 9. Jatropha oil exhibits higher HC emissions compared to standard diesel operation. This is because JCO have higher viscosity which causes poor atomization. The poor atomization leads the incomplete combustion and increases more unburned fuel in exhaust gas. The gap of HC density between these two kinds of fuels is in average 22%. The Figure 9 shows for both fuels the drop of HC density when loads are increased. For DJO it changes from 149.4 ppm to 82.24 ppm while for light oil the variation is from 124.37 ppm to 69.2 ppm.

An evolution of the CO2 and O2 emissions with variation of the power loads is shown in Figure 10. The concentrations of the CO2 for light oil and DJO are similar. The values of CO2 for both fuels were increased from 3.04% to 7.51% with increasing of the loads respectively from 20% to 80%. In inverse, the values of oxygen for the both fuels were decreased with increasing of the loads. The amounts of O2 emission for both fuels are very close each to other in range of 16.73% for 20% load and around 10.71% for 80% load. This shows the regular proportion of the combustion product after fuel is burned with oxygen in air.

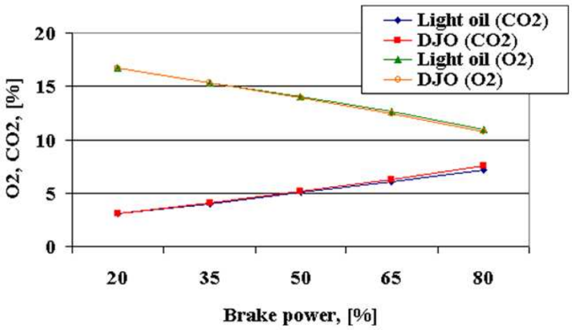

Fig.10. Evolution of CO2 and O2 emissions.

7. CONCLUSIONS

An experimental investigation was conducted to explore the performance of Jatropha oil in diesel engine generator. The improvement results show that roasting seed is squeezed efficiently. Jatropha crude oil can be extracted 30% by weight from the seed. Phosphor remaining in DJO was around 10 ppm. It has been removed by development of water degumming method. The combustion has been improved by rising injection pressure for 16%. The kinematic viscosity of DJO was reduced to around $20mm^2/s$ by using the heat released from cooling water that allows engine operated smoothly.

The results of exhaust gas emission during durability test show that only the amount of CO concentration for DJO was higher than which of light oil, but it is still acceptable for this kind of machine. The values of the other exhaust gas emission for DJO are comparable with light oil. Overhaul check has been done and shown that the engine components are still in normal operational conditions.

The engine performance test provided us very satisfied results which is proven that the higher BSFC and low thermal efficiency of DJO are proportional to it properties as vegetable fuel regarding to fossil fuel, whereas an exhaust gas temperature was presented the similar evolution with the loads. The results of emission test were also acceptable. The amount of NOx, HC, CO2, and O2 gases were very close each to other for both tried fuels, except for CO emission that shown higher at low power load. As mentioned hereinabove it is not exceed 382 ppm. This result seems better comparing to value recorded at durability test.

The durability and performance tests are fully confirmed the possibility of straight use of dephosphorized Jatropha oil as alternative fuel in diesel engine generator. The research and development is continuing to improve the combustion technology and energy efficiency from Jatropha seed oil.

For improvement of the combustion we recommend that the viscosity of DJO should be reduced more than indicated value by modifying heat exchanger. This change is not caused any damage for diesel engine, just to extend the flown time of DJO in heat exchanger.

As mentioned before, we advise to use DJO as fuel for diesel engine generator. In this case we can increase energy balance by using biomass gasification from Jatropha seed cake to mix with DJO for running diesel engine generator. The development of generation technology by mixed combustion of biomass fuel from JCO and Jatropha seed cake is being experimented.

In the near future, we expect that with increasing of the price of the light oil Rural Electrification Entrepreneurs (REE) in remote areas, where Jatropha seeds are available, will refer to use straight DJO or biomass gasification in their power plant to generate electricity. We estimate also, when DJO production is grown, in term of industrial scale, widely practical applications of DJO will be suitable for many kinds of agricultural machines with modification of diesel engine fuel supply system.

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Diagnosis Techniques for Condition Assessment of Power Transformer Load Tap Changer

Juthathip Haema, Rattanakorn Phadungthin, and Thanapong Suwanasri

Abstract— *Power transformers in Thailand are failed mostly due to load tap changer failures. To evaluate the condition of the load tap changer, four categories of diagnostics consisting of contact condition analysis, oil contamination analysis, dielectric property analysis of the insulating oil and dissolved gas analysis are proposed in this work. Catastrophic consequences of the tap changer are caused by its aging mechanisms, which subsequently generate abnormal gases in the insulating oil. Hence, the historical test data of gases dissolved in the load tap changer oil of ten sample transformers rating 230/115 kV 200 MVA and 115/22 kV 50 MVA are selected and analyzed by key gas, ratio, and Duval triangle techniques. The worst case of each transformer group is investigated further by the oil contamination and dielectric property measurements over a period of time. Then the result of this work is useful for planning an appropriate maintenance strategy to keep the load tap changer in acceptable condition.*

Keywords— **Condition assessment, diagnosis techniques, failure statistics, load tap changer, power transformer.**

1. INTRODUCTION

Power transformer is one of significant equipment in power system. Its main function is to transform electrical power from one voltage level to another in order to meet various requirements in the network. As power transformer is very costly, adequate routine maintenance is required. Failure statistics in the last 10 years of the scattering 144 failure events of 71 power transformers rating 115/22 kV 50 MVA in Thailand are shown in Fig.1. The failures of power transformers are caused by aging effects of on load tap changer (OLTC). The main cause of failures from the recorded data is crack. The tap changer aims to modify the voltage ratio of a power transformer by means of adding or subtracting the tapping turns from the main windings. There are two types of OLTC for tap selection and arcing control method. The first part is a selector switch, at which the tap selector and diverter switches are combined together, as shown in Fig. 2(a). The other is so called a diverter switch type, at which both the selector and diverter switches are separately enclosed, as shown in Fig. 2(b). According to current limiting method, OLTC can be classified into two types: reactor and resistor. The first is frequently used for the voltage regulation at the low voltage side of the power transformer [1]. The latter is mainly used on the high voltage side. To eliminate the problem of oil contamination, vacuum interrupters have been introduced and used in both reactor and resistor types as well as for both of the selector and the diverter switch types.

Juthathip Haema and Rattanakorn Phadungthin (corresponding author) are with the College of Industrial Technology (CIT), King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand. Phone: +66-2913-2500 Ext: 2914; Fax: +66-2913-5805; Email: rattanakornp@kmutnb.ac.th.

Thanapong Suwanasri (Dr.-Ing.) is an Assistant Professor at the Sirindhorn International Thai – German Graduate School of Engineering (TGGS), KMUTNB, Thailand.

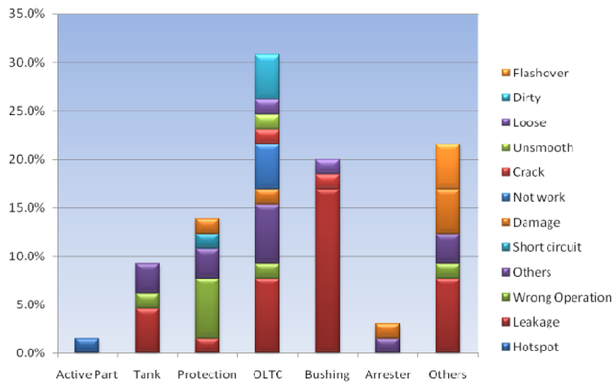
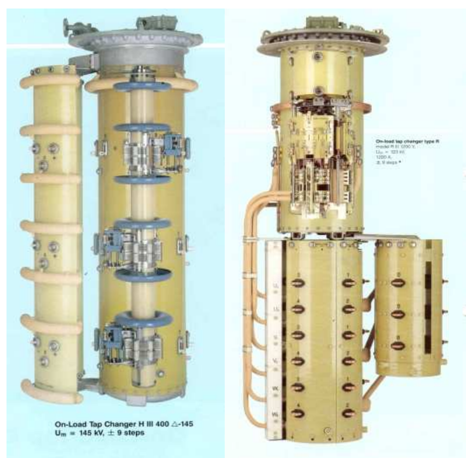


Fig.1. Defective Components and Their Failure Causes of Power Transformer, Rating 115/22 kV 50 MVA.



(a) (b)

Fig.2. Type of On Load Tap Changer [2].
(a) Selector Switch (b) Diverter Switch

However, only reactor type with the selector and the diverter switches is investigated in this paper with proposed diagnostics for the condition evaluation. As a tap changer faces various aging mechanisms, the insulating oil inside the tap changer housing becomes dirty. Moreover, the abnormal gases from arc and heat due to the switching of diverter switch are generated. Thus, the quality of the insulating oil is primarily concerned. Therefore, this paper focuses on condition assessment of OLTC insulating oil of ten transformers rating 230/115 kV 200 MVA and 115/22 kV 50 MVA as examples by applying dissolved gas analysis method with three techniques: key gas, ratio and Duval triangle. The integrity of the insulating oil is firstly checked by the key gas and ratio techniques. The Duval triangle is subsequently used to identify the fault type. Moreover, the investigation on the worst case of each transformer group is performed further by means of the oil contamination as well as dielectric property tests.

2. BASIC KNOWLEDGE

Due to the fact that the condition of tap changer is one of significant causes to an operating performance of power transformer, the condition of the tap changer and the integrity its insulating oil should be evaluated. The diagnosis tests comprise four main groups such as contact condition analysis, oil contamination analysis, dielectric property analysis of the insulating oil, and dissolved gas analysis (DGA). The first three groups of the diagnosis tests are utilized for accessing the condition of the tap changer and its insulating oil. The last, DGA analysis, is applied to identify the possible fault types from gases dissolved in the insulating oil.

2.1 Contact Condition Analysis

Condition of tap changer contact can be assessed by two measurements: transition resistance and contact wear. The limits of these tests are shown in Table 1.

1) Transition Resistance

The measured value of transition resistance is compared to the nameplate value. The maximum limit of deviation for transition resistance is 5% otherwise the contact condition is poor.

2) Contact Wear

The wear of the main switching contacts and the transition contacts is measured in terms of millimeter (mm) per 100,000 tap change operations to evaluate the contact wear condition. If it exceeds 1 mm/100,000 operations, the contact is in poor condition.

2.2 OLTC Oil Contamination Analysis

Condition evaluation of the oil contamination can be performed by two measurements such as color and water content. The limits of these tests are shown in Table 1.

1) Color

Color is represented by a number, which is compared with color standard to assess whether or not the oil is contaminated. Poor condition is represented by high color number. The maximum limit of the color number for the load tap changer is 5.5 for all high voltage transformer ratings.

2) Water Content

Some water content always occurs in the transformer when the oil is service-aged. This accelerates a degradation of transformer insulation and decreases transformer cooling efficiency [3]. The maximum water content in the insulating oil for all high voltage transformer ratings is 45 parts per million (ppm).

2.3 Dielectric Property Analysis of OLTC Insulating Oil

Two measurements consisting of dielectric strength and power factor are used to analyze dielectric property of OLTC insulating oil. The limit values are presented in Table 1.

1) Dielectric Strength

Dielectric strength or dielectric breakdown voltage measures the ability of the insulating oil to withstand the electrical stress. The low value of breakdown voltage implies that the oil has been contaminated by a large amount of particles. Referred to the standard ASTM D1816 with 2 millimeter gap, the acceptable minimum breakdown voltage is 30 kV for all power transformers.

2) Power Factor

Power factor indicates the dielectric loss in the insulating oil. A high power factor means deterioration and/or contamination of the oil. As the power factor value is dependent on temperature, the measured values should be converted to the reference temperature 20ºC by a correcting factor (CF). The value above or equal to 1.0 indicates poor condition of dielectric property [4].

Table 1. Limit Value of Each Diagnostic Test

Analysis	Diagnostic Test	Limit Value	
OLTC Contact	Transition Resistance (%Deviation)	≤ 5	Good
		> 5	Poor
	Contact Wear (mm/100,000 operations)	≤ 1	Good
		> 1	Poor
OLTC Oil Contamination	Color	< 1.0	Good
		1 - 5.4	Suspect
		≥ 5.5	Poor
	Water Content [ppm]	< 20	Good
		20 - 44	Suspect
		≥ 45	Poor
OLTC Dielectric Property	Dielectric Strength [kV]	≥ 46	Good
		31 - 45	Suspect
		≤ 30	Poor
	% Power factor at 20 °C	≤ 0.05	Good
		0.06 -0.9	Suspect
		≥ 1.0	Poor

2.4 OLTC Dissolved Gas Analysis

Dissolved gas analysis, so called DGA, is a well-known technique for insulating oil analysis to identify incipient faults inside transformers before catastrophic damages occur [5]. Nowadays, it becomes one of routine measurements for all power transformers. The DGA of

OLTC, insulating oil used in the analysis, consists of three techniques as key gas, ratios and Duval triangle. The key gas method is primarily used to evaluate the condition of the insulating oil by applying scoring and weighting technique. The scoring is utilized for condition classification into three levels: good, suspect and poor. The weighting is determined according to the importance of each gas. The oil condition is eventually presented by color indicators: green indicating good condition for 0-40% DGA factor (DGAF), yellow indicating fair condition for 41%-60%, and red indicating poor condition for 61%-100%. Subsequently, the ratio method is used to evaluate the oil condition according to its specified good and poor limits. Finally, the Duval triangle technique is applied to identify the fault type.

1) Key Gas Method

The four key gases are CH_4 (Methane), C_2H_6 (Ethane), C_2H_4 (Ethylene) and C_2H_2 (Acetylene). The limit values of each key gas for OLTC are summarized in Table 2 [6]. Working procedure of the oil condition evaluation is shown in Fig. 3. The abbreviation "n" is 4 because of 4 types of key gases.

Table 2. Limit Value of Each Key Gas for OLTC Oil

Type	Si					Wi
	Gas	1 Good	2	3	4 Poor	
Vacuum	CH_4	<30	30-50	50-100	≥100	3
	C_2H_6	<20	20-30	40-50	≥50	3
	C_2H_4	<50	50-100	100-200	≥200	4
	C_2H_2	<3	3-4	4-5	≥5	5
Resistive	CH_4	<100	100-200	200-300	≥300	3
	C_2H_6	<50	50-100	100-200	≥200	3
	C_2H_4	<200	200-400	400-600	≥600	5
	C_2H_2	<500	500-1000	1000-5000	≥500	3
Reactive (Diverter Comp.)	CH_4	<200	200-300	300-700	≥700	3
	C_2H_6	<100	100-150	150-500	≥500	3
	C_2H_4	<300	300-500	500-1400	≥1400	5
	C_2H_2	<1000	1000-3000	3000-7500	≥7500	3
Reactive (Selector Comp.)	CH_4	<50	50-150	150-250	≥250	3
	C_2H_6	<30	30-50	50-100	≥100	3
	C_2H_4	<100	100-200	200-500	≥500	5
	C_2H_2	<10	10-20	20-25	≥25	3

2) Ratio Method

The five combustible gases dissolved in the insulating oil and used for ratio calculation are H_2 (Hydrogen), CH_4 (Methane), C_2H_6 (Ethane), C_2H_4 (Ethylene), and C_2H_2 (Acetylene). The ratios and their limits are shown in Table 3.

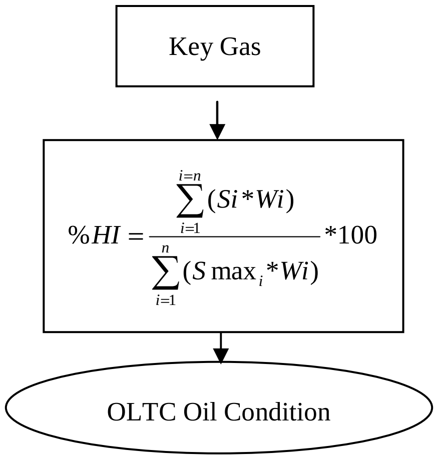
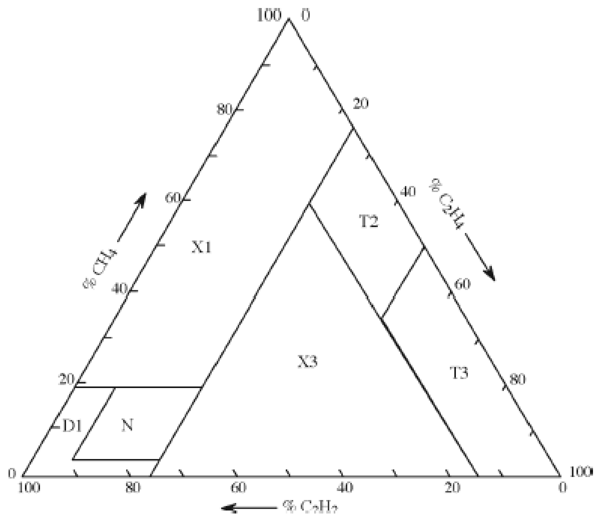


Fig. 3. Working Procedure of OLTC Oil Condition Evaluation by Key Gas Method.

Table 3. Limit Value of Each Ratio for OLTC Oil

Gas Ratio	Limit Value	
1. Ratio1: $(CH_4+C_2H_6+C_2H_4)$ / $(H_2+CH_4+C_2H_4+C_2H_2+C_2H_6)$	<0.5	Good
	≥0.5	Poor
2. Ratio 2 : $(CH_4+C_2H_6+C_2H_4)/(C_2H_2)$	<2.0	Good
	≥2.0	Poor
3. Ratio 3 : (C_2H_4/C_2H_2)	<1.0	Good
	≥1.0	Poor



Fault Codes:

N: Normal Operation

T2: Severe thermal fault (300-700ºC), coking

T3: Severe thermal fault (above 700ºC), heavy coking

X1: Abnormal arcing or thermal fault in progress

X3: Fault T3 or T2 in progress (mostly) with light coking or increased resistance of contacts. Or, severe arcing

D1: Abnormal Arcing

Fig. 4. Coordinate and Fault Zones of the Duval Triangle for Oil Type Load Tap Changer.

3) Duval Triangle Method

The Duval triangle method concerns only three hydrocarbon gases: CH_4, C_2H_4, and C_2H_2. Concentrations in ppm of the gases are expressed as percentages of the total of CH_4+C_2H_4+C_2H_2 and plotted as a coordinated point of %CH_4, %C_2H_4, and %C_2H_2 in a Duval triangle. Fig. 3 shows several fault types of the Duval triangle for load tap changers of oil type [7].

3. ANALYSIS AND TEST RESULTS

The available historical test data of OLTC insulating oil of ten sample transformers rating 230/115 kV 200 MVA and 115/22 kV 50 MVA are selected in the analysis. Firstly, the data in 2009 of the first group including five sample 200 MVA transformers is analyzed by the DGA method with three different techniques. It is followed by focusing on the worst case by means of oil contamination and dielectric property tests. After that the second group data in 2009 of five sample 50 MVA transformers is analyzed with a similar procedure.

3.1 The First Group of Transformers with 200 MVA

1) OLTC Insulating Oil Condition of Five Sample Transformers

According to the DGA test result of the 200 MVA transformers shown in Table 4, concentrations in ppm of gases dissolved in the oil of all five transformers are very high. To interpret the result, three techniques of the DGA method are applied.

Table 4. DGA Result of the First Transformer Group

Tx \ Gas	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6
Tx1	14349	7033	14939	40138	11437
Tx2	220	1141	2375	4539	644
Tx3	27977	6861	15303	20333	4022
Tx4	12688	5249	11417	21286	3661
Tx5	19749	6283	12146	20767	3690

- ***Key Gas Technique***

The %DGAF is obtained from the calculation of OLTC insulating oil condition. The obtained results are that the %DGAF of four transformers equals 100% while the other is 89%. This implies very poor condition of the insulating oil for all sample transformers represented by red color indicators.

- ***Ratio Technique***

The results of three ratios calculated by using the concentration in ppm of three gases generated in the oil are shown in Fig. 5. It can be seen that three transformers which are Tx1, Tx2 and Tx4 encounter critical OLTC oil problem as their three ratio values exceed the limits.

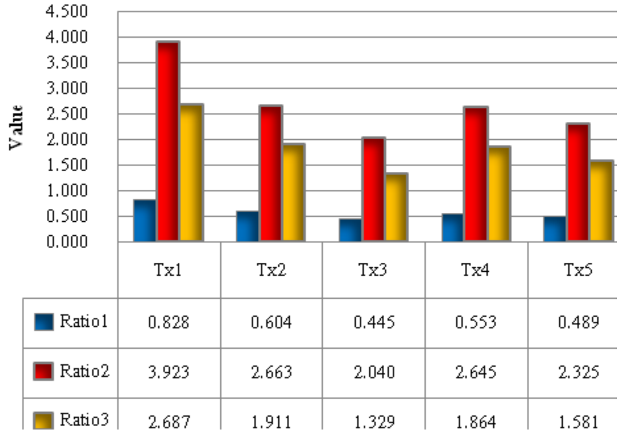


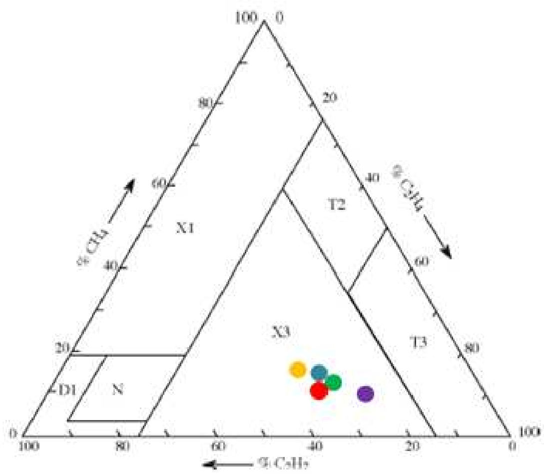
Fig.5. Ratio Values of Dissolved Gases of the First Transformer Group.

Table 5. Percentage of Duval Gases of the First Transformer Group

Key Gas \ Tx	Tx1	Tx2	Tx3	Tx4	Tx5
%C_2H_2	24.052	29.485	36.010	30.083	32.877
%C_2H_4	64.624	56.350	47.846	56.087	51.971
%CH_4	11.323	14.165	16.145	13.831	15.152

- ***Duval Triangle Technique***

The percentages of three gases in the Duval triangle technique are represented in Table 5. By plotting these percentages of five sample transformers in the Duval triangle, all coordination points are in X3 zone as shown in Fig. 6. It means that the OLTC should be inspected for light coking sign or resistance of contacts or severe arcing.



Purple = Tx1, Green = Tx2, Orange = Tx3, Red = Tx4, and Blue = Tx5

Fig.6. Duval Triangle of the First Transformer Group.

All oil conditions of the first transformer group, which are assessed by three distinguish techniques of the DGA methods, are summarized in Table 6.

Table 6. OLTC Oil Condition by the DGA Method of the First Transformer Group

Test \ Rated		200MVA				
		Tx1	Tx2	Tx3	Tx4	Tx 5
Key Gas Method		R	R	R	R	R
Ratio Method	Ratio1	R	R	G	R	G
	Ratio2	R	R	G	R	R
	Ratio3	R	R	R	R	R
Duval Triangle Method		X3	X3	X3	X3	X3

R=Red or poor condition and G=Green or good condition

2) OLTC Insulating Oil Condition of the Worst Case of the 200 MVA Sample Transformers (Tx1)

- ***Oil Contamination Test***

The test results of color and water content during 2006-2009 of Tx1 are shown in Table 7. It is seen that the values of water content have been in suspect condition since 2006, but poor condition occurs in July 2009. The values of color have been zero, which were within the limit. However, the water content results imply that the insulating oil of this transformer is contaminated with water and other particles.

Table 7. Oil Contamination Test Result of 200 MVA Tx1

Diagnostic Test Result for Oil Contamination		
Date	Color	Water Content [ppm]
19/04/2006	0	37
19/09/2007	0	32
26/11/2007	0	38
24/06/2008	0	42
04/06/2009	0	33
13/07/2009	0	45

Table 8. Dielectric Property Test Result of 200 MVA Tx1

Diagnostic Test for Oil Contamination		
Date	Break Down Voltage	%PF
04/05/2003	37.30	0.01
21/12/2004	28.46	0.01
04/06/2006	45.42	0.03
11/03/2007	41.98	0.04

- ***Dielectric Property Test***

The results of dielectric strength and power factor tested during 2003-2007 are presented in Table 8. The values of dielectric strength have mostly been in suspect condition, but in 2004 the condition was poor. In addition, the values of power factor corrected at 20ºC seemed to increase over time even in good condition. These results indicate that the insulating oil of the transformer faces the problem of withstanding the electrical stress due to oil contamination with particles.

3.2 The Second Group of Transformers with 50 MVA

1) OLTC Insulating Oil Condition of Five Sample Transformers

The DGA test result of the 50 MVA transformers is shown in Table 9. The number of gas concentration in ppm dissolved in the insulating oil of these five sample transformers is very high when compared to their limits. Three techniques of the DGA method are applied for result interpretation.

Table 9. DGA Result of the Second Transformer Group

Tx \ Gas	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6
Tx1	7227	1713	15239	3243	307
Tx2	11032	2636	2208	2440	220
Tx3	33971	26250	19924	31197	6189
Tx4	3899	542	4877	1024	172
Tx5	8888	2269	207	887	299

- ***Key Gas Technique***

As the very high concentration of combustible gases, the calculated %DGAF is 100% as very poor condition for all five sample transformers. This indicates that these transformers must be immediately inspected to avoid severe problem.

- ***Ratio Technique***

The calculated results of three ratios are shown in Fig. 7. The result shows that the most critical tap changer condition is TX3 with all out-of-limit ratios. It is clearly seen that Tx5 may face a problem of its OLTC insulating oil because the value of second ratio is very high.

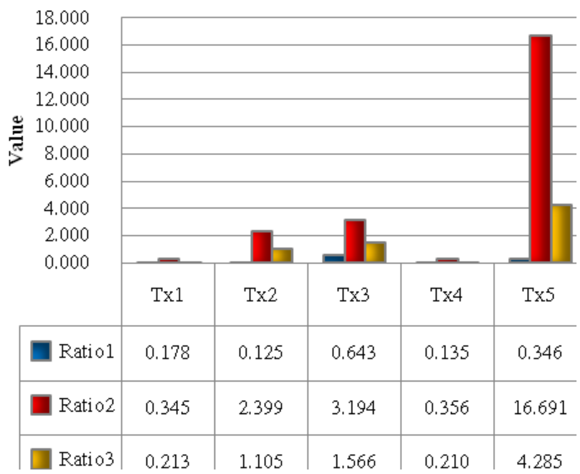


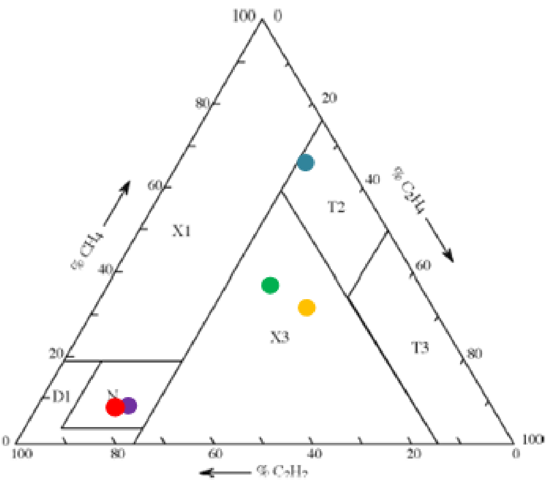
Fig.7. Ratio Values of Dissolved Gases of the Second Transformer Group.

- ***Duval Triangle Technique***

Referred to the percentages of Duval gases in Table 10, the coordinated points of Tx2 and Tx3 are in X3 zone, indicating arcing problem. The coordination of Tx1 and Tx4 are in N-zone indicating normal operation, while Tx5 is in T2 indicating severe thermal fault.

Table 10. Percentage of Duval Gases of the Second Transformer Group

Key Gas \ Tx	Tx1	Tx2	Tx3	Tx4	Tx5
$\%C_2H_2$	75.459	30.313	25.751	75.695	6.155
$\%C_2H_4$	16.058	33.498	40.321	15.893	26.375
$\%CH_4$	8.482	36.189	33.927	8.412	67.470



Purple = Tx1, Green = Tx2, Orange = Tx3, Red = Tx4, Blue = Tx5

Fig.8. Duval Gases of the Second Transformer Group.

The oil conditions of the second transformer group by three different techniques of the DGA methods are accessed and summarized in Table 11.

Table 11. OLTC Oil Condition by the DGA Method of the Second Transformer Group

Test \ Rated		50MVA Tx1	Tx2	Tx3	Tx4	Tx5
Key Gas Method		R	R	R	R	R
Ratio Method	Ratio1	G	G	R	G	G
	Ratio2	G	R	R	G	R
	Ratio3	G	R	R	G	R
Duval Triangle Method		N	X3	X3	N	T2

2) OLTC Insulating Oil Condition of the Worst Case of the 50 MVA Sample Transformers (Tx3)

- ***Oil Contamination Test***

As seen from Table 12, the values of water content have been in good condition since 2008. These results show that the transformer did not face the problem of oil contamination.

Table 12. Oil Contamination Test Result of 50 MVA Tx3

Diagnostic Test for Oil Contamination		
Date	Color	Water Content
19/03/2008	0	9
08/04/2008	0	8
11/03/2009	0	10

- ***Dielectric Property Test***

The available results of dielectric strength and power factor were recorded during 2004-2008 and summarized in Table 13. The value of the dielectric strength was in good condition in 2007. After that it decreases to suspect condition in 2008. For power factor values corrected at 20ºC, the data is not available for the analysis. These results referring to the dielectric strength imply that the insulating oil of the transformer should be taken care.

Table 13. Dielectric Property Test Result of 50 MVA TX3

Diagnostic Test for Oil Contamination		
Date	BD	%PF
10/02/2004	42.32	N/A
27/02/2006	44.82	N/A
21/02/2007	46.32	N/A
06/02/2008	42.46	N/A

4. CONCLUSION

Condition evaluation of power transformer load tap changer can be accessed by four diagnostic techniques: OLTC contact, oil contamination, dielectric property and DGA. Due to available historical OLTC test results, the data of reactor type with the selector and the diverter switches is used in the analysis by applying the proposed diagnostics. First of all, the insulating oil conditions of ten transformers rating 230/115 kV 200 MVA and 115/22 kV 50 MVA are assessed by the DGA method with key gas and ratio techniques. The Duval triangle is subsequently applied to identify the fault type. It is clearly seen that only one technique is not recommended to detect faults inside the transformer. After that the investigation on the worst two cases is additionally performed by using the oil contamination and dielectric property tests. Therefore, according to the known condition and specific problem of power transformers OLTC, it is recommended that maintenance strategy and time interval should be planned to diminish catastrophic damage occurrence to the power transformer and its network. As the OLTC condition evaluation is still further researched in the utility in Thailand for getting higher reliability, all proposed techniques except Duval triangle are used in practice now. The triangle is optional because it is one of popular techniques in the world. Among the proposed techniques, the DGA with key gas technique is more popular in practice although it is much more expensive tool than the others. Furthermore, after some transformers in the network are untanked and the inspection is done, it seems that the ratio method might be unreliable technique whereas other techniques should be combined together to increase the reliability of the analysis.

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A Multi-objective Optimal Placement of Multi-Type DG for Enhancement of Power System Performance by NSGA-II

Kittavit Buayai, I Made Wartana, Sasidharan Sreedharan, and Weerakorn Ongsakul

Abstract— *This paper proposes a multi-objective optimal placement of multi-type distributed generator (DG) for enhancement of power system performance. A Pareto-based non-dominated sorting genetic algorithm II (NSGA-II) is proposed to determine locations and sizes of specified number of DG units within the power network. Three objective functions are considered as the indexes of the system performance: maximization the Normal Operation Loadability (NOL) (i.e. the maximum loading which can be supplied by the system while the voltages at all nodes and transmission lines loading are kept within the limits), minimization of the system real power loss and minimization of the annualized investment costs of DG. A fuzzy decision making analysis is used to obtain the final trade off optimal solution. The proposed methodology has been tested on modified IEEE 14-bus system. Test results indicate that NSGA-II is a viable planning tool for practical DG placement in improving the steady state system performance of the power system by the optimal allocation, setting and sizing multi-type DG.*

Keywords— **Distributed Generation, Multi-objective optimization, NSGA-II, PSAT, System loadability.**

1. INTRODUCTION

Distributed generators (DG), based on renewable energy technologies are becoming popular as they address climate change and energy security issues to some extent. Renewable energy based DGs do not contribute to GHG emission and also diversity of sources also increases due to different renewable energy options that address energy security concerns. Apart from climate change and energy security concerns, there are other driving forces for increasing penetration of DG in distribution system [1]. There are a number of technical benefits that the DG can bring such as better voltage profile, loss reduction and reliability improvement.

Several approaches to solve the DG siting and sizing problem in distribution system have been proposed. In [2], they use evolutionary programing approach for optimal placment and size of DG in a radial feeder. The objective is minimize the system real power loss, hybrid distributed generation for a mixed realistic load model is consdered. A technique to determine optimal location and sizing of DG units in a MG based on loss sensitivity factor and priority list compare with analytical approach is developed by [3]. A simple methodology for placing a distributed generator with the view of increasing the loadability of the distribution system is presented in [4]. In [5], they use exact loss formula for optimal placement and size of DG in radial distribution system. The objective is minimizingthe system real power loss, loadability and voltage stability index. A Genetic Algorithm (GA) combined with power analysis to evaluate DG impacts in system power losses and voltage profile for radial network. The fuzzy power flow is presented in [6]. In [7] DG siting and sizing problem is fulfilled to compromise multi-objective function consisting of energy not-supplied cost, improving cost of network and energy loss cost. In [8, 9], DG siting and sizing problem in distribution network are analyzed to improve only power loss by particle swarm.

From the previous work, we can conclude that the most of the problem of optimal placement and sizing of DG is generally formulated as single-objective optimization problems that optimize a single objective function or transform several objectives to a single objective by aggregating them. Two the most common used of this optimization are the weighted sum method and the ε-constrained method [10]. More study is required to define adequate weights and master objectives, respectively, and the problem is demanding high computational effort. Therefore, multiple objective optimizations are needed in DG placement.

This paper proposes a multi-objective optimal placement of multi-type of DG for enhancement of power system performance. A Pareto-based NSGA-II is proposed to find locations and sizes of a specified number of DG within Power system. Multi-objective functions include maximize NOL within system security margin, minimize system real power loss and annualized investment cost. The final decision will be made by the fuzzy method to find the tradeoff solutions among three different objective functions.

The rest of this paper is organized as follows: Section 2 illustrates the DG placement problem formulation. Section 3 presents a NSGA-II approach for the DG placement. Results and discussions are presented in Section 4. Section 5 summarizes the conclusion and contribution of the paper.

2. DG PLANNING PROBLEM FORMULATION

The normal operation of power system presupposes that

Kittavit Buayai (corresponding author), I Made Wartana, Sasidharan Sreedharan, and Weerakorn Ongsakul are with Energy Field of Study, School of Environment, Resoureces and Development, Asian Institute of Technology, Pathumthani 12120, Thailand. Email: st104642@ait.ac.th.

a number of constraint parameters are maintained within predetermined bounds of which the most significant ones are voltage and frequency. The quality of interconnected operation of DG to the grid is specified in terms of operational constraints. DG cluster is assumed to be under the direct supervision and control of the utility operators. The system design assures that there is only unidirectional power flow from DG to the grid and there is safe operation in the event of fault conditions on both sides (DG and grid) by using suitable protection devices. The harmonics analyses are not considered. The model study is conducted in MATLAB - PSAT environment using NSGA-II algorithm. The multi-objective optimization technique to determine the optimal locations and sizes of DG units within power system is as follows:

2.1 Multi-objective

$$\text{Min} \quad f(x) = [\,f_1(x),\ f_2(x),\ f_3(x)] \tag{1}$$

where f_1, f_2 and f_3 represent : normal operation loadability, system real power loss, and annualized investment cost respectively.

2.1.1 Maximize the normal operation loadability

$$Max \quad f_1(x,u) = \{\lambda\} \tag{2}$$

$$\text{Subject to } VL = \sum_{j=1}^{N_E} BVV_j + \sum_{i=1}^{N_L} OLL_i \tag{3}$$

where VL is the bus violations and thermal limit factors, BVV_j and OLL_i represent the bus voltage violation factor and the overloaded line factor respectively and will be expatiated on later; N_E and N_L are the total load buses and numbers of transmission lines respectively; and λ is a loading parameter of the system, i.e. a scalar variable which multiplies the load direction as follows:

$$P_{Di}(\lambda) = \lambda P_{D0i} \tag{4}$$

$$Q_{Di}(\lambda) = \lambda Q_{D0i} \tag{5}$$

If the $\lambda = 1$, indicates the base load case. The NOL is the maximum loading which can be supplied by the system while the voltages at all nodes and the all branches loading are kept within the limits.

The NOL constrain contains two parts. The first part, BVV_j in (3) concerns the voltage levels for each bus of the power network. The value of BVV_j is defined as:

$$BVV_j = \begin{cases} 1; & \text{if } 0.9 \le V_b \le 1.1 \\ \exp\left(\Gamma_{BVV} \left|1 - V_b\right|\right); & \text{otherwise} \end{cases} \tag{6}$$

where BVV_j is the bus voltage violation factor at bus j and Γ_{BVV} represents the coefficient used to adjust the slope of the exponential function in the above equation. The equation indicates that appropriate voltage magnitudes are close to 1 p.u. The value of BVV_j equals to 1 if the voltage level falls between the voltage minimal and maximal limits. Outside the range, BVV_j increases exponentially with the voltage deviation.

The second part, OLL_i, relates to the branch loading and penalizes overloads in the lines. Similar to BVV_j, The value of OLL_i equals to 1 if the jth branch loading is less than its rating. OLL_i increases logarithm (actual logarithm) with the overload and it can be calculated from:

$$OLL_i = \begin{cases} 1; & \text{if} \quad P_{ij} \le P_{ij}^{\max}, \\ \exp\left(\Gamma_{OLL}\left|1 - \dfrac{P_{ij}}{P_{ij}^{\max}}\right|\right); & \text{if} \quad P_{ij} \ge P_{ij}^{\max}, \end{cases} \tag{7}$$

where P_{ij} and $P_{ij}^{\max}$ are the real power flow between buses i and j and the thermal limit for the line between buses i and j respectively. Γ_{OLL} is the coefficient which is used to adjust the slope of the exponential function.

2.1.2 Minimize the system real power loss

$$Min \quad f_2(x,u) = P_L \tag{8}$$

2.1.3 Minimize the annualized Investment Cost

$$Min \quad f_3(x,u) = \sum_{i=1}^{N_{DG}} AF_i \times UC_i \times C_{DGi,\max} \tag{9}$$

The annualized investment cost of DG unit i is assumed to be proportional with the maximum rating of DG, where the unit cost UC_i is in (\$/KVA). The UC_i is different for different type of generating units. The total of investment cost is transformed to cash value in the beginning of the planning period by using economical expression (i.e. annual cost based on certain interest rate and life span). AF_i is the annualized factor associated with the installation cost (annual cost based on certain interest rate 'i' and life span 'T') as shown in (10).

$$AF_i = \frac{(i/100)(1+i/100)^T}{(1+i/100)^T - 1} \tag{10}$$

2.2 Dependent and Control Variables

In the three objective functions, **x** is the vector of dependent variables such as slack bus power P_{G1}, load bus voltage V_L, generator reactive power outputs Q_G and apparent power flow S_k. **x** can be expressed as:

$$\mathbf{x}^T = [P_{G1}, V_{L1} \ldots V_{L_{NB}}, Q_{G_1} \ldots Q_{G_{NG}}, S_1 \ldots S_{N_L}] \tag{11}$$

Furthermore, **u** is a set of the control variables such as generator real power outputs P_G except at the slack bus P_{G1}, generator voltages V_G, the locations of DG units, L, and their setting parameters. **u** can be expressed as:

$$\mathbf{u}^T = [P_{G_2} \ldots P_{G_{NG}}, P_{DG}, V_{G_1} \ldots V_{G_{NG}}, L_1 \ldots L_{N_F}, \; Q_{S_1} \ldots Q_{S_{N2}}, \lambda] \tag{12}$$

where N_F is the total number of DG devices to be optimally located, and N_1 to N_2 are the total numbers of PV and MT respectively. The equality and inequality constraints of the NRPF problem incorporating DG are given bellow.

2.3 Equality Constraints

These constraints represent the typical load flow equations as follows:

$$\begin{cases} \sum_{i=1}^{N} P_{Gi} = \sum_{i=1}^{N} P_{Di} + P_L \\ \sum_{i=1}^{N} Q_{Gi} = \sum_{i=1}^{N} Q_{Di} + Q_L \end{cases} \tag{13}$$

where N is the number of buses, P_{Gi} and Q_{Gi} are real power reactive power generated by generating unit i (including slack bus) respectively, in MW.

2.4 Inequality Constraints

The inequality constraints are limits of control variables and state variables. Generator active power P_G, reactive power Q_G and voltage V_G are restricted by their limits as follows:

$$\begin{cases} P_{DGi,\min} \le P_{DGi} \le P_{DGi,\max} \\ Q_{DGi,\min} \le Q_{DGi} \le Q_{DGi,\max} \\ |V_i|_{\min} \le |V_i| \le |V_i|_{\max} \\ |P_{bi}| \le P_{bi,\max} \end{cases} \tag{14}$$

The load factor λ is constrained by its limits as:

$$0 \le \lambda \le \lambda^{\max} \tag{15}$$

2.5 Distributed Generation Model

DG units are modeled as synchronous generators for small hydro power, geothermal power, combined cycles and combustion turbines. They are treated as induction generators for wind and micro hydro power. DG units are considered as power electronic inverter generators such as micro gas turbines, solar power, photovoltaic power and fuel cells [11]. In general, DG can be classified into four types:

- Type 1: DG capable of injecting constant P only (PV)
- Type 2: DG capable of injecting both P and Q (Micro Turbine)
- Type 3: DG capable of injecting constant P but consumes Q (Wind Turbine)
- Type 4: DG capable of delivering Q only (Synchronous condenser).

3. NSGA-II FOR DG PLACEMENT

A NSGA-II combined with NRPF based on PSAT [12] is used to solve multi-objective optimization to identify appropriate sizes and locations of a specified number DG unit within power system. The fitness function for the above problem can be written as

$$f(x) = [\, f_1(x),\, f_2(x),\, f_3(x)] + \sum_{kp=1}^{N_k} (Pf_{kp} * U_{kp}) \tag{16}$$

The final trade off solution is determined by the fuzzy method.

3.1 NSGA-II Algorithm

In case of multiple conflicting objectives, there may not exist one solution which is the best compromise for all objectives. Therefore, a “trade-off” solution is needed instead of a single solution in multi-objective optimization. Non-dominated sorting genetic algorithm (NSGA) uses nondominated sorting and sharing has not been widely used mainly because of (i) high computational complexity, (ii) nonelitism approach and (iii) the need for specifying a sharing parameter. NSGA-II is developed to overcome these difficulties [13],[14].

NSGA-II is one of the most efficient algorithms for multi-objective optimization on a number of benchmark problems [14]. In addition, with NSGA-II based approach, the multi-objective of MG planning is retained without the need for any tunable weights or parameters. As a result, the proposed methodology is applicable to solving microgrid planning in a distribution network. NSGA-II has been developed to determine locations and sizes of DG units within MG area. The NSGA-II procedure can be found in [14] and may be stated as follows:

Step 1: Create a random parent population of size N;

Step 2: Sort the population based on the nondomination;

Step 3: Assign each solution a fitness (or rank) equal to its nondomination level (minimization of fitness is assumed);

Step4: Use the usual binary tournament selection, recombination, and mutation operators to create a new offspring population of size N;

Step 5: Combine the offspring and parent population to form extended population of size 2N;

Step 6: Sort the extended population based on nodomination;

Step 7: Fill new population of size N with the individuals from the sorting fronts starting from the best;

Step 8: Invoke the crowding comparison operator to ensure diversity if a front can only partially fill the next generation (This strategy is called “niching”);

Step 9: Repeat the steps 2 to 8 until the stopping criterion is met. The stopping criterion may be a specified number of generations.

It is clear from the above description that NSGA-II uses (i) a fast non-dominated sorting approach, (ii) an elitist strategy, and (iii) no niching parameter [14].

For each iteration k do:

1) $R^k = P^k \cup Q^k$ (combine parent and offspring population)
2) $F = non\_dom\_sort\left(R^k\right)$ (Application the non-dominated sorting on k R^k)
3) $P^{k+1} = \Phi$ & $i = 1$
4) until $\left|P^{k+1}\right| + \left|F_i\right| \le N$ (until the parent population is filled)
   a. *i=i+1*
   b. Calculate the crowding distance for each particle in F_i
   c. $P^k = P^{k+1} \cup F^i$
5) Sort (F_i) (sort in descending order)
6) $\left|P^{k+1}\right| = \left|P^{k+1}\right| \cup F_i\left(N - \left|P^{k+1}\right|\right)$ (Choose the first $N - \left|P^{k+1}\right|$ elements of F_i)
7) Q^{k+1} (use selection, crossover and mutation to create a new population with using P^{k+1}) \
   k=k+1

3.2 Fuzzy Method for Best compromise Solution

Once the Pareto optimal set is obtained, it is practical to select one solution from all solutions that satisfies different goals to some extent. Such a solution is the best compromise solution. In this paper, a simple linear membership function is considered for each of the objective functions. The membership function is defined as follow [15].

$$\mu_{f_i}(z) = \begin{cases} 1 & f_i(z) \le f_i^{\min} \\ \dfrac{f_i^{\max} - f_i(z)}{f_i^{\max} - f_i^{\min}} & f_i^{\min} < f_i(z) < f_i^{\max} \\ 0 & f_i(z) \ge f_i^{\max} \end{cases} \qquad (17)$$

The membership function $\mu_{f_i}(z)$ is varied between 0 and 1, where $\mu_{f_i}(z) = 0$ indicates incompatibility of the solution with the set, while $\mu_{f_i}(z) = 1$ means full compatibility. Figure 1 illustrates the graph of this membership function.

The compromised solution can be found by using the normalized membership function [16]. For each non-dominated solution k, the normalized membership function μ^k is calculated as:

$$\mu^k = \frac{\sum_{i=1}^{N_{obj}} \mu_i^k}{\sum_{k=1}^{M}\sum_{i=1}^{N_{obj}} \mu_i^k} \qquad (18)$$

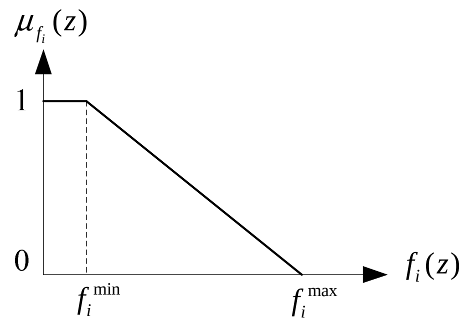

Fig. 1. Linear type membership function.

In all optimization problems several cases in terms of use of

Multi-type DG is considered namely:

(1) Base case (without DG).
(2) Case 1: PV only.
(3) Case 2: GT only.
(4) Case 3: coordinated PV and GT.

4. SIMULATIONS

4.1 Analytical Tool and Test System

The load flow analysis used NRPF based on PSAT [12]. Multi-objective optimization problem is solved by NSGA-II.

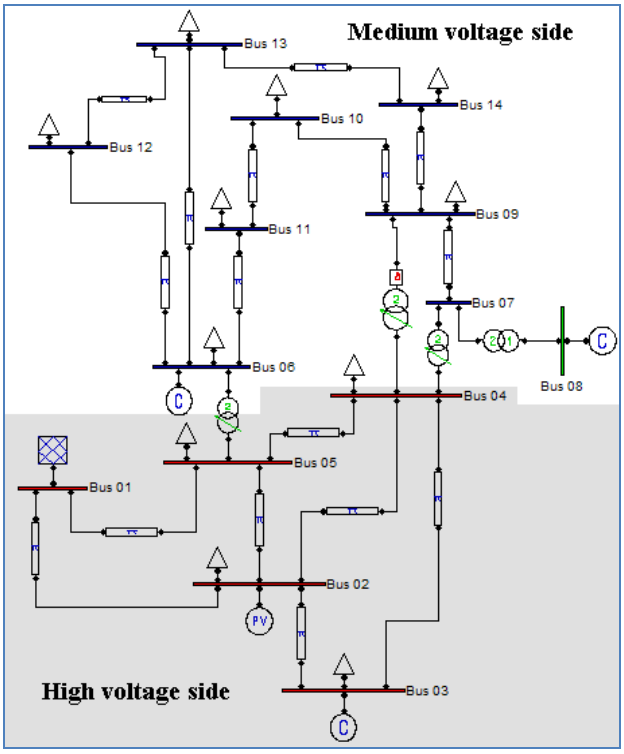

Fig. 2. The IEEE 14-bus test system.

The power system is the modified IEEE 14-bus test system [12, 17], which consists of two generators, located at bus 1 and 2; three synchronous compensators used only for reactive power support at buses 3, 6 and 8. The system has 11 loads totaling 362.6 MW and 113.96

MVAR, real and reactive load respectively. The IEEE 14-bus test system is depicted in Figure 2.

4.2 Assumptions and Constraints

In this section, it is assumed that:

- Loads are typically represented as constant PQ loads with constant power factor, and increased according to (4) and (5).

- NOL constrains are $0.9 \leq V_b \leq 1.1$ and $S_b \leq 100.0 MVA$

- The maximum allowable number of DG is two.

- DG placement is not allowed at the same bus.

- All DG resources are evenly distributed within medium voltage area of system.

- Limitation of DG capacity taken into account (as shown on Table A.1 in Appendix), in this paper is not dependent on the category but depend on the total demand of considered power system.

4.3 Evaluation of DG placement within power system

The decision variables considered, are the location and setting of DG units. The DG should be formed at medium voltage side (13.8 kV), consisting of buses 6, 7, 9, 10, 11, 12, 13, and14. The NSGA-II combined with NR approach is maximized the NOL loadability (f_1), minimizing system real power loss (f_2), and annualized investment cost (f_3). The best parameters for the NSGA-II, selected through ten runs, are given in Table 1. Parameters of all DGs are shown in Table A.I in Appendix. The number of DG to be installed will be initially specified to two. Simulations have been carried out for optimal placement and size of DG in 3 different DG configurations compared to the base case (without DG) as shown in Table 2.

Table 1. NSGA-II parameters

Population	Generation	Pool size	Tour Size	η_c	η_m
100	100	25	2	20	20

4.3.1 Case 1: PV only

The best configuration plan of DG within MG is found at buses 10 and 14 with sizes of 0.7531p.u.(75.31MW) and 0.2614 p.u. (26.14 MW), respectively. The process has been repeated for all the three cases and compare to base case as shown in the Table 2. Figure 3 shows the Pareto front, in the objective function space (objective function NOL, system loss and annualized investment cost) for PV only. This set of solutions on the non-dominated frontier is used by the decision maker as the input to select a final compromise solution by using the normalized membership function in (17).

Table 2. Comparison of the results of the 3 caseses to the base case

Cases	Objectives	Best Compromise
Base Case	NOL(pu)	0.85
	RPL (pu)	0.327
PV only (case 1)	Location (bus)	10,14
	Setting (P,Q) in pu	(0.7531,0), (0.2614,0)
	NOL (pu)	1.0211
	RPL (pu)	0.1710
	C_1(million \$/year)	0.2165
MT only (case 2)	Location (bus)	6,9
	Setting (pu)	(0.9612,0.1207),(1.7033 ,0.3411)
	NOL (pu)	1.1261
	RPL (pu)	0.0992
	C_2 (million \$/year)	0.5701
Coordinated PV and MT (case 3)	Location (bus)	14,7
	Setting (pu)	(0.400,0),(1.7090,0.592 3)
	NOL (pu)	1.0464
	RPL (pu)	0.1071
	$C_1 + C_2$(million \$/year)	0.4172

Case 4.3.2: MT only

The best configuration plan of DG within MG is found at buses 6 and 9 with sizes of 0.961 p.u. (96.12 MW) and 1.703 p.u. (170.3 MW), respectively. Their optimal setting of reactive power found to be 0.121 p.u. (12.1 MVAR) and 0.341 p.u. (34.1 MVAR), respectively.

Case 4.3.3: Coordinated PV and MT

The best configuration plan of DG within MG is found at buses 14 and 7 with sizes of 0.400 p.u. (40 MW)and 1.709 p.u. (170.9 MW), respectively. Their optimal settings of reactive power are found to be 0p.u. (0 MVAR)and0.592 p.u. (59.2 MVAR), respectively.

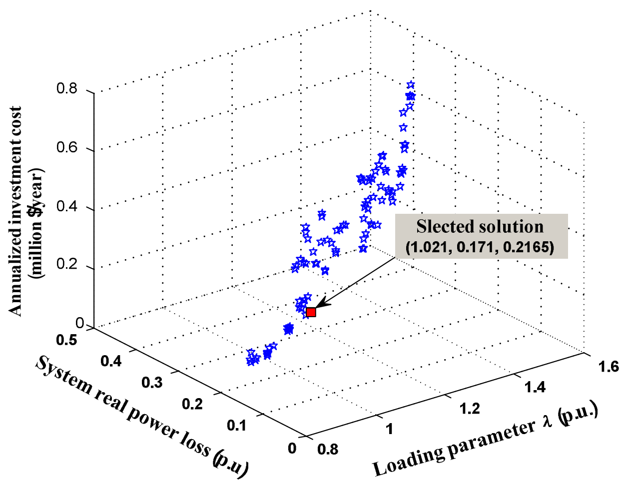

Fig. 3: Pareto front to find optimal location and size of DG only.

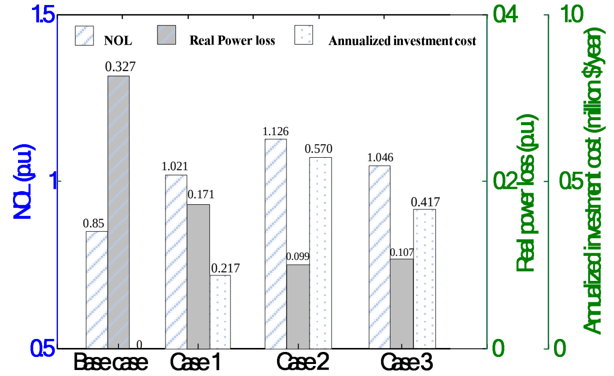

Fig. 4. Comparison of NOL, system real power loss and annualized investment cost of DG (Type1, Type 2, and Type 1&2) and base case.

Figure 4 shows the comparison of the level of NOL improving, system real power loss and annualized investment cost for the base case, DG type 1, type 2 and type 1&2. Obviously, the DG type 2 is the best plan with respect to system NOL improving of 91.0% and system real power loss reduction of 81.8% compared to the base case. For economic consideration, DG type 1 should be the best plan due to the lowest annualized investment cost. The annualized investment cost for highest NOL level is the lowest at 0.2165 million $/year.

5. CONCLUSION

This paper proposes an efficient multi-objective DG placement methodology. NSGA-II is used to determine locations and sizes of a specified number of distributed generators (DG) within power system. A fuzzy decision making analysis is used to obtain the final trade off optimal solution. The proposed methodology is tested on IEEE 14-bus system. Using the fuzzy method, DG can improve the system performance by trading off the maximize system NOL, minimize system real power loss and minimize annualized investment cost. Moreover the method does not impose any limitation on the number of objectives. This work will be further extended to address the problem of optimal location of multi-type of DG units to enhance system reliability.

NOMENCLATURE

λ	Loading parameter of the system, in p.u.
VL	Bus violation and thermal limit factors.
BVV_j	Bus voltage violation factor.
OLL_i	Overloaded line factor.
N_E	Total load buses.
N_L	Number of transmission lines.
P_{Di}	Load demand at bus i, in MW.
Q_{Di}	Load demand at bus i, in MVAR.
P_{D0i}	Load demand at bus i of the base case, in MW.
Q_{D0i}	Load demand at bus i of the base case, in MVAR.
V_b	Actual voltage magnitude at bus b, in p.u.
P_{ij}	Real power flow between buses i and j, in MW.
P_L	System real power loss, in p.u.
Q_L	System reactive power loss, in p.u.
AF_i	Annualized factor associated with the installation cost of DG unit i
UC_i	Unit cost of DG unit i ($/kVA)
i	Interest rate (%)
T	Life span in year
P_{Gi}	Real power generated by generating unit i, in p.u.
Q_{Gi}	Reactive power generated by generating unit i, in p.u.
S_k	Apparent power flow of transmission line i, in p.u.
$f_i^{\min}$	Minimum value of the i^{th} objective function among all solutions non-dominated.
$f_i^{\max}$	Maximum value of the i^{th} objective function among all solutions non-dominated.
$\mu_{f_i}(z)$	Membership function (varied between 0 and 1).
μ^k	Normalized membership function.
NOL	Normal operation loadability, in p.u.
$P_{DGi,\max}$	Upper real power generating limit of unit i, in kW.
$P_{DGi,\min}$	Lower real power generating limit of unit i, in kW.
U_{kp}	the violated constraint
N_k	the total number of violated constraints
Pf_{kp}	the penalty factor associated with the violated constraint U_{kp}

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APPENDIX

Table A.1. Parameter for simulation

No.	Description	Parameter of Simulation		
		DGs		
1	DG technology	Photo Voltaic	Gas Turbine (Biomass)	Wind Turbine
2	DG type	1	2	3
3	Size (MVA)	0.001 –200	0.001 – 200	0.001 – 200
4	Unit cost ($/ kVA)	5250	1800	2150
5	Fuel	Solar energy	Biogas	Wind
6	Equipment Life (years)	20	10	20
	Economic			
1	Interest rate	7%		

Optimization of Off-grid Hybrid Wind-Diesel Electrification in Thailand: A Case Study of Remote Island

Bundit Limmeechokchai and Prachuab Peerapong

Abstract— *This paper investigates the influence of energy efficiency in the process of sizing and optimization of operation of off-grid hybrid wind-diesel system for electric power supply to a remote island of 90 households in the south of Thailand. System sizing is optimized using HOMER model. The techno-economic analysis is used to investigate the hybrid wind-diesel power plant to serve the loads of the village. This study found that the use of efficient lamp and efficient electric appliances, which consume less electrical energy, reduces the time of operation of the diesel generator by about 15-20% in comparison with using only diesel generator. Furthermore, the results show that greenhouse gas emissions can be avoided by the proposed hybrid power plant.*

Keywords— **Off-grid electrification, Hybrid wind-diesel system, Optimization, Remote island, Techno-economic analysis.**

1. INTRODUCTION

During the past 15 years (1993-2009), electricity consumption in Thailand increased significantly from 63,279 GWh to 146,182 GWh and peak demand increased from 9,839 MW to 22,315 MW [1-2]. As of April 2009, peak demand of electric power system was recorded at 22,315 MW which was 78.4 MW or 0.35% higher than the record of 2008 and peak consumption of electricity was 146,182 GWh with 74.8 percent of load factor. As of December 2009, the total national capacity was 29,212 MW comprising 14,328 MW (49.0%) of EGAT's power plant, 14,243 MW (48.8%) of domestic private power producers (IPPs and SPP) and 640 MW (2.2%) of neighboring power purchase [1]. Energy Policy and Planning Office (EPPO) reported that total energy consumption in 2010 can be categorized by economic sectors: residential; 33,213 GWh (22.34%), commercial; 35,980 GWh (24.19%), industrial; 65,956 GWh (44.36%), agricultural sectors; 335 GWh (0.22%), and others 13,222 GWh (8.89%). The power forecasted in PDP 2010 for peak load demand in 2030 is approximately 52,890 MW or 2.37 times higher than that of 2009 (22,315 MW). The growth rate of the forecasted peak demand during 2010-2030 is 4.19 percent per year compared with 2.44 percent per year during 2005-2009. The forecasted energy demand in 2030 is about 347,947 GWh or 2.38 times higher than that of 2009 (146,182 GWh). An average growth rate of forecasted energy demand during 2010-2030 is 4.22% per year compared with 2.83% per year during 2005-2009. Thus, the long term load factor is between 74% and 75%. The Ministry of Energy has come up with a policy to develop the renewable energy (RE) and released the Alternative Energy Development Plan (AEDP) for a fifteen years period (2008-2022). The objective of AEDP is to increase the portfolio of renewable energy to 20.3% of the final energy consumption in 2022. At the end of the plan, the portion of renewable energy in power generation will be 2.4% or 5,608 MW. The electricity accessibility level in island areas in Thailand is very low due to long distance from the grid, and high cost of grid extension to the areas, compared with 98% accessibility rate in the urban area. In island areas, electricity is supplied by using diesel generators. Though diesel systems have their distinct advantages of electricity generation, but their operational and maintenance costs are high, especially at low loads, and storage & transportation of fuel to the remote island is also difficult. There is also a problem of oil leakage into the neighboring areas. In Thailand, application of renewable energy technologies (RETs) for rural and island areas, is increasing in recent years, but not very widespread. Therefore, the concept of wind-diesel hybrid electricity system is a reliable alternative energy source because it uses wind energy combined with diesel energy to create a stand-alone energy source to provide electricity in remote islands.

Bundit Limmeechokchai (corresponding author) is an Associate Professor at Sirindhorn International Institute of Technology. P.O. Box 22, Klong Luang, Pathumthani 12121, Thailand. Tel: +662-986-9009; Fax: +662-986-9112-3; E-mail: bundit@)siit.tu.ac.th.

Prachuab Peerapong is with Sirindhorn International Institute of Technology. P.O. Box 22, Klong Luang, Pathumthani 12121, Thailand. E-mail: prachuab@siit.tu.ac.th.

2. WIND-DIESEL OFF-GRID HYBRID MODEL

2.1 Wind energy as a source of renewable energy

In Thailand, the wind speed in island has high potential to produce electricity with an average speed of 5 m/s or more, depending on seasons and times of day. The probability density of the Weibull distribution (Patel, 2006) is commonly used for calculation of average available power in wind turbine per unit area. The Weibull distribution function (Weibull, 1957) is a two parameter function, which is written as:

$$f(v) = (\frac{k}{c})(\frac{v}{c})^{k-1}\exp[-(\frac{v}{k})^{k}] \quad (1)$$

where k is the shape parameter, describing the dispersion of data, and c is the scale parameter, with the unit of speed (m/s). The two parameters *c* and *k* are related to the average wind speed by the following relation:

$$\bar{v} = c\Gamma(\frac{1}{k}+1) \quad (2)$$

where Γ is the gamma function. To fit a Weibull distribution to measured wind data, HOMER model uses the maximum likelihood method. The predicted and actual wind speeds are also investigated.

The wind energy (*E*) that can be extracted by a wind turbine is defined by the following equation:

$$E = T\int_{0}^{\infty} P(U)\cdot f(v)\cdot d(U) \quad (3)$$

where $f(v)$ is the probability density function of wind speed, *P(U)* is the power curve of the turbine, and *T* is time period.

Using the equation (1) substitutes in equation (3), we can obtain the wind energy in terms as of Weibull distribution.

$$E = T\int_{0}^{\infty} (\frac{k}{A})(\frac{U}{A})^{k-1}\cdot \exp(-(\frac{U}{A})^{k})P(U)\cdot d(U) \quad (4)$$

The capacity factor (C_f) is one element that enables to measure the productivity of a wind turbine. It compares the plant's actual production over a given period of time to the amount of power that the plant would have produced if it had run at full capacity of the same amount of time. It can be calculated by the following equation, and expressed in %.

$$C_f(\%) = \frac{\text{Wind energy produced (Wh/year)}}{\text{Max wind energy produced (Wh/year)}} \quad (5)$$

2.2 Diesel electricity generation in Thailand

The consumption of diesel to produce electricity in Thailand is only a small portion, and decreased significantly. For example, the annual consumption rate decreased from 177 GWh in 2005 to 45 GWh in 2009 or with the average of -12.6% annually. However, in remote areas or island or the areas that are off-grid connection, the diesel fuel-based for electricity production is the most alternative way to supply the most needed demand.

2.3 The hybrid configurations in Thailand

The most hybrid electricity configuration in Thailand for decentralized generation (DG) or off-grid electricity is diesel-PV hybrid system. The most successful case of diesel-PV hybrid system in remote island is installed in Kojig island located in Chantaburi province on the eastern coast of Thailand. This project was installed in 2004 through the cooperation of King Mongkut's University of Technology Thonburi, Kasetsart University and Mahidol University. Another alternative hybrid electricity configuration is diesel-wind turbine. With the limitation of wind potential in Thailand, the diesel-wind turbine is also a site specific. The most wind potential areas are in seashore coastlines or in islands. As the selected site for this study has a high wind potential. It is located 45 km from the main land in the gulf of Thailand.

3. METHODOLOGY

3.1 Optimization model

Hybrid systems consist of several renewable energy production structures and storage units. One has to consider lots of probability calculations while planning the proper hybrid system in order to respond to the energy demand. Hybrid Energy Performance Equations and the associated Energy Performance Curves are derived and introduced, respectively, which provide a visualization model, simplifying hybrid system analysis. The cost effectiveness of the present diesel system and the wind/diesel electricity for the remote island in the South of Thailand is evaluated employing the HOMER model, developed by the National Renewable Energy Laboratory (NREL), USA. HOMER is a powerful simulation tool, considering sustainability factors such as system efficiency, weather, fuel costs, O&M costs. Subsequently, simple novel HOMER software is a user friendly micro-power design tool that simulates and optimizes stand -alone and grid connected power systems. Recently, it has been used widely in the field of hybrid systems. It can be used with any combination of wind turbines, PV arrays, run-of-river hydro power, biomass power, internal combustion engine generators, micro-turbines, batteries, and hydrogen storage, serving both electric and thermal loads. HOMER expresses the economics of controllable energy sources with two values: fixed cost and energy cost per kWh. These costs represent the cost for generating energy at any time for a power source. HOMER searches for combination of sources meeting the load and then finds the system that achieves the goal with minimum costs. The advantage of the HOMER is that it can involve also all costs such as the initial capital and the maintenance costs including pollution penalties. The simulation considers one-year time period using minimum time-step of 1 minute. It performs a sensitivity analysis which can help the analyst to investigate the effects of uncertainty or changes in input variables. The Objective of the optimization simulation is to evaluate the economic and technical feasibility for a large number of technological options, while considering variations in technology costs and energy resources availability. Results obtained in this study show that combined power scheme is more sustainable in terms of electricity supply to the remote islands and in terms of avoided greenhouse gas emissions when compared to stand-alone diesel system.

3.2 Literatures review

Many literatures reported to determine the optimum hybrid energy system for small loads (ranging from few watts to few kilowatts) in a given location [3–6]. These studies showed that the renewable energy-based off-grid hybrid generation systems can compete with power from the gird in remote locations, where the grid is neither feasible nor nonexistent.

The hybrid systems such as wind/diesel are now proven technologies and options to supply small electrical loads at remote locations as reported by Lundsager and Bindner [7] and Zhang Hongyi et al. [8]. In developing countries, interest in medium to large-scale wind-diesel hybrid power system for rural electrification has grown enormously.

With growing global awareness of the need for clean sources of energy, wind energy in particular, many researches on scientific study are being carried out in Saudi Arabia. Rehman et al. [9] conducted a study to perform an economical feasibility assessment of an existing grid-connected diesel power plant supplying energy to a remote village by adding wind turbines in the existing power system in order to reduce the diesel consumption and environmental pollution, using the HOMER model. They found that the wind-diesel hybrid system becomes feasible at wind speeds above 6.0 m/s and a fuel price of 0.1$/L or higher.

3.3 Optimal wind turbine size selection

The optimal wind turbine size selection is based on results that are listed of best system configuration first, to worst system configuration last. The most important parameters to consider are the Cost of Energy (COE) and the Net Present Cost (NPC). So, the hybrid systems of wind turbines and diesel are based on wind potentials or wind velocities and diesel prices. The system includes battery banks for energy storages and inverters for converting DC to AC electricity. The least cost of COE and NPC of the system is the optimal solution. For example, when the wind velocities and diesel prices are both high, the selected wind turbine optimal size is also high in terms of renewable energy (wind) penetrations. In contrast, when the wind potential and diesel prices are both low, costs of wind turbine system are high. In this case, it means that it could not be competitive with only diesel systems, the wind turbine optimal size selected is also low in terms of renewable energy (wind) penetrations, or the only diesel system is the optimal case. Therefore, the variation of input values is needed for both annual average wind speeds and diesel prices to perform sensitivity analysis on these variables. HOMER software allows the users to explore variations in average annual wind speed and diesel prices affecting the optimal design of the system.

3.4 Wind data collection and power demand

The wind data and electrical power demand was collected by Provincial Electricity Authority (PEA). The system is consisted of the tiled-up tower with 40 meters in height, instrument, sensors, and accessories. During January-December 2009, wind data and electricity demands were collected. Performances of wind power are obtained, processed and analyzed using HOMER optimization model.

4 PLANT DESCRIPTIONS

Ko Tao is used as a model for study of wind-diesel off-grid hybrid electrification for remote island. It is a small famous tropical island, destination for tourism. It is located on southeast coast of Thailand (latitude 10.06 N°, longitude 99.83°E), about 45 km from Chumphon Province. The 33 kV electric system is supplied by 6 small diesel generators with a capacity of approximately 3,000 kW operated by PEA. The system peak load demand consumed by 920 habitants, is nearly 3,000 kW as of April 2009. It can be seen that the system is needed to extend more power generators in the future to meet the increased demand. The wind-diesel is a good option to consider with much potential of wind and in terms of environmental concerns. The map of island is shown in Fig.1. The island is fully mountain area and tropical forest. There is no electrification in the areas since it is difficult to extend the diesel-based PEA small grid and being of diesel generation limit.

Fig. 1 Map of Ko Tao, 45 km from the coast of Thailand.

5 WIND-DIESEL HYBRID OPTIMIZATION

5.1 The electricity load demand by the islander

The monthly mean wind speed of this island is shown in Fig.2. The annual peak load is approximately 3,000 kW observed in April. The higher demand exists from March to July due to high season for tourism while relatively lower in September to November due to low season for tourism.

The energy consumption mostly depends on diesel generation. The increased demand is due to its famous destination for tourism and its population growth.

5.2 Wind speed data

The wind data were collected at the height of 40 meters above the ground level. The 250 kW wind turbine rotor are placed at the hub height at 50 meters by using 1/7 power law. At 50 meter height the average wind speed became 5.48 m/s as shown in Fig. 3.

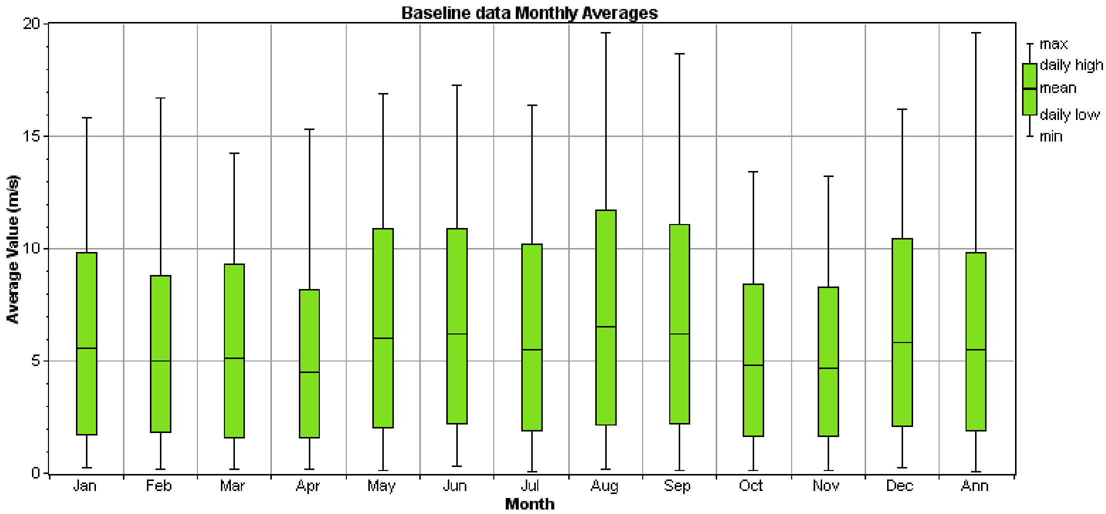


Fig.2 Variation of mean wind speed during January-December 2009.

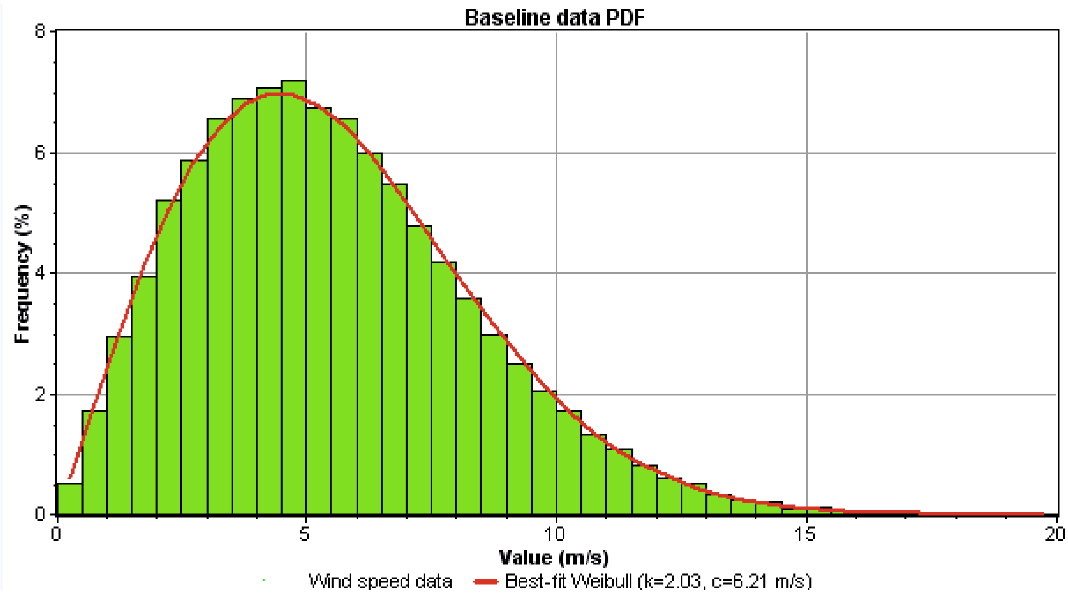


Fig.3 Hourly mean wind speed distribution.

Table 1. Diesel generator information

Parameters	Value/ information
Rated power	500 kW
Minimum allowable power	74 kW
Full load fuel consumption	140 L/hr
Power factor	0.82
Voltage	400 V
Rated current	902 A
Frequency	50 Hz
Rotating speed	1500 rpm
Battery (voltage)	24 V

Table 2. Diesel generator data

Rating kW	Capital cost (US$)	Replacement (US$)	O&M cost (US$/hr)
500	80,355	53,570	0.301

Table 3. Fuel cost and technical data

Parameter	Value
Cost	0.75 US$/L
Lower heating value	45.62 MJ/kg
Density	0.831 kg/L
Carbon content	80%

5.3 System components

The main components of an isolated grid-connected wind-diesel hybrid system are 3 diesel generators and a 250 kW wind turbine. The diesel system consists of generator 1 with capacity of 1,500 kW, generator 2 with capacity of 1,000 kW, and generator 3 with capacity of 500 kW. The cost of each component, the economical and control parameters required by the HOMER software are discussed in the forthcoming paragraphs. The overall system includes converter and battery as shown in Fig. 4

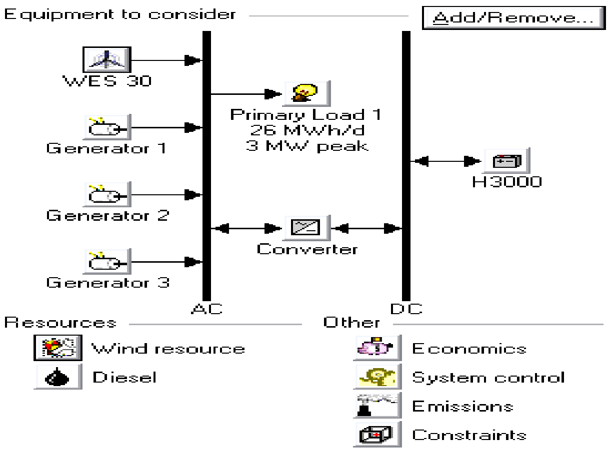


Fig. 4 Wind-diesel energy system for an isolated grid.

Table 4. Wind turbine technical data

Parameter	Value/ information
Rated power	250 kW
Cut in speed	3.5 m/s
Cut out speed	22.0 m/s
Rotor diameter	28.5 m
Hub height	50 m
Voltage	400 V
Rated current	410 A
Frequency	50 Hz
Rotating speed (High/Low)	39.8/26.5 rpm
Wind turbine capital cost ($)	250,000
Replacement cost ($)	175,000

Table 5. Converter and battery cost

Cost	Capital ($)	Replacement ($)	O&M ($/yr)
Converter			
Cost per kW	150	100	0.1
Battery			
Cost per set	420	360	0.2

5.3.1 Diesel generator

The diesel power plant consists of 6 units of 500 kW rated capacity; three units for generator 1, two units for generator 2, and one unit for generator 3. The details of each unit in terms of both technical data and the cost data are shown in Tables 1 and 2, respectively. Table 3 shows the fuel cost and its technical data.

The operation and maintenance cost of 0.301$/hr was used in the simulation. The fuel costs are obtained locally, including the transportation cost of 0.80 $/L, as given in Table 3. This table also includes technical information related to diesel fuel.

5.3.2 Wind turbine

The other major component of the wind-diesel hybrid system after the diesel-generating set is the wind energy conversion system.

The modern wind machines are very efficient and are found in big sizes. Today's standard market size of the wind turbine is greater than 1.5 MW. The rotor diameter of these machines varies between 40 and 110 m or more.

The modern wind turbine produces more energy due to high wind speeds at higher hub heights, since the energy yield from the wind energy conversion system depends on the availability of wind and its variation. In this case, WES30 of 250 kW from Wind Energy Solutions manufacturer is used. The technical and cost information of the wind machines is summarized in Table 4. The annualized operation and maintenance cost of $1,500 per wind turbine has been used for analysis.

5.3.3 Converter and battery

A battery bank consists of 24V H3000 batteries and inverters. The battery nominal capacity was 3000 Ah per set. It is noted that the converter functions as both an inverter (converting DC to AC) and converter (AC to DC). The costs of converter and battery are shown in

6 RESULTS AND DISCUSSION

HOMER provides results in terms of optimal systems and sensitivity analysis. In the analysis, the optimized results are presented on a particular set of sensitivity parameters. The results are presented in the following paragraphs.

6.1 Optimization results

The optimization results for a wind speed of 5.5 m/s and a fuel price of 0.80 $/L are summarized in Fig.7. In this case, a diesel power system seems to be most economically feasible with the minimum total net present cost (NPC) of $35,619,588 and minimum energy cost (COE) of 0.288$/kWh, although the system represents a higher initial capital when compared to the system run by diesel only. Generally, at wind speed less than 4 m/s, the only diesel system was found to be most feasible solution with COE, less than 0.277 $/kWh corresponding with a diesel price of 0.7 $/L.

As seen from Fig.8, about 55% of initial cost of wind-diesel hybrid system was accounted for diesel power system, and 98.6% of the operation and maintenance cost and fuel cost were accounted for diesel system. The total annualized cost for wind equipment including converter and battery system are accounted for $80,187 (3% of the entire wind-diesel power plant cost), while for diesel power system is accounted for $ 2,706,218 (97% of the entire wind-diesel power plant cost). The energy yield from different components of the wind-diesel power plant cost is shown in Fig. 6 for the total energy requirement of the island. The wind machine produced 313,428 kWh/yr (3% of the total energy served), while the diesel generators produced 9,482,455 kWh/yr. The system with battery back-up was almost no excess electricity with any capacity shortage, as shown in Fig. 7.

Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 5.5 Diesel Price ($/L) 0.8

Double click on a system below for simulation results. ○ Categorized ● Overall

WES30	Label (kW)	Label (kW)	Label (kW)	H3000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Label (hrs)	Label (hrs)
1	1500	1000	500	250	300	$ 880,000	2,717,564	$ 35,619,588	0.288	0.03	3,184,694	3,425	3,924	2,229
1	1500	1000	500	200	300	$ 859,000	2,719,301	$ 35,620,796	0.288	0.03	3,186,823	3,455	3,939	2,187
1	1500	1000	500	300	300	$ 901,000	2,716,852	$ 35,631,488	0.288	0.03	3,183,429	3,412	3,897	2,266
1	1500	1000	500	350	300	$ 922,000	2,715,902	$ 35,640,340	0.288	0.03	3,182,141	3,393	3,900	2,274
1	1500	1000	500	400	300	$ 943,000	2,715,350	$ 35,654,288	0.289	0.03	3,181,336	3,382	3,892	2,294
1	1500	1000	500	200	250	$ 851,500	2,722,823	$ 35,658,316	0.289	0.03	3,197,992	3,699	3,936	2,062
1	1500	1000	500	250	250	$ 872,500	2,722,418	$ 35,674,132	0.289	0.03	3,197,164	3,685	3,935	2,077
1	1500	1000	500	300	250	$ 893,500	2,722,450	$ 35,695,540	0.289	0.03	3,196,758	3,681	3,927	2,089
1	1500	1000	500	350	250	$ 914,500	2,722,396	$ 35,715,852	0.289	0.03	3,196,363	3,673	3,931	2,092
1	1500	1000	500	400	250	$ 935,500	2,723,283	$ 35,748,200	0.289	0.03	3,196,176	3,672	3,928	2,095
1	1500	1000	500	300	500	$ 931,000	2,738,578	$ 35,939,220	0.291	0.03	3,180,158	3,008	4,144	2,216
1	1500	1000	500	350	500	$ 952,000	2,737,430	$ 35,945,540	0.291	0.03	3,178,550	2,992	4,116	2,241
1	1500	1000	500	250	500	$ 910,000	2,741,664	$ 35,957,668	0.291	0.03	3,183,946	3,089	4,112	2,188
1	1500	1000	500	400	500	$ 973,000	2,736,760	$ 35,957,972	0.291	0.03	3,177,302	2,947	4,152	2,240
1	1500	1000	500	200	500	$ 889,000	2,744,885	$ 35,977,848	0.291	0.03	3,187,994	3,168	4,090	2,180
1	1500	1000	500	300	600	$ 946,000	2,748,981	$ 36,087,208	0.292	0.03	3,180,279	3,010	4,141	2,216
1	1500	1000	500	350	600	$ 967,000	2,747,673	$ 36,091,476	0.292	0.03	3,178,510	2,990	4,118	2,240
1	1500	1000	500	400	600	$ 988,000	2,747,057	$ 36,104,608	0.292	0.03	3,177,325	2,946	4,153	2,240
1	1500	1000	500	250	600	$ 925,000	2,752,168	$ 36,106,944	0.292	0.03	3,184,161	3,090	4,111	2,188
1	1500	1000	500	200	600	$ 904,000	2,755,189	$ 36,124,556	0.292	0.03	3,188,027	3,168	4,091	2,178
	1500	1000	500	300	300	$ 651,000	2,792,682	$ 36,350,844	0.294	0.00	3,281,072	3,546	3,919	2,180
	1500	1000	500	250	300	$ 630,000	2,794,551	$ 36,353,736	0.294	0.00	3,283,357	3,586	3,911	2,157
	1500	1000	500	200	250	$ 601,500	2,796,827	$ 36,354,328	0.294	0.00	3,293,704	3,845	3,896	2,039
	1500	1000	500	200	300	$ 609,000	2,796,589	$ 36,358,792	0.294	0.00	3,285,959	3,623	3,928	2,111
	1500	1000	500	250	250	$ 622,500	2,795,841	$ 36,362,736	0.294	0.00	3,292,412	3,825	3,898	2,053

Fig. 5. Optimization for wind speed of 5.5 m/s, diesel price of 0.8$/L and renewable energy fraction of 3%

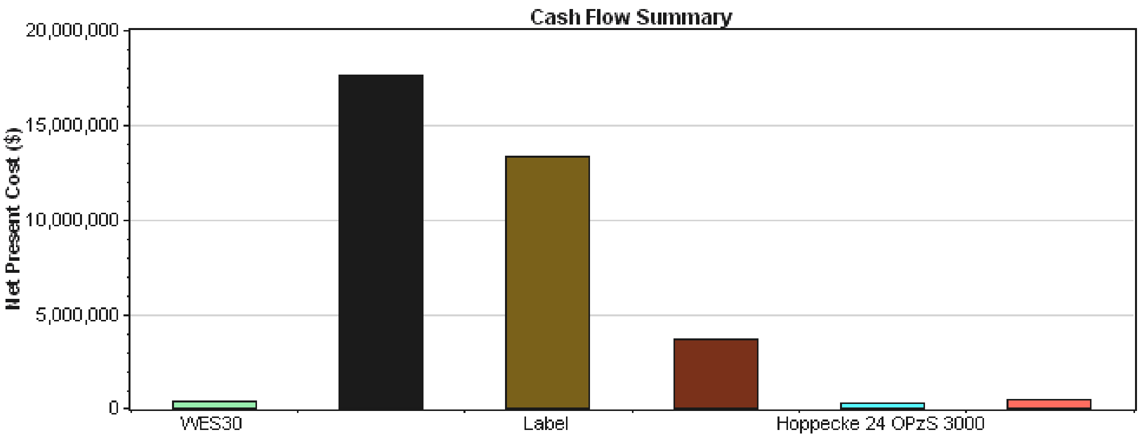
System Architecture: 1 WES 30; 1,500 kW Generator 1; 1,000 kW Generator 2; 500 kW Generator 3; 250 Hoppecke 24 OPzS 3; 300 kW Inverter; 300 kW Rectifier; Cycle Charging

Total NPC: $ 35,619,588
Levelized COE: $ 0.288/kWh
Operating Cost: $ 2,717,564/yr

Cost Summary | Cash Flow | Electrical | WES30 | Label | Label | Label | Battery | Converter | Emissions | Hourly Data

Cost type: ● Net present ○ Annualized ☑ Reverse sign

Categorize: ● By component ○ By cost type ☐ Show details



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Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
WES 30	250,000	73,021	19,175	0	-13,592	328,605
Generator 1	240,000	397,972	394,047	16,580,762	-10,907	17,601,876
Generator 2	160,000	316,168	300,971	12,600,330	-11,468	13,366,002
Generator 3	80,000	77,066	85,482	3,387,791	-3,553	3,626,788
Hoppecke 24 OPzS 300	105,000	89,104	63,917	0	-371	257,650
Converter	45,000	12,518	383,501	0	-2,330	438,689
System	880,000	965,850	1,247,094	32,568,886	-42,221	35,619,608

Fig. 6. Cost analysis of wind-diesel hybrid power system of island electrification.

System Architecture:	1 WES 30	500 kW Generator 3	300 kW Rectifier	Total NPC: $ 35,619,588
	1,500 kW Generator 1	250 Hoppecke 24 OPzS 3Cycle Charging		Levelized COE: $ 0.288/kWh
	1,000 kW Generator 2	300 kW Inverter		Operating Cost: $ 2,717,564/yr

Cost Summary | Cash Flow | Electrical | WES30 | Label | Label | Label | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
Wind turbine	313,428	3
Generator 1	4,841,291	49
Generator 2	3,672,731	37
Generator 3	968,439	10
Total	9,795,889	100

Consumption	kWh/yr	%
AC primary load	9,664,478	100
Total	9,664,478	100

Quantity	kWh/yr	%
Excess electricity	0.0830	0.00
Unmet electric load	0.0215	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.0320

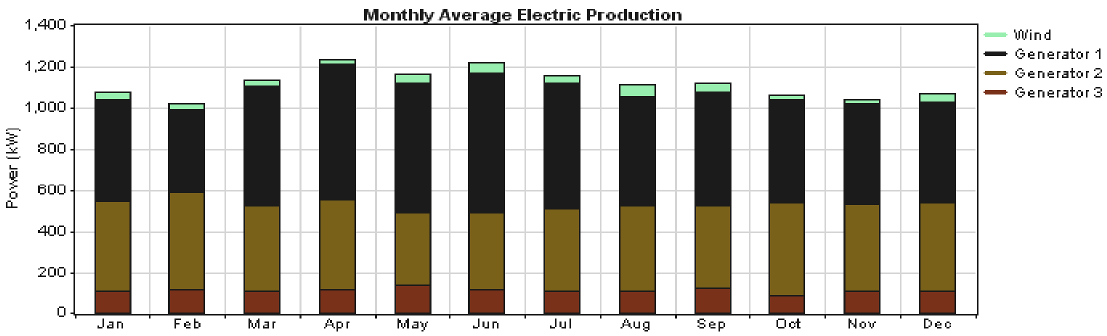

Fig. 7. Monthly energy yield from wind-diesel hybrid electrification for the island electrification

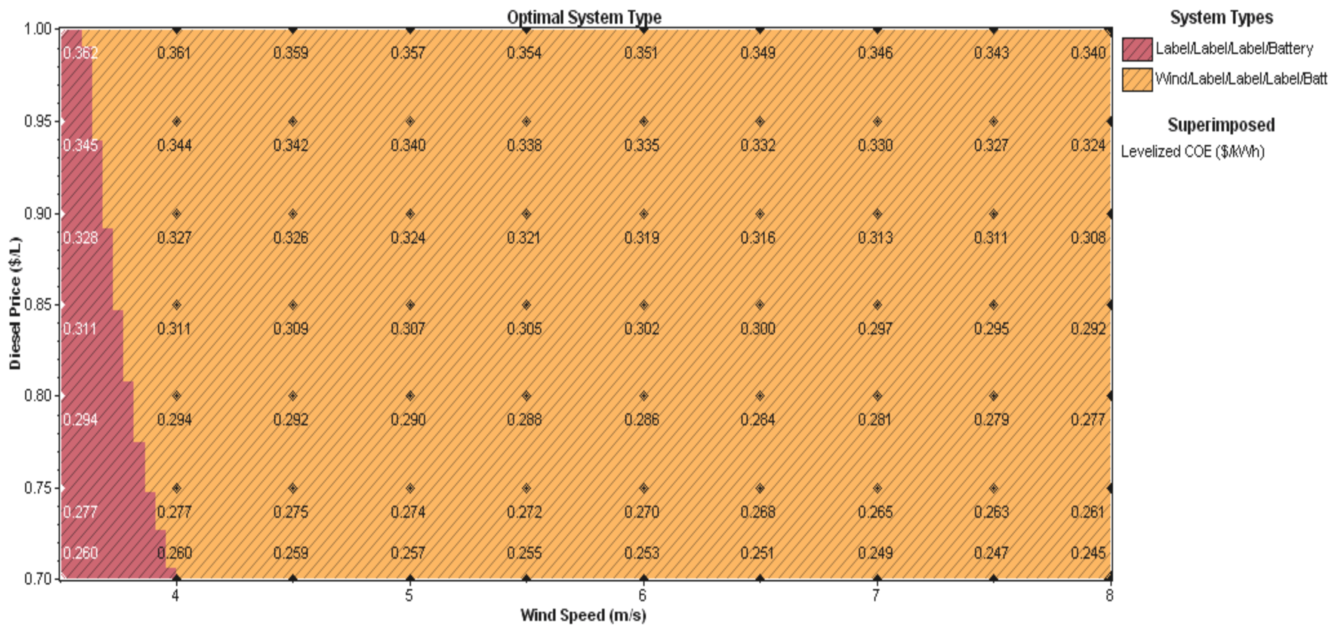

Fig. 8. Optimized wind-diesel hybrid system for island electrification.

Pollutant	Emissions (kg/yr)
Carbon dioxide	8,640,141
Carbon monoxide	21,327
Unburned hydrocarbons	2,362
Particulate matter	1,608
Sulfur dioxide	17,351
Nitrogen oxides	190,302

Fig. 9. GHG from diesel system

Pollutant	Emissions (kg/yr)
Carbon dioxide	8,386,349
Carbon monoxide	20,701
Unburned hydrocarbons	2,293
Particulate matter	1,561
Sulfur dioxide	16,841
Nitrogen oxides	184,712

Fig. 10. GHG from wind-diesel hybrid system

6.2 Sensitivity results

The HOMER eliminates all feasible systems and presents the results in ascending order of NPC. In this present case, wind speeds (3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0 m/s), and diesel prices (0.7, 0.75, 0.80, 0.85, 0.90, 0.95 and 1.0 $/L) were used as sensitivity variables. However, when the different interest rates are included, the cost of energy or electricity price slightly changes. For example, interest rate in this calculation is 7.5%, the cost of energy (COE) or electricity price is 0.288 $/kWh. The sensitivity studies showed that when interest rates are increased to 8.5% and 9.5% COEs are constantly increased to 0.293 $/kWh or increased by 1.73%. In contrast, when interest rates are decreased to 6.5% and 5.5%. COEs are decreased to 0.273 $/kWh and 0.258 $/kWh or decreased by 5.5 % and 5.8%, respectively.

The optimization results are shown in terms of wind speed and diesel prices, as shown in Fig.5. This type of graphical representation of optimal system-type provides information that a particular system will be optimal at certain wind speed and a certain fuel cost. Furthermore, the wind speed and diesel cost are usually site-dependent, so one can conclude that at a particular wind speed and fuel cost the system will be optimal for a particular place or location.

The hybrid wind-diesel optimal system for this network shows that the cost of energy or electricity price is 0.288 $/kWh or 8.68 Baht/kWh in comparison with a retail price of 0.116 $/kWh or 3.50 Baht/kWh from the national grid. When the network operation is optimized, it shows that the cost of energy or electricity price in wind-diesel system can be decreased significantly compared to the energy production cost on diesel generator-based or decreased from 0.348 $/kWh to 0.288 $/kWh or decreased with 0.06 $/kWh. It can be saved 587,753 $/year.

6.3 Greenhouse gases (GHG) reduction

The GHG pollutes the environment, which adversely affects the life of human beings. An indirect or hidden cost, which is not taken into consideration while using fossil fuels, is paid by the human beings. The diesel power system being used at this island emits 8,873,091 kg of pollutants into the local atmosphere of the island every year. The wind-diesel hybrid system can reduce pollutants to 8,612,457 kg per year. It shows a reduction of 260,634 kg of pollutants per year. The concentrations of various constituents of pollutants like CO_2, CO, nitrogen, etc. for diesel and hybrid system are summarized in Fig.9 and Fig.10, respectively.

7 CONCLUSIONS

The aim of this study is to perform an economical feasibility of an existing grid-connected diesel power plant supplying energy to a remotely located village by adding wind turbine in the existing power system in order to reduce the diesel consumption and environmental pollution, using the HOMER simulation model. It was found that in this study the wind-diesel hybrid system becomes optimized at wind speed above 5.5 m/s and fuel price of 0.80 $/L or higher. In the case, wind turbine was accounted for only 3% of energy consumption. The feasibility expansion of wind-diesel hybrid to other remote island is studied for the near future.

ACKNOWLEDGMENT

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The Successive Development of Nuclear Energy in Southeast Asia

Vivat Chutiprapat, Woraratana Pattaraprakorn and Pornrapeepat Bhasaputra

Abstract— *Southeast Asian countries are embarking on a program to develop nuclear energy. While this promises to help satisfy the region's growing energy thirst in a high cost-efficient and friendly environmentally friendly way, nuclear power also has its risks. The specter of proliferation looms large and the potential for nuclear accidents exists remains high in a region inclined to natural disasters and averse to strong institutional safeguards and export controls. Policymakers will have to be alert in mitigating these threats in order to ensure the region's safe passage to a nuclear future. Electricity in Southeast Asia is primarily sourced from coal, oil, natural gas, and hydro-power. While the region is awash with energy resources, rising demand has placed as starin on them. Southeast Asia has been a net oil importer for some years and significant natural gas reserves are often located far from demand centers and hence require massive infrastructure investments. Given this gloomy picture, the region is turning to alternative sources, including nuclear power, to meet its growing appetite for energy. Several regional trends suggest that this trend will accelerate in the decades to come.*

Keywords— **Association of Southeast Asian Nations(ASEAN), Foreign Direct Investment (FDI), Asian Development Bank (ADB), Asia Pacific Energy Research Center (APERC), Electricity Generating Authority of Thailand's (EGAT), International Atomic Energy Agency (IAEA),Vietnam Atoms Energy Commission (Vinatoms), European Union's European Atomic Energy Community (EURATOM), Tenaga Nasional Be (TNB) , Korean Electric Power (Kepco), International Atomic Energy Agency (IAEA).**

1. INTRODUCTION

The Association of South East Asia Nations (ASEAN) consists of 10 member countries, namely,Indonesia, Thailand, Malaysia, Singapore, Philippines, Vietnam, Mynmar, Brunei, Cambodia, and Laos. ASEAN has, by and large, been an open and outward looking region. External trade and foreign direct investment (FDI) are the principal means for globalization as well as an engine of economic growth among the ASEAN economics. Economies that are members of ASEAN have been growing at an annual averge rate of 5-6% since 2000 see detail on Fig 1. The volume of trade in the region recorded 18% increase annually,with US$ 7 billion annual trade balance, before the current global economic crisis. Investment in ASEAN has surged at an annual average rate of 37% since 2003. [1]

Energy consumption and economy in the Southeast Asia region have been growing in tandem over the last few decades. This trend is expected to continue into ythe future as Southeast Asia economies move towards the GDP per capita levels of developed nations. The growing energy demand however, is likely to put pressure on existing energy sources and supplies, forcing the government to think about energy security.

V. Chutiprapat (corresponding author), P. Bhasputra, and W. Pattaraprakorn are with Department of Electrical Engineering, Faculty of Engineering, Thammasat University, 99 M18 Phaholyothin Road, Khlongluang, Pathumthani 12120, Thailand. E-mail: 5310030027@student.tu.ac.th, bporr@engr.tu.ac.th, pworarat@engr.tu.ac.th.

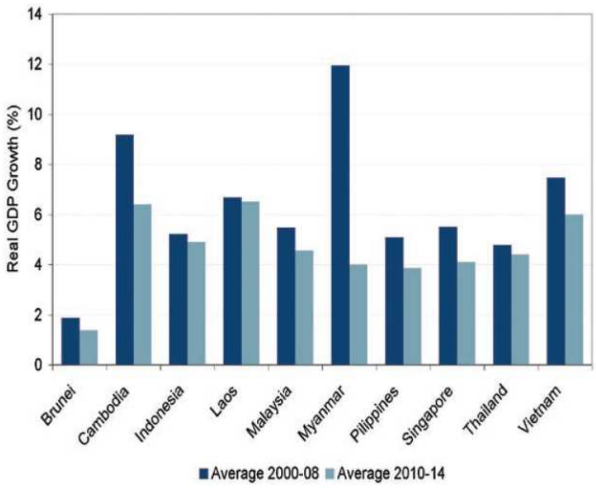

Fig. 1. Economic growth in ASEAN.

The current energy mix in the region is dominated by oil, which accounts for more than half of primary energy consumption in top energy consuming nations. A recent study carried out by Asian Development Bank (ADB) analyzed the energy mix of countries, namely, Indonesia, Thailand, Philippines, and Vietnam. The study pointed towards a rise in energy consumption shown in Fig 2&3. Going forward, the role of coal and gas is expected to increase at a fast rate. Use of alternative energy sources such as nuclear and biomass is also expected to increase overtime. However, while the share of oil consumption in total energy mix is expected to decline, it is still expected to remain a large contribution. The ADB report forecasts oil's share in energy at above 40% by 2020 for the four countries analyzed. [1]

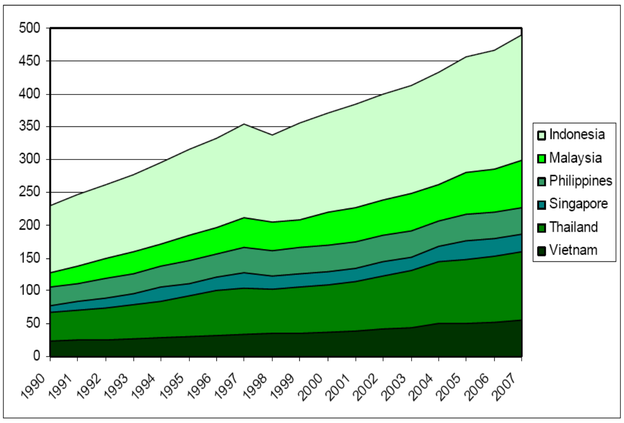

Fig. 2. Primary energy consumption in key ASEAN countries.

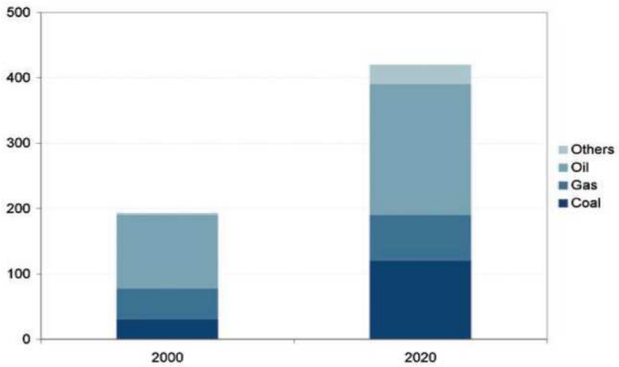

Fig. 3. Primary energy consumption in fours countries, Indonesia, Thailand, Philippines and Vietnam.

Southeast Asia states will similar pursue nuclear energy over the next few decades. Rising energy demand and Energy prices, both with increasing aware about climate change and the relative unattractiveness and unavailability of alternative energy sources, will combine to create a strong impulse to embark on a nuclear path.

According to the Asia Pacific Energy Research Center (APERC), are sustained by at least three main factors: first, Incresing energy demand in the most economies despite price increases; second, the unwillingness of major players to expand production and export capacity coupled with intensifying resource nationalism in oil and natural gas producing economies; and, third, a worsening geopolitical situation in the Middle East [2].

Despite price decreases in the short term, all three factors are not similar to decline in the long term, and energy prices will thus continue only increase. If the prices of conventional energy resources continue their upward turn, the demand for alternatives like nuclear energy will increase. Nuclear power is much high cost-efficient compared with fossil fuels, costing approximately 1.76 cents per kilowatt hour compared to coal (2.47cents), natural gas (6.78 cents) and oil (10.26 cents) that is.

Corresponding to rising prices, there will also be a greater than thirst for energy, particularly as the region emerges from the late economic down turn. Southeast Asia's recovery after the Asian Financial Crisis in 1998, coupled with strong economic reforms and burgeoning industrialization, has expanded regional economic growth rates since 2001. This is turn sharply boosted energy consumption in the region – for example, in the period from 2001 to 2003, consumption increased by 8%. If the region's economies continue the growth trend of the last decade, rising energy consumption will put more pressure on conventional sources and place even more urgency on investing in alternatives way like nuclear energy. Despite the fact that the global economic downturn has put a dent on this growth, Southeast Asian economies are still expected to bounce back strong in 2010 and will likely continue on a path of sustained economic growth. In fact, the International Energy Agency's World Energy Outlook 2009 projects that Southeast Asia's primary demand could expand by 76% between 2007 and 2030 and at an annual growth rate of 2.5% – much faster than the average rate in the rest of the world [3].

The region's rising awareness of global climate change may also cause it to turn toward low emission energy alternatives like nuclear energy. Nuclear energy has a very low carbon footprint, producing minimal levels of carbon dioxide (mostly during certain processes used to build and fuel the plants) comparable to geothermal, hydro power and wind energy detal show in Fig. 4. And while Southeast Asia has relatively low per capita emissions of carbon dioxide compared to the developed world (4.2 tons per capita is expected by 2030 in contrast to 23 tons in the United States), APERC's Institute for Energy Economics expects a whopping fourfold increase in total carbon-dioxide emissions (the green house gas) from 2002 to 2030 produced by energy production and consumption in Southeast Asia [4].

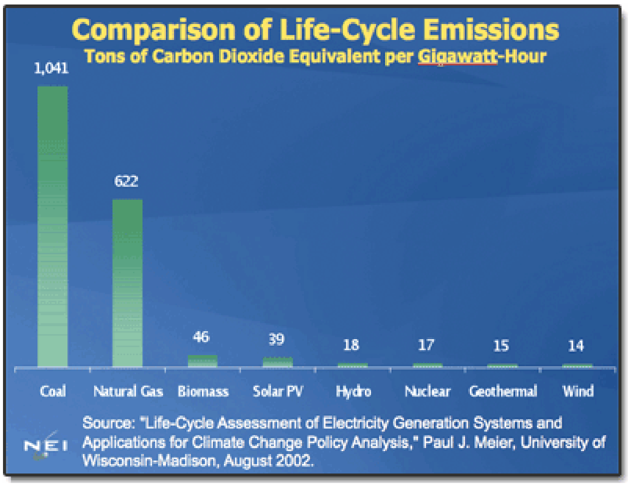

Fig. 4. Comparison of Carbon Footprints for Various Energy Sources.

If Southeast Asian states act on this warming trend, they may consider nuclear power as a path to clearing green house gas emissions. There are already gimplement signs of such climate change consciousness in Southeast Asia. For example, the 'Singapore Declaration on Climate Change, Energy and the Environment, which Southeast Asia states inked at the 3rd annual East Asia Summit in 2007, specifically states they will be a part of their commitment to "urgently act to address the growth of global green house gas emissions", "intensify ongoing cooperation to improve energy efficiency, and the use of cleaner energy by cooperating for the development and use of civilian nuclear power ".

The increasing consensus on nuclear power as a form of defense against climate change is bolstered by nuclear power's relative availability in comparison to other forms of low emission alternate energy. In case of, Indonesia has learned that natural gas requires too much supply infrastructure – a major structural problem that probably will not be remedied in the near future. Other options, like Capital in Thailand or hydro-power in the Greater Mekong Sub-region, have recently raised the specter of environmental damage and dislocation, and in some cases have generated widespread protests. it shows this region hydropower Dams plan in Fig. 5 In Addition, while they may appear promising in theory, countries are beginning to grasp that energy sources like solar energy can only function as marginal power generators in reality [5].

Fig. 5 Hydropower Dam in the Greater Mekong sub-region.

Nuclear power, by contrast, can produce energy on a much wider scale, effective cost competitiveness, accessible fuel supply, and limited environmental impact. These factors are likely to contribute to nuclear power's attractiveness.

2. THE NUCLEAR ENERGY SITUATION IN SOUTHEAST ASIA

Nuclear power is being explored in Indonesia, Vietnam, Thailand and possibly eleswhere in the region as part of the solution to meeting the need for very large increses in power generation capacity over the next two decades to support the fuel industrial and urban growth. Essentially, nuclear power is seen as a means of strengthening energy supply security (for electricity) by diversifying beyond reliance on fossil fuels. Much less of a driver in planning, at this stage, is concerned over reducing greenhouse gas emissions and threat of climate change. Of course, arguments for nuclear power can be made on the basis of its far lower output of carbon dioxide and other greenhouse gases.

Country wise, Indonesia, Vietnam and Thailand are the "Leader" who have already floated proposals for the election of 17 nuclear reactors, while the Philippines, Malaysia, Cambodia and Myanmar are the "Follower" that are considering the nuclear option. It is possible that by 2020, all six "Leader" and "Follower" could possess some form of nuclear facility. The four "abstainers" – Brunei, Cambodia, Laos, and Singapore, for various reasons, will most likely abstain from nuclear energy, absent any tectonic geo political changes in the region that may compel nuclear ambitions.The advance Southeast Asia have plan for NPP shown in Table 1.

Table 1. Advanced Southeast Asia Nuclear Efforts

Country	Reactors Planned	Proposed	Research reactor	Being rebuilt
1. Indonesia	2	4	3	
2.Thailand	2	4	1	1
3.Vietnam	2	8	1	
.Philippines		1	1	
5.Malaysia			1	
Total	**6**	**17**	**7**	**1**

Remark:
********= Approvals, funding or major commitment in place, mostly expected in operation within 8 year*
Proposes *= Clear intention or proposal but still without firm commitment*

Indonesia, Thailand and Vietnam are the most serious about developing nuclear energy in Southeast Asia. All three have set targets of possessing a functioning nuclear energy program by 2020, and the International Atomic Energy Agency (IAEA) has concluded that they are very advanced in developing the capabilities necessary for constructing such a program. Their motive thus far, as mentioned earlier, has been purely energy-centric, all three are trying to ease a growing gap between rising electricity demand and the declining availability of other non-nuclear alternatives in a cost-effective fashion with light of stratospheric energy prices [6].

The Follower are countries that are considering the nuclear option but are either not that enthusiastic about and are not yet deeply invested in it, or face significant obstacles that may obstruct a potential pursuit. Malaysia and Cambodia have both shown signs of considering the nuclear option. However, they probably will not take concrete steps in that direction any time soon since the former has sufficient oil and gas reserves for now, while the later is focused on developing its infrastructure and investing in other forms of renewable energy such as hydro-power in the short term. Resource-rich Myanmar does not need nuclear energy for power generation purposes, but only initiate the early stages of trying to build a small research reactor with Russian assistance. While the Philippines may embark on the project. In a few years, it is still reeling from its failed experience with nuclear energy in the 1980s, when its 630-megawatt Bataan nuclear plant was embroiled in corruption allegations under Goverment Leader. That alone will make nuclear energy a difficult sell in the Philippines.

Although, the resultant nuclear power generation for both Leader and Follower, it must be stressed, will only make a small dent on total projected power demand in these countries. For example, Indonesia , has planed initial tranche of 4,000 MW of nuclear generation which would serve the main Java-Bali grid which meets 75% of total energy demand, where total capacity is projected to increase from 15,000 MW in 2006 to 59,000 MW in 2026. The target is for nuclear power to contribute at least 4% of total enegry output by 2026. Under a 2006 Law on Nuclear reactors, the project seems likely to be given an independent power producer to build and operate, on one the three sites on the central north coast of java, around 450 kilometers east of Jakatar. Plans are to call tender in 2008 for two 1,000 MW units, Muria 1 and 2, leading to adecision in 2010 with construction starting soon after and commercial operation from 2016 and 2017,respectively. The goverment says reastors will be purchased from abroad and fuel world preferably be leased. Used fuel would be stroed centrally in the medium term. Tenders for Muria Units 3 and 4 are expected to be called in 2016, for operation from 2023 [7].

In Thailand, the Electricity Generating Authority of Thailand’s (EGAT) has put forward the goal of 5,000 MW of nuclear capacity by 2020, to make a dent into the additional 30,000 MW, where totoal capacity is projected to increse from 26,999 MW in 2006 to 50,000 MW in 2020. The government plans to establish safety and regulatory infrastructure by 2014 and commissioned a three-year feaibility study early in 2008. However, these efforts could also be precursors to much greater country commitments to nuclear energy in the future should they prove effective or should energy demands become more urgent [8].

Vietnam seems determined to establish civilian nuclear power plants. Hanoi wants to have 8,000 MW in operation by 2020 in the Ninh Thuan. To make a dent into the additional at 48,700 MW , where totoal capacity is projected to increasing from 12,000 MW in 2006 to 60,000 MW in 2015 and 120,000 MW in 2025. To ease public concerns over plan, state power utility Electricity Vietnam , the Ministry of Industry and trade and Vietnam Atoms Energy Commission (Vinatoms) have held public exhibitions about nuclear energy and power genergation in Hanoi, Ho chi Minh City, Ninh Thuan and neghbouring Phu Yen, Regulation frameworks are being fashioned. A law on nuclear energy is before the national legislature.

The Philippines, is considering reactive the 621 MW Bataan nuclear power plant in Morong. In April 2007, the philippine goverment made the final payment for the plant and the Philippines Depaertment of Energy set up a project to study the development of nuclear energym in the context of an overall energy plan for the country. In early 2008, Manila asked the IAEA to advise as to whether Bataan could economically and safety be operated, and to recommend a policy framework for nuclear power development in the country. The IAEA in turn has recommended that the goverment undertake an extensive feasibiity study of possible role should nuclear in the Philippines power system [9].

Malaysia is also looking at the atomic power options, with an energy policy study including conseration of nuclear power to be completed before 2010, In March 2008, the Malaysia state power utility, Tenaga Nasional (TNB) signed a prelininary agreement with its South Korean counterpart, Korean Electric Power (Kepco) to co-operate in the sale of region and beyond, as well as other energy resources and electricity business segments. Kepco has strong expertise in nuclear power generation, which a subsidary operating more than 17,000 MW of nuclear plant.

Myanmar’s Military leader is embarking on a small research reactor, to be built with Russian assiatance – through Moscow’s Federal Agency for Nuclear Energy, Rostaom – which it says would be in line with inetrnational standards and safetguards in place through IAEA.

Abstainers in Southeast Asia are countries that, for various reasons, are similar as pursue nuclear energy in the near future. For Singapore, the complication is technical: it lacks the necessary space for the required safety stand-off range of a nuclear site from urban areas (30 kilometers), which generates the majority of its power from increasing scare gas, has a feasibilty plan for power under way. Neither Brunei nor Laos see a need for nuclear energy in the short- term – the former has a wealth of other resources like oil and natural gas, while the later has significant proven hydro- power capabilities [10].

Table 2. Estimate Nuclear Power Plant in Southeast Asia

Country	Estimate Nuclear Time Line
1. Indonesia	Between 2016 and 2020
2.Thailand	By 2020
3.Vietnam	By 2020
4.Philippines	By 2025
5.Malaysia	By 2023
6.Cambodia	As early as 2020
7.Mynmar	By 2014
8.Singapore	Abstain
9.Loas	Abstain
10.Brunei	Abstain

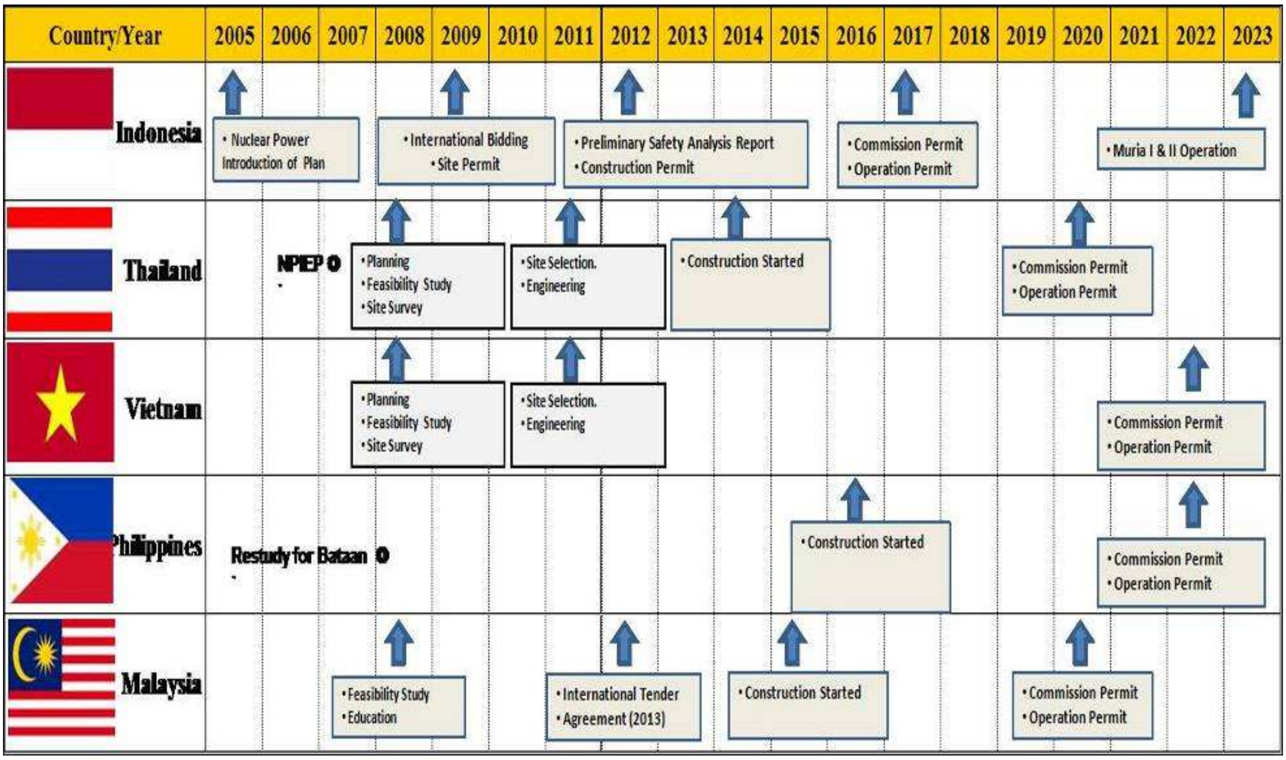

Fig. 6. Road Map of Nuclear Power Plant Development in Southeast Asia.

Overall, as the nuclear timeline below illustrates in Table 2 and Fig. 6, a futuristic assessment of energy portfolios shows that at least three and up to seven Southeast Asian countries could possess some form of nuclear power generation or begin using nuclear power by 2022 [11].

3. THE FUTURE OF NUCLEAR ENERGY IN SOUTHEAST ASIA

There are several sources of anxiety as more South-east Asian nations strive toward a nuclear future. In particular, the environmental and proliferation hazards associated with nuclear power, combined with the lack of strong regional policing and global norm adherence, are worrying trends that ought to concern policymakers going forward.

The environmental and safety sizing of nuclear is especially prominent in Southeast Asia. Since the region is inclined to intense natural disasters, nuclear power experts and managers will have to deal with the challenge of seismic hazard and the risk of radiation leakage in the future. While most plants are designed to withstand these natural disasters, much will depend on how adequate their safety standards are in areas such as radiation protection, predisposal management, and emergency preparedness and response, and how strongly these standards are enforced. According to APERC, the main concern as nuclear energy expands its reach in Southeast Asia will be “safety issues a increasing from fuel handling and the operation of nuclear power”.

History offers several cautionary tales about nuclear safety, such as the Three Mile Island incident in the United States (1979), the Chernobyl disaster in the former Soviet Union (1986), and the Tokaimura and Kashiwazaki incidents in Japan (1999 and 2007). Though Chernobyl was the result of a mechanical error (a chain reaction got out of control), detailed investigations into the Chernobyl and Tokaimura incidents clearly found that they could have been ameliorated or avoided entirely if there with better education, training, quality control and safety standards. And the Kashiwazaki case, where nuclear reactors were placed above a fault plane prone to earthquakes, indicates the importance of knowing the geographical terrain before positioning nuclear facilities.

Such problems are not merely historical or hypo-thetical for Southeast Asia. For example, Indonesia’s decision to locate its first nuclear power plant on a site near Mt.Muria, a dormant volcano, has already raised eyebrows among engineering safety experts and evoked comparisons to the Kashiwazaki case. Total disaster in Indonesia is recorded in Fig. 7. The concern is even more palpable because Jakarta is particularly susceptible to natural disaster sowing to its location in the “Ring of Fire” – an area where the hightest numbers of earthquakes and volcanic eruptions occur in the Pacific Ocean. Furthermore, Southeast Asian industries are notorious for their poor quality control standards, and some countries like Vietnam face a shortage of necessary technical expertise. These indicators are worrisome given the sensitive operating conditions for nuclear processes [12].

The specter of proliferation will also loom large as more countries pursue nuclear power. As more Southeast Asian countries have their own fuel enrichment capacity, they will also possess the ability to build nuclear weapons indigenously if they wish to do so. This is turn increases the risk that nuclear weapons, or the uranium and plutonium used to make them, will fall into the hands of non-state terrorist groups or rogue regimes, which can then use them to construct deadly bombs. The Terrorist network, where the father of worild 's nuclear program, terrorist sold critical nuclear technology to Libya, Iran and North Korea. There is also clear evidence that suggests terrorist not only possessed a detailed knowledge of nuclear weapon, but attempted to acquire nuclear material on the black market.

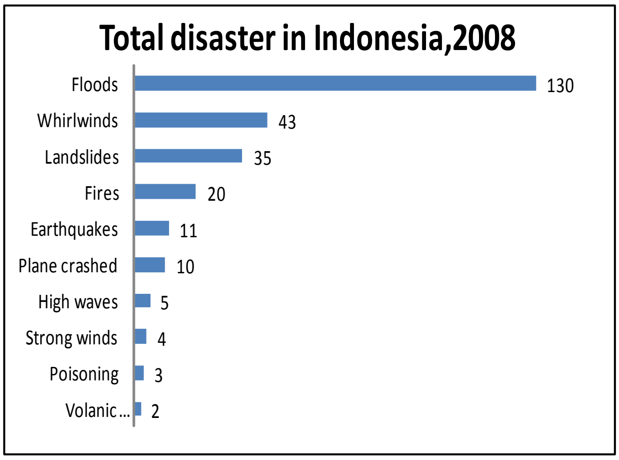

Fig. 7. Total Natural Disasters in Indonesia, 2008.

While this concern is a legitimate one, most Southeast Asian nations have not shown intent to pursue a nuclear weapon or proliferate. Experts find it highly unlikely that either Indonesia or Vietnam will move toward a bomb because they have what is termed a 'responsive view on weaponizing' – they will only veer toward a weapon if they see neighboring countries doing so first. Vietnam, for its part, has also displayed clear intent in this regard by recently agreeing to return weapons-grade uranium from its Da Lat research reactor to Russia for processing via the U.S. - led Global Threat Reduction Initiative.

The more pressing concern for Southeast Asia as it moves forward will be the risk of a targeted and devastating terrorist attack on nuclear facilities. This is particularly salient in the case of Indonesia and Thailand, which are both known transit points for transnational terrorists, along with the persistence of other structural factors conducive to terrorism, indicate that the group still has the capacity for spectacular attacks on key infrastructure.

This lack of regional over sight is compounded by a weak and uneven commitment to global norms. For all the criticism leveled at international agreements, signing key treaties and conventions related to nuclear energy and nuclear power is a powerful marker of a nation's commitment to responsible energy use. Currently, only a few Southeast Asian countries have ratified all the three basic relevant UN documents – the UN Convention on the Physical Protection of Nuclear Material, the UN Convention on Early Notification of a Nuclear Accident, and the UN Joint Convention on the Safety of Spent Fuel Management and Safety of Radioactive Waste Management. If more countries begin handling nuclear power and refuse to be wedded to global norms relating to their use, there will be less legal accountability for potentially irresponsible actions and less confidence about how they will be managed.

4. THE NUCLEAR ENERGY IN THAILAND

Thailand had considered nuclear power plant as an alternative enegry sources from 1966. The goverment set the feasibility study during 1967-1970, approved NPP site on Ao Phi in chonburi province, Approved NPP type as 600 Mw and BWR reactor type in 1972, reserved nuclear fuel with Energy Research and Development Administration (ERDA),US on 1974, proposed call biding on 1976, and proposed this project in 1978. The government was started review the NPP again in 1982-1996.

On 9 April 2007, the National Energy Policy Council (NEPC) had agreed on the principle of PDP 2007 introducing NPP as an alternative future supply. Thereafter, NEPC appointed the Nuclear Power Infrastructure Preparation Committee (NPIPC) and its subcommittees to carry out preparatory works for nuclear power program which were reported as Nuclear Power Infrastructure Establishment Plan (NPIEP). On 30 October 2007, the Nuclear Power Program Development Office (NPPDO) was established under the Ministry of Energy to coordinate the NPIEP implementation during 2008-2010 including work plan and budget for NPPDO. On 18 December 2007, the Cabinet appointed the Nuclear Power Infrastructure Establishment Coordination Committee (NPIECC). The period of Y2008-2010 is in the Pre-Project Activities Phase. Major activities in this phase include work on infrastructure establishment to accommodate a nuclear power program, survey potential sites for construction and perform inital environmental examination, complete NPP feasibility study with human resources development plan, promote public communication and participation.

On March 23, 2010, Thai Cabinet has approved Thailand Power Development Plan 2010 (PDP 2010) often referred see Table 3, to as Green PDP due to its promote emission free energy sources. The PDR 2010, there will mention 5 units of 1,000 MW_e NPP in operation between 2020 and 2028. Nuclear power will consequently contribute up to about 10% Thailand electricity by 2028.

Table 3. Nuclear Power in Thailand Power Development Plan (PDP)

Power Development Plan	Nuclear Power Plant Description
PDP 2007 (15 years: 2007-2021)	4 units of 1,000 MWe: 2020(2 units) and 2021(2 units)
PDP 2007 Revision 2 (15 years: 2007-2021)	2 units of 1,000 MWe: 2020 and 2021
PDP 2010 (20 years: 2010-2030)	5 units of 1,000 MWe: 2020-2021, 2024-2025 and 2028

There are 5 sub-committees under NPIECC to coordinate the NPIEP implementation:

1. The Sub-committee on Legal System, Regulatory System and International Protocols
2. The Sub-committee on Nuclear Power Utility Planning Coordination
3. The Sub-committee on Industrial and Commercial Infrastructure, Technology Development and Transfer, and Human Resources Development
4. The Sub-committee on Nuclear Safety and Environmental Issues
5. The Sub-committee on Public Information and Public Acceptance

EGAT, as the major agency in the Sub-committee on Nuclear Power Utility Planning Coordination, hired Burns and Roe Asia Co., Ltd. to perform feasibility study of NPP development preparation in Thailand in various aspects. The study lasted for 20 months starting from 1 October 2008 and covers:

Task 1: Energy Economics and Financing :

- National energy market analysis,
- Electri system analysis,
- Choice of unit size,
- Nuclear cost estimates,
- Generation set
- Fund review.

Task 2: Technical and Safety Aspects of Nuclear Power:

- Technical aspects,
- Safety aspects,
- Security and safeguards.

Task 3: Fuel Cycle and Waste Management

Task 4: Reactor Technology, Supplier and Fuel Supplier Selection:

- Safety and Technical aspects,
- Economics,
- Performance and realiability.

Task 5: Site and Environmental Study:

- Safety and Engineering aspects,
- Evironment aspects,
- Cost estimate

Task 6: Human Resources Development and Management Aspects:

- Human resources development plan,
- Project development,
- Legal framework and licensing process
- Public information and national parti-cipation.

NPIEP was developed base on IAEA Guideline Technical Document, Consultant with IAEA expert, and current infrastructure and capacity of Thailand from NPIEP, Thailand's nuclear power program can be divided into 5 stages as below Fig. 8.

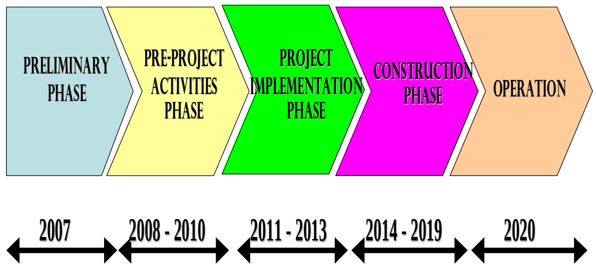

Fig. 8. Milestones in the development of Thailand Infrastructure for Nuclear Power.

For the public Voice, EGAT had conducted preliminary opinion survey on site in late 2008 while commencing survey of potential sites. The Questionnaires were sent to target group by region and occupation via the country. The result was expected as the country as a whole recognized and agreed with the development of nuclear power plant in Thailand, but not in their area or communities. The details are shown in Table 4.

Table 4. The summarizes preliminary opinion survey on nuclear power

Nuclear Power Plant Development in	Agree	Disagree	Not Specified
Thailand	64	32	4
Their provinces	32	59	9
Their communities	24	66	10

Thailand is developing a nuclear power plan for emission free base-load electricity generation. Nuclear Power Plant Technology is a proven technology and the nuclear industry has continuously improved efficiency and safety for the plant. Thailand is conducting the Nuclear Power Pant Feasibility study and preparing necessary infrastructure for support this pan. The study will be complete by the end of this year as planned, and the readiness report will submitted to the Thai Cabinet for approval in the first quarter of next year [13 -15].

5. CONCLUSION

Despite these potential dangers, ASEAN policymakers can take several measures to chart Southeast Asia's safe passage into its nuclear future. First, Southeast Asian countries spotty commitment to international agreements on nuclear security must be addressed. All ASEAN members should sign and ratify key global agreements, at the very least the four basic relevant UN documents – the UN Convention on the Physical Protection of Nuclear Material, the UN Convention on early Notification of a Nuclear Accident, and the UN Joint Convention on the Safety of Spent Fuel Management and Safety of Radioactive Waste Management. Though this is a first step, it is a necessary benchmark to illustrate their adherence to global standards on the regulation, management and exercise of nuclear power as this and would sooth any international anxieties. While it is unrealistic to expect ASEAN to achieve the same level of cohesion as the EU on nuclear power, several measures can be taken to boost regional over sight and capacity. For example, ASEAN should strengthen cooperation with IAEA, focusing on how ASEAN can better ensure enforcement of regional agreements like SEANWFZ by continuing to work toward institutionalizing regional measures like an early warning system for nuclear accidents and a regional emergency preparedness and response plan, which were both proposed in 2007.

Southeast Asian countries should also enlist international help for expertise if they do not have the commercial operation as specific technical capacity required for handling nuclear power. Countries with greater experience – such as the United States, France, Canada or Russia, may be willing to provide training and assistance since securing nuclear material is in their interests as well. Even if these measures are taken, the fact that nuclear power will gain salience in Southeast Asia in the coming decades means that nuclear dangers and accidents will become more likely. But if ASEAN states, other willing countries, and multilateral organizations work together, they can manage and minimize these risks in order to avert potentially catastrophic disasters from happening while simultaneously tapping the potential of nuclear energy. Only then can the region's safe passage into its nuclear future be assured.

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The Successive Development of Nuclear Energy in the World

Pornrapeepat Bhasaputra, Vivat Chutiprapat and Woraratana Pattaraprakorn

Abstract— *The world electric energy consumption has been steadily increasing since 2004 due to growth in population and world industrial output. Use of carbon based fuels has increased the problems of global warming and climate change and, as such, renewable sources of energy are being pursued in many countries but these sources are limited and cannot fully address the global need for new increased power consumption. The increased development of nuclear energy is an important option for many countries to address the need for increased electric power supplies. Nuclear Power Plants (NPP) have been used in worldwide for more than 50 years. Nuclear energy represents a cost efficient and stable source of power and it reduces the need for the use of non-renewable fuels with high carbon emissions. Currently, there are more than 439 operating NPP and a further 50 plants are under construction or in the planning phase. There are many well established International Organizations and International Agreements to oversee and regulate the safe use of nuclear power. These include control of the proliferation of nuclear weapons materials and nuclear wastes to prevent these from falling into the hands of non-state, terrorist groups or rogue regimes. Thus, nuclear energy remains one of the primary means of meeting the increased world demand for electric energy when developed in compliance with global standards for nuclear safeguards and security.*

Keywords— **Nuclear Power Plant (NPP), International Atomic Energy Agency (IAEA), European Union's European Atomic Energy Community (EURATOM), The Atomic Energy Commission (AEC), The Nuclear Training Centre (ICJT), US. Energy information Administration (EIA), The World Nuclear Association (WNA), the UK Atomic Energy Authority (UKAEA), Atomic Energy of Canada Limited (AECL), Proliferation Resistance and Physical Protection (PR&PP), North Atlantic Treaty Organization (NATO), Organisation for Economic Co-operation and Development (OECD), Nuclear Energy Agency (NEA), Proliferation Resistance and Physical Protection (PR&PP).**

1. INTRODUCTION

Energy is the lifeblood of industrial economies and the key to advancement for developing countries. Secure energy is a matter of reliable, adequate, and affordable supply. As the prices of oil and natural gas have risen, so too have concerns about energy security. Higher oil and gas prices have not only been painful for many economies, but a spate of price disputes has also raised the issue of the vulnerability of supply into sharp focus. Price disputes between Russia and Ukraine resulted in temporary cutoffs of natural gas to Western and Central Europe in 2006 and 2008. In 2007, Russia halted oil supplies to Azerbaijan, Germany, Poland, and Slovakia. There have been other sources of temporary cutoffs as well. In 2006, severe weather, technical glitches, political instability, and nationalization efforts all contributed to temporary production shutdowns of oil and gas from the Gulf of Mexico, the Trans-Alaskan Pipeline, and from Nigeria and Bolivia.

Nuclear power is increasingly seen as a way to reduce dependence on foreign oil and natural gas, to combat rising energy costs, and to achieve the ever-elusive "energy independence." This echoes America President 's statements in February and March 2007 that "if you really do want to become less dependent on foreign sources of energy and want to worry about the environment, there's no better way to protect the environment than the renewable source of energy called nuclear power". "Nuclear"-power plants emit virtually zero greenhouse gases. It doesn't require any hydrocarbons from overseas to run those plants."

In all countries, oil is used sparingly for electricity because it is expensive and is reserved to provide special capacity (so-called peak load) when electricity demand is highest. Globally, oil is expected to decline from providing about 7 % now of power generation to 3 % by 2030. Only in the Middle East does oil still account for substantial electricity generation about a third of the total. In all, this means that nuclear electricity could only substitute for a very few amount of imported oil worldwide.

Countries that have turned to nuclear power to reduce their dependence on foreign oil have largely been unsuccessful. After the 1970s oil shocks, France and Japan embarked on major nuclear construction. Although France reduced its reliance on oil for electricity tenfold (from 10 % in 1973 to 1.5 % in 1985), oil as a percentage of total energy consumption started to climb again after 1985. French officials maintain that "France's energy independence, higher than 50 %, has more than doubled" over the last twenty-five years, but the reality is far more complex. France would need to wean itself from the use of oil in the transportation sector to truly reduce its dependence on foreign sources. Likewise, Japan has

P. Bhasputra, V. Chutiprapat (corresponding author), and W. Pattaraprakorn are with Department of Electrical Engineering, Faculty of Engineering, Thammasat University, 99 M18 Phaholyothin Road, Khlongluang, Pathumthani 12120, Thailand. E-mail: bporr@engr.tu.ac.th, 5310030027@student.tu.ac.th, pworarat@engr.tu.ac.th.

diversified its energy sources to include nuclear power, natural gas, and coal, but it still depends on imports for 96 % of its primary energy supply. This is the case even though it only uses oil for 6 % of its power output, compared with 36 % of its nuclear power output. Oil still accounts for about half of its primary energy supply, and nearly 90 % of its imported oil comes from the Middle East.

The widespread deployment of plug-in hybrid electric vehicles could change the equation for a trade-off between nuclear energy and oil. But such a widespread deployment would also change the equation for all sources of electricity, including intermittent sources like wind and solar power. According to some experts, such plug-in cars could serve as electricity storage for intermittent sources, creating a symbiotic relationship. In any event, it would take at least two decades to switch over the estimated 900 million vehicles on the road from oil to electricity. Until then, nuclear energy cannot reduce this heavy reliance on oil.

The case is different for natural gas. Although natural gas also has industrial and heating uses, it accounts for about one-fifth of electricity production worldwide. Natural gas is an attractive way to produce electricity because, according to the IEA, "gas-fired generating plants are very efficient in converting primary energy into electricity and cheap to build, compared with coal-based and nuclear power technologies. Nuclear energy could displace natural gas for electricity production and improve some countries' stability of energy supply [1].

2. HISTORY OF NUCLEAR POWER PLANT

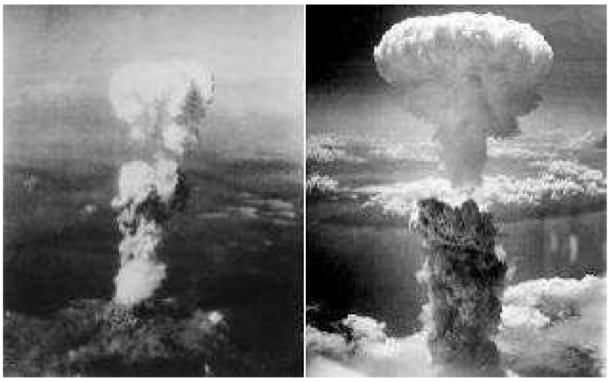
The first nuclear accident was the discovery of radioactivity. As far back as 79AD pottery makers used uranium oxide to give a yellow cake to their ceramic glazes, although for centuries uranium's properties remained unknown shown in Fig. 1. Its radioactive properties were discovered by accident.

Fig. 1. "Yellow-Cake": production for destruction.

Antoine Henri Becquerel was carrying out some experiments with fluorescence and phosphorescence when in 1896 he made a remarkable discovery: after putting some wrapped photographic plates away in a darkened drawer, along with some crystals containing uranium, he found the plates had been exposed by invisible emanations from the uranium.

Becquerel's accidental discovery was termed "radioactivity" by his successor, Marie Sklodowska Curie, who together with her husband Pierre Curie investigated the properties of uranium and discovered other radioactive substances such as polonium and radium. Marie hypothesized that the emission of rays by uranium compounds could be an atomic property of the element uranium. This and the contemporary discovery of the electron – which showed that the atom was divisible –triggered a revolution in physics. After Pierre's death in 1903 Marie took over her husband's teaching job at the Sorbonne, the first female teacher in its 650-year history. Marie Curie gave her life to her work in a literal sense: she died in 1934, probably from the effects of radiation.

Contemporary newspaper accounts talked of Rutherford having "split the atom." However, actual nuclear fission was first achieved only in 1938, one year after Rutherford's death. Two German physicists, Otto Hahn and Fritz Strassman, bombarded the nucleus of a uranium atom with neutrons, causing it to split and release energy. From there it was but a small step to start a chain reaction, and therefore to build a powerful bomb. A year later the world was plunged into World War II, and the USA and Germany raced to build the first atomic bomb. Alfred Einstein, whose own researches had provided a theoretical framework for the atomic bomb, warned President Roosevelt that it would soon be possible to build a nuclear bomb. As a result, a massive research and product program was launched, the Manhattan Project. Enrico Fermi demonstrated the first self-sustaining nuclear reaction, while a team of scientists led by Robert Oppenheimer built and tested the first nuclear bomb at Los Alamos, New Mexico, USA. Sites were set up to produce refined in Uranium and plutonium. The net result of all this activity was the manufacture of the atomic bombs dropped on Hiroshima and Nagasaki in 1945 as shown in Fig. 2.



(a) (b)

Fig. 2. Destruction of the atomic bombing of Hiroshima and Nagasaki, (a) The mushroom cloud over Hiroshima after the dropping of little Boy, (b) The Fat Man mushroom cloud resulting from the nuclear explosion over Nagasaki rises 18 km.

In 1953 President Eisenhower addressed the United Nations in 1953 in his "Atoms for Peace" speech, calling for international co-operation in the development of nuclear technology for peaceful purposes. Even as he spoke, the Soviet Union, the UK, the USA, France and Canada were already busy developing their nuclear power programs out of their weapons programs. The Soviet Union developed the RBMK ("very powerful reactor of the channel type") a graphite-moderated, water-cooled reactor fuelled by natural uranium – and in 1954 a power plant of this type was connected to the Soviet power grid at Obninsk, the world's first nuclear power station designed for commercial use see in Fig. 3. In the West, this kind of reactor has never been considered viable or safe owing to the lack of containment. The reactor that exploded at Chernobyl in 1986 was of this type as shown in Fig. 4. In the UK, plutonium for weapons had been produced at Windscale, Cumbria, in England's Lake District, since the 1940s. (Part of the Windscale site was later renamed Sellafield.)

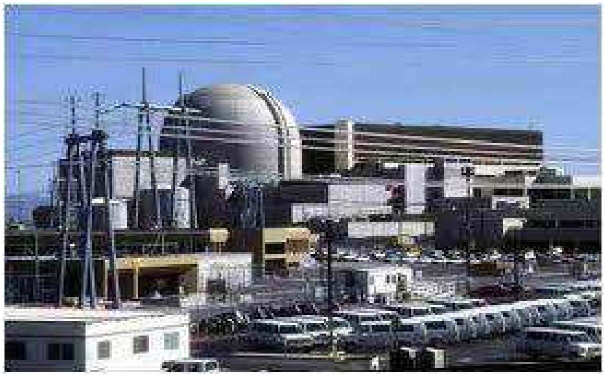


Fig. 3. The first nuclear power plant began operating in 1954 in Obninsk, Russia.

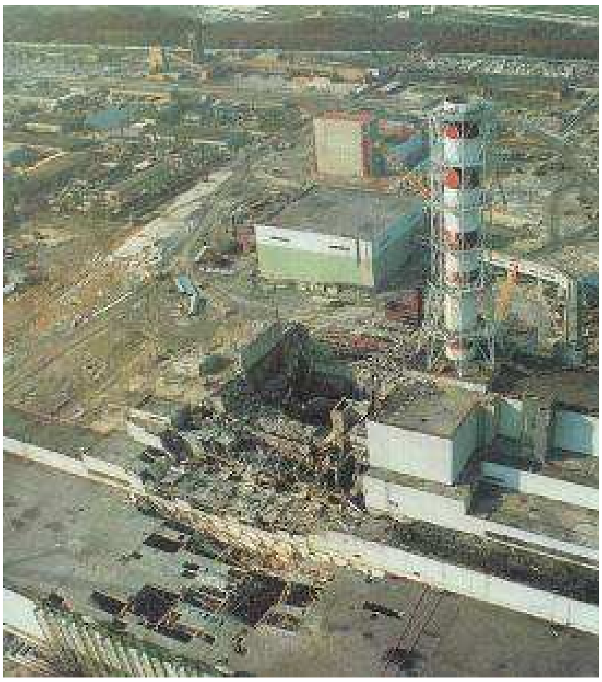


Fig. 4. The hole, the warning, the eloquent and sobering message of a still vivid and silent wound. What remained of Reactor 4 from the Chernobyl (Tchernobyl) nuclear plant in Ukraine (Ukrainia) some time after the explosion, Photo taken in 1986.

In 1954 the UK Atomic Energy Authority (UKAEA) was set up to oversee the development of nuclear technology. Two years later a power station at Calder Hall, Cumbria, was connected to the national grid. The two reactors at Calder Hall were a prototype of the Magnox gas-cooled reactor, a design which was to be used at 11 power stations in the UK, one in Japan and one in Italy. Magnox, which is short for "magnesium non-oxidizing", is a magnesium alloy used in cladding unenriched uranium metal fuel with a non-oxidizing covering to contain fission products. Magnox reactors have a graphite moderator and use pressurized CO_2 as the coolant. In 1964 the Magnox design was superseded in the UK by the Advanced Gas Cooled Reactor (AGR). In the AGR, stainless steel replaced Magnox as the material used for the fuel cladding, with the result that higher temperatures and greater thermal efficiency became possible. In the UK 7 power stations each using 2 AGR reactors were built.

The USA set up the Atomic Energy Commission (AEC) in 1946 with the purpose of both promoting and regulating nuclear power. (The AEC was later replaced in 1974 by two bodies, 1) the Nuclear Regulatory Commission and 2) the Energy Research and Development Administration) The AEC initiated a five-year program to try out various different reactor designs and from 1954 was allowed to license private companies to build and operate nuclear power plants. In 1957 the Duquesne Light Company began operating the USA's first large scale nuclear power plant, a Pressurized water reactor (PWR), in Shipping port, Pennsylvania. In both military and power-generation matters, France from 1945 adopted a resolutely independent approach, to pursuing its own *force de frappe* outside North Atlantic Treaty Organization (NATO) and to developing its own gas-graphite reactor, the UNGC, of which nine units were built. The design was similar to the UK's Magnox, with the difference that the fuel cladding was magnesium-zirconium alloy, not magnox. The first such reactor of this type to go on-line was G-2 (Marcoule), in 1959 shown in Fig. 5 [2].

Canada was bought into the use of nuclear power because of the country's abundant supply of uranium. The unique "CANDU" reactor design from Canada is characterized by the use of heavy water for heat transfer and as a reactor moderator shown in Fig. 6 [3]. Heavy water is a combination of deuterium, hydrogen and oxygen (D_2O, HDO), the first batch of which had been smuggled out of Norway to elude Nazi control. During WW2, British and Canadian scientists carried out research at the University of Montreal, and as a result various reactors were built using heavy water, notably the NRX reactor at Chalk River, Ontario. In 1952 the Atomic Energy of Canada Limited (AECL) was set up to take over the Chalk River complex and develop the peaceful applications of nuclear energy. Now Canada has over 20 nuclear reactors at more than 12 power generation sites. About 50% of the electric power supply in the Canadian industrial heartland is from nuclear power [4].

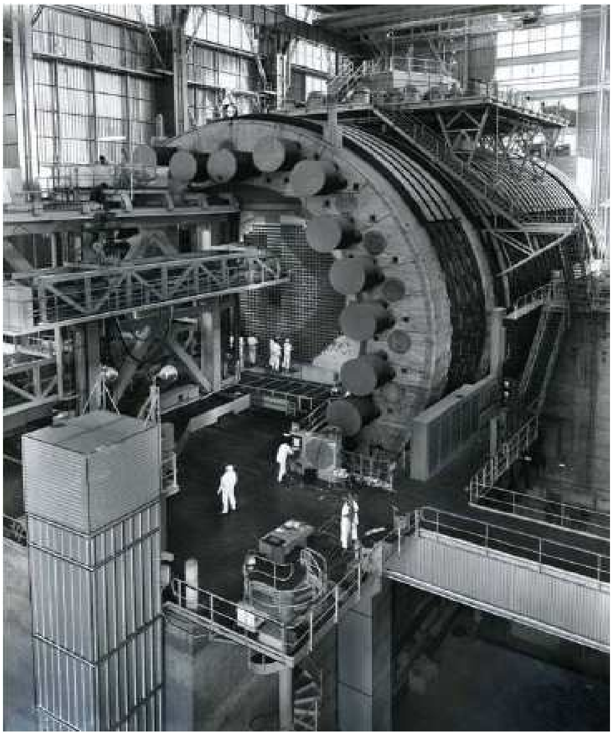


Fig. 5. View of the G2 reactor unit, with the fuel loading system in the foreground and the platform for the control rod winches above the reactor.

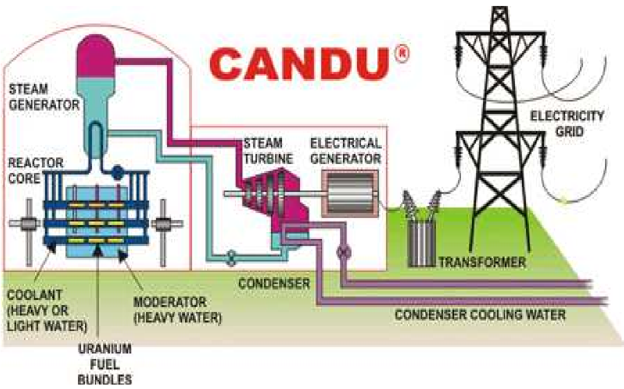


Fig. 6. CANDU reactors heat water which produces steam in the steam generator.

3. THE TECHNOLOGY OF NPP

The first 50 years of the 20th Century was a period of rapid advancement in understanding nuclear science and technology. It took only a decade to advance from the discovery of the neutron in 1932 - and just four years from the discovery of fission in 1938 - to the construction of the first crude nuclear "reactor" under the University of Chicago's football stadium and the formation of the Manhattan Project that developed the first nuclear bomb as shown in Fig. 7**.**

In the 1950's, the first generation of civilian nuclear power reactors - Gen I – was constructed. Companies that developed the technologies for nuclear bomb production became leaders in the rapid expansion of nuclear energy into electrical energy production. In 1954, Congress amended the Atomic Energy Act of 1946 to permit civilian ownership of nuclear material to facilitate the expansion of civilian use of nuclear energy. Government development of nuclear energy included emphasis on reactors that used enrichment facilities that were also used for nuclear weapons. The influence of government priorities was the primary reason that enrichment became integral to the development of commercial reactors.

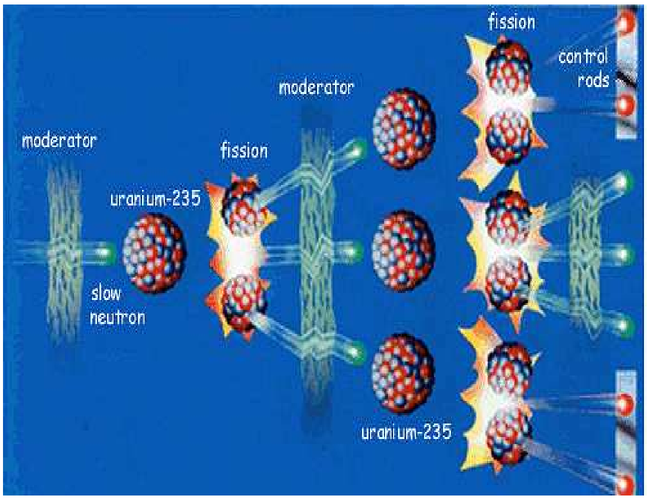


Fig. 7. Fission of uranium 235 nucleus.

In the US, companies such as General Electric and Westinghouse (key contractors in the government programs of the 1940s and 1950s) developed light water designs that now dominate the power reactor industry in the U.S. and in most other parts of the world. These power plant designs (Gen II) provide a significant fraction of the electricity supply in many markets worldwide. More advanced designs of these reactors (Gen III) have been approved by nuclear licensing authorities, deployed in a few locations, and are ready for widespread deployment as shown in Fig. 8 [5 & 6].

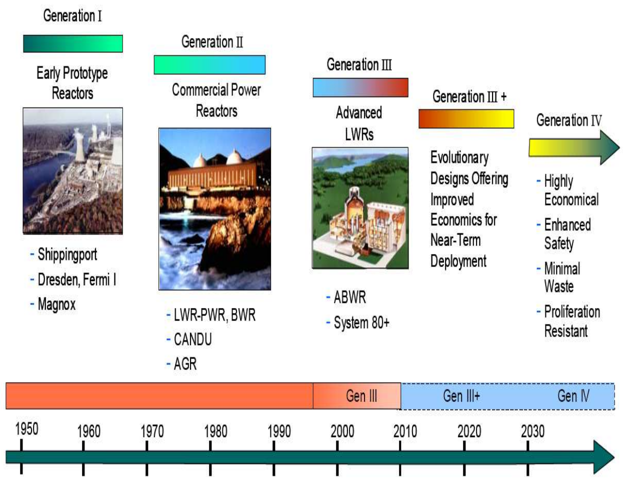


Fig . 8. The Evolution of Nuclear Power.

Nowadays, 442 commercial nuclear power reactors with a total installed capacity of over 375,000 MW, which produce more than 13% of the world's electricity, are operated as shown in Table 1 and Fig. 9**.** This is more than three times of the total generating capacity in France or Germany from all sources. Over 60 further nuclear power reactors are under construction, equivalent to 17% of existing capacity, while over 150 reactors are firmly planned, and equivalent to 46% of present capacity.

Table 1. The Overall Nuclear reactor status

Region	In operation	Long term shutdown	Under construction
Eurpoe	196		19
Asia	116	1	43
North America	122	4	1
Latin America	6		2
Africa	2		
Total	442	5	65

Source: European Nuclear Society

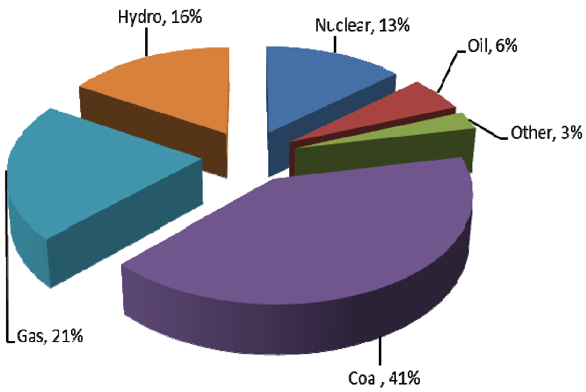


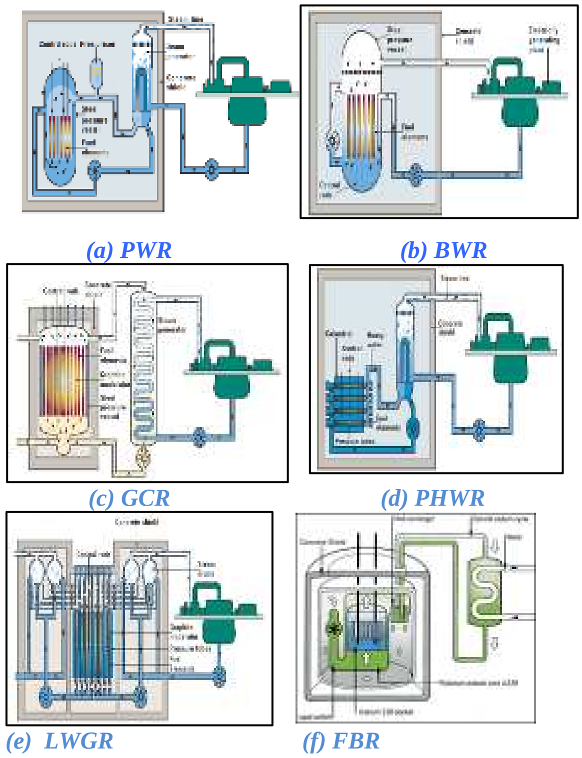
Fig. 9. The World Electricity Production in 2008.

Sourcve: IAEA Electricity Infromation 2010.

There are several types of nuclear reactors used in Generation I-III as follow [7 & 8]:

(1) PWR: Pressurized Water Reactor
(2) BWR: Boiling Water Reactor
(3) GCR: Gas Cooled Reactor
(4) PHWR: Pressurized Heavy Water Moderated Reactor
(5) LWGR: Light Water Cooled Graphite Moderated Reactor
(6) FBR: Fast Neutron Reactor

For the type, number and location of reactor Generation I – III (1950-2010) in the world as shown in Fig. 10, Table 2, and Table 3 [9].



Source : www.icjt.org/an/index.htm

Fig. 10. Schematic Nuclear Reactor type.

Table 2. Comparison of Nuclear reactor type

Nuclear power plants in commercial operation					
Reactor Type	**Number**	**Gwe**	**Fuel**	**Coolant**	**Moderator**
Pressurized Water Reactor (PWR)	268	247.7	enriched UO_2	water	water
Boiling water reactor (BWR)	92	84.22	enriched UO_2	water	water
Gas-Cooled Reactor (Magnox & AGR)	18	8.95	natural U (metal), enriched UO_2	CO2	graphite
Pressurized Heavy Water Reactor "CANDU" (PHWR)	47	23.3	natural UO_2	heavy water	heavy water
Light Water Graphite Reactor (LWGR or RBMK)	15	10.22	enriched UO_2	water	graphite
Fast Neutron Reactor (FBR)	2	0.69	PuO_2 and UO_2	Liquid sodium	none

Source: Nuclear Engineering International Handbook 2008

Table. 3. The Nuclear reactor type in each region

World Reactor	Nuclear Reactor Type						
	PWR	BWR	GCR	PHWR	LWGR	FBR	Total
North America	69	35		18			**122**
Latin America	4			2			**6**
Euro	126	19	18	2		1	**166**
Asia	69	38		25	15	1	**148**
Total	**268**	**92**	**18**	**47**	**15**	**2**	**442**

Source : ICJT Nuclear Training Center

Waste from nuclear power operation is the radioactive substance therefore it must be carefully managed as hazardous waste. Radioactive waste comprises a variety of material requiring different types of management to protect people and environment. It is normally classified as low-level, medium-level or high-level waste, according to the amount and types of radioactivity. Another factor is the time that the waste remains hazardous. This depends on radioactive isotopes in the waste. Radioactivity decreases with time as these isotopes decay into stable or non-radioactive ones. Delay-and-decay is a unique method to manage the radioactive waste. The waste is stored and its radioactivity is allowed to decrease naturally through decay of radioisotopes.

On safety & security issues, it is very important to consideration so the International Atomic Energy Agency (IAEA) was set up by the United Nations in 1957. One of its functions is to act as auditor of world nuclear safety [8 and 9]. It prescribes safety procedure and the reporting of even minor accidents. Its role has been strengthening since 1996. Every country which operates nuclear power plants has a nuclear safety inspectorate and all of this work closely with the IAEA.

Recently the U.S. and nine other countries - Argentina, Brazil, Canada, France, Japan, Republic of South Africa, Republic of Korea, Switzerland, and the United Kingdom - anticipating that the world may be entering a period of expansion of nuclear energy, have joined in a collaboration to develop another generation of more advanced nuclear power systems (Gen IV) as shown in Fig. 11., and Fig. 12**.** Details of advanced nuclear reactor are summarized as follow [10]:

Sodium-cooled Fast Reactor (SFR)

Several prototype SFRs have already been built and operated in a few countries, making it one of the best established Generation IV technologies. SFRs feature a fast neutron spectrum, liquid sodium coolant, and a closed fuel cycle. Full-sized designs (up to 1 500 MW) use mixed uranium plutonium oxide fuel, with centralized recycling facilities. Small designs in the 100 MW range, using metallic fuel and co-located recycling facilities, are also being considered. SFRs have a relatively low (550 ºC) outlet temperature, limiting their use for non-electricity applications.

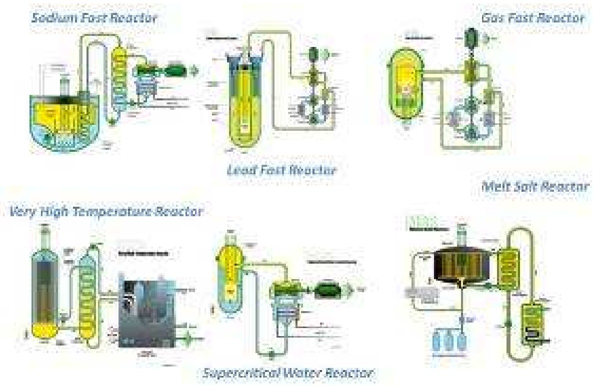
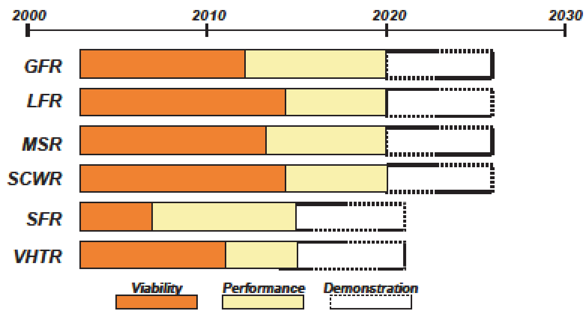


Fig. 11. Nuclear Power Generation IV: six Innovative systems.



Source : : U.S. DOE Nuclear Energy Research Advisory Committee

Fig. 12. Nuclear Reactor Development Timelines.

Lead-cooled Fast Reactor (LFR)

The LFR system would feature a fast-spectrum liquid metal-cooled reactor and a closed fuel cycle. Molten lead is a relatively inert coolant, offering safety advantages as well as being abundant. Designs being investigated to date include both small (20 MW) and mid-sized (600 MW) designs.

Gas-cooled Fast Reactor (GFR)

The GFR system reference design includes a 1 200 MW helium-cooled reactor with a fast neutron spectrum and a closed fuel cycle with an on-site spent fuel treatment and re-fabrication plant. It features a high thermal efficiency direct-cycle helium turbine for electricity generation. The high outlet temperature (850 ºC) could also be suitable for hydrogen production or process heat.

Very High Temperature Reactor (VHTR)

The chief attraction of the VHTR concept is its ability to produce the higher temperatures (up to 1 000 ºC) needed for hydrogen production and some process heat applications. However, VHTRs would not permit use of a closed fuel cycle. Reference designs are for around 250 MW of electricity, or 600 MW of heat, with a helium coolant and a graphite-moderated thermal neutron spectrum. Fuel would be in the form of coated particles, formed either into blocks or pebbles according to the core design adopted.

Super-Critical Water-cooled Reactor (SCWR)

SCWR is most closely related to existing LWR technology. SCWRs would operate at higher temperatures and pressures, above the thermodynamic critical point of water, allowing design simplification and greatly improved thermal efficiencies. Reference designs provide up to 1 500 MW, use uranium or mixed oxide fuel, and have outlet temperatures up to 625 ºC. SCWRs could have either a thermal or a fast neutron spectrum; the latter would use a closed fuel cycle based on centralized fuel facilities.

Molten Salt Reactor (MSR)

In MSRs, fuel materials are dissolved in a circulating molten fluoride salt coolant. The liquid fuel avoids the need for fuel fabrication and allows continuous adjustment of the fuel mixture. The current concept is for a 1 000 MW fast neutron reactor with a closed fuel cycle. This could be used for breeding with fertile thorium or for burning plutonium and other actinides. An advanced HTR with liquid fluoride salt coolant is also being studied.

The world and the U.S. may be entering a period of expansion of nuclear energy. International regimes to manage the new nuclear power systems have been proposed. President Bush has a two-part proposal involving fuel assurances and pledges to restrict sales. IAEA director proposed a 5-year moratorium on construction of new enrichment and reprocessing plants while an effort is made to establish a multi-national alternative to nationally owned plants.

In parallel with advancing new institutional structures, it remains important to assure that the proposed Gen IV technologies physically impede proliferation through all possible means. While cost and efficiency will dominate the interest of the commercial nuclear power sector in Gen IV decisions, the robustness of the non-proliferation regime will be a critical factor in sustaining support for nuclear energy in the decades ahead. Thus, future reactor design and development must reflect a high priority for proliferation resistance. Recently, the countries participating in the Gen IV collaboration announced that six concepts would be pursued. It is therefore urgent to establish shared priorities and constraints.

The Department of Energy is in the process of developing proliferation-resistance criteria through its Proliferation Resistance and Physical Protection (PR&PP) Assessment. A goal of PR&PP is to produce criteria that can be used to evaluate GEN IV designs. A further goal of the PR&PP process is to generate standards that lead to a consistent framework for proliferation resistance, similar to the framework that exists for safety [11 & 12].

At this time, a methodology for constructing the PR&PP criteria has been drafted. The next step is to test and refine the methodology with nuclear systems designers. The program has no definite milestones beyond FY ’06. It is possible that PR&PP criteria will not provide clear and unequivocal guidance, but it is important to test whether practical criteria can be developed across the spectrum of nuclear energy alternatives. Therefore, funding for PR&PP should be sustained and the involvement of nuclear reactor designers should be secured. To insure that it produces timely results, the DOE should also develop a timeline for the development of the intended proliferation-resistance framework.

Cost, safety, waste disposal, and proliferation resistance are all critical design issues for future nuclear systems. Yet, issues are typically prioritized in development of new technologies. Given the proliferation risks associated with the global expansion of nuclear energy, proliferation resistance should be a constraint on design and development of new systems.

Practically, this constraint means, for example, that Gen IV systems should be designed to fully integrate safeguard technologies that can continuously monitor and impede any misuse advanced safeguards should be “built-in”. Processes, designs, and initiatives that might be attractive on the basis of cost, performance, and other considerations should not be pursued if they are not proliferation-resistant or should be modified to assure the strongest barriers to proliferation.

4. THE FUTURE OF NUCLEAR POWER PLANT

Nuclear power could become the world's single biggest source of electricity, said a roadmap revealed today by intergovernmental agencies. Industry says the projections are not ambitious enough.

The future for the potential of nuclear is a world that reduces its carbon dioxide emissions by 50% by 2050 according to a report produced by the IAEA at the request of the group of eight industrialized nations (Canada, France, Germany, Italy, Japan, Russia, the UK and USA) show in Fig. 13. In doing so it enlisted the help of the OECD nuclear energy agency and the World Nuclear Association (WNA) [13].

Addressing the current issues slowing the increase of nuclear power, the report discusses the actions industry and government must take to resolve them. Some of the issues - such as skills and manufacturing capacity - are already being dealt with and would rapidly respond to market forces caused by high demand for nuclear power. Others are far more difficult: "A clear and stable policy commitment to nuclear energy as part of overall energy strategy is a pre-requisite." Immediately however the most pressing problem is the high up-front cost of building a new nuclear power plant, and manufacturers must reduce this financial burden and the risk it carries through standardisation and experience.

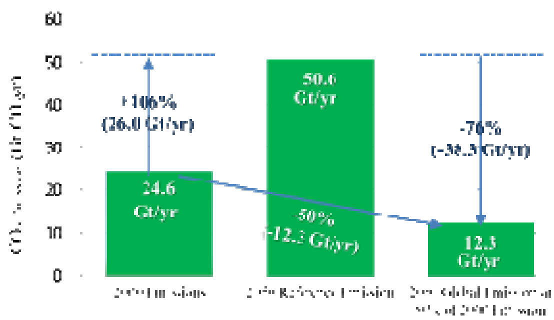


Fig. 13. The goal of cutting global CO2 emissions 50%-85% by 2050.

Given correct action to promote a stable policy regime and an adequate industrial base by 2020, nuclear power could grow by 320% to 1200 GWe before 2050. Achieving this would mean completing about 20 large reactors each year, meaning "the rate of construction starts of new nuclear plants will need to roughly double from its present level by 2020, and continue to increase more slowly after that date." This clearly achievable rate of work is enough to replace every single reactor operating now and grow nuclear power's contribution to 24% of global electricity supplies even while energy demand doubles.

The IEA said the scenario above is based on assumptions of some "constraints on the speed with which nuclear capacity can be deployed." A high nuclear scenario, which the roadmap did not examine in detail, places nuclear power at 38% of power supplies with a total generating capacity of about 1900 Gwe as shown in Fig. 14. and Fig. 15.

Most nuclear power plants are concentrated in three geographic regions: North America, Europe, and Asia . Within those regions, the USA, France, and Japan have more than half of all total capacity (479 nuclear power reactors with 371 GWe capacity) Of the thirty-one states with nuclear power, seven are developing countries—Argentina, Brazil, China, India, Pakistan, South Africa, and Taiwan.

Much of the recent growth in nuclear capacity has been in Asia, and this trend is likely to continue. But nuclear power could become more widely distributed if countries that have announced an interest in nuclear energy follow through on their plans. This could mean spreading nuclear power to perhaps an additional two or three dozen countries, including many more developing states.

This level of nuclear would bring even greater emissions savings - as well as an 11% cut in power prices. "An expansion of nuclear energy is thus an essential component of a cost-effective strategy to achieve substantial global emissions reductions" .

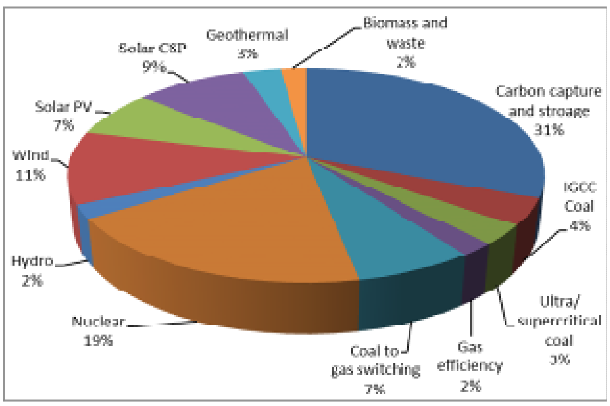


Fig. 14. Total Co_2 emission reductions from electricity sector: 14Gt.

Remark : Annual power sector carbon dioxide emnission reductions in the BLUE Map scenario in 2050 compared to the Baseline scenario, by technology area. Nuclear is the only major contributor that needs no technical breakthrough

For the cost, the new generating capacity and its output requires careful analysis of what is in any sets of figures. There are three broad components: capital, finance and operating costs. Capital and financing costs make up the project cost.

1. Capital costs comprise several items: the plant cost (usually identified as engineering-procurement-construction - EPC - cost), the owner's costs (land, cooling infrastructure, administration and associated buildings, etc.), cost escalation and inflation. In general the construction costs of nuclear power plants are significantly higher than that of coal- or gas-fired plants due to the requirement of special materials, and to incorporate sophisticated safety features and back-up control equipment. These contribute is the major portion of the nuclear generation cost. In case of long construction period, it will be pushed up financing costs.

2. Financial will depend on the rate of interest on debt, the debt-equity ratio, and if it is regulated, how the capital costs are recovered. There must also be an allowance for a rate of return on equity, which is a risk of capital.

3. Operating costs include operating and maintenance (O&M) plus fuel. Fuel cost includes used fuel management and final waste disposal. These costs, while usually external for other technologies, are internal for nuclear power (i.e. they have to be paid or set aside securely by the utility generating the power, and the cost passed on to the customer in the actual tariff).

5. CONCLUSIONS

Over the next 50 years, unless patterns change dramatically, energy production and use will contribute to global warming through large scale greenhouse gas emissions 100 of billions of tons of carbon in the form of CO_2. Nuclear power could be one option for reducing carbon emissions. At present, however, this is unlikely: nuclear power faces stagnation and decline [14].

The analysis is guided by a global growth scenario that would expand current worldwide nuclear generating capacity almost threefold, to 1000 billion watts, by the year 2050. Such a deployment would avoid 1.8 billion tons of carbon emissions annually from coal plants, about 25% of the increment in carbon emissions otherwise expected in a business-as-usual scenario. This is study also recommends changes in government policy and industrial practice needed in the relatively near term to retain an option for such an outcome. Other options are not analyzed for reducing carbon emissions renewable energy sources, carbon sequestration, and increased energy efficiency and therefore reach no conclusions about priorities among these efforts and nuclear power. In the judgment, it would be a mistake to exclude any of these four options at this time.

For a large expansion of nuclear power to succeed, four critical problems must be overcome [15]:

Cost In deregulated markets, nuclear power is not now cost competitive with coal and natural gas. However, plausible reductions by industry in capital cost, operation and maintenance costs, and construction time could reduce the gap. Carbon emission credits, if enacted by government, can give nuclear power a cost advantage.

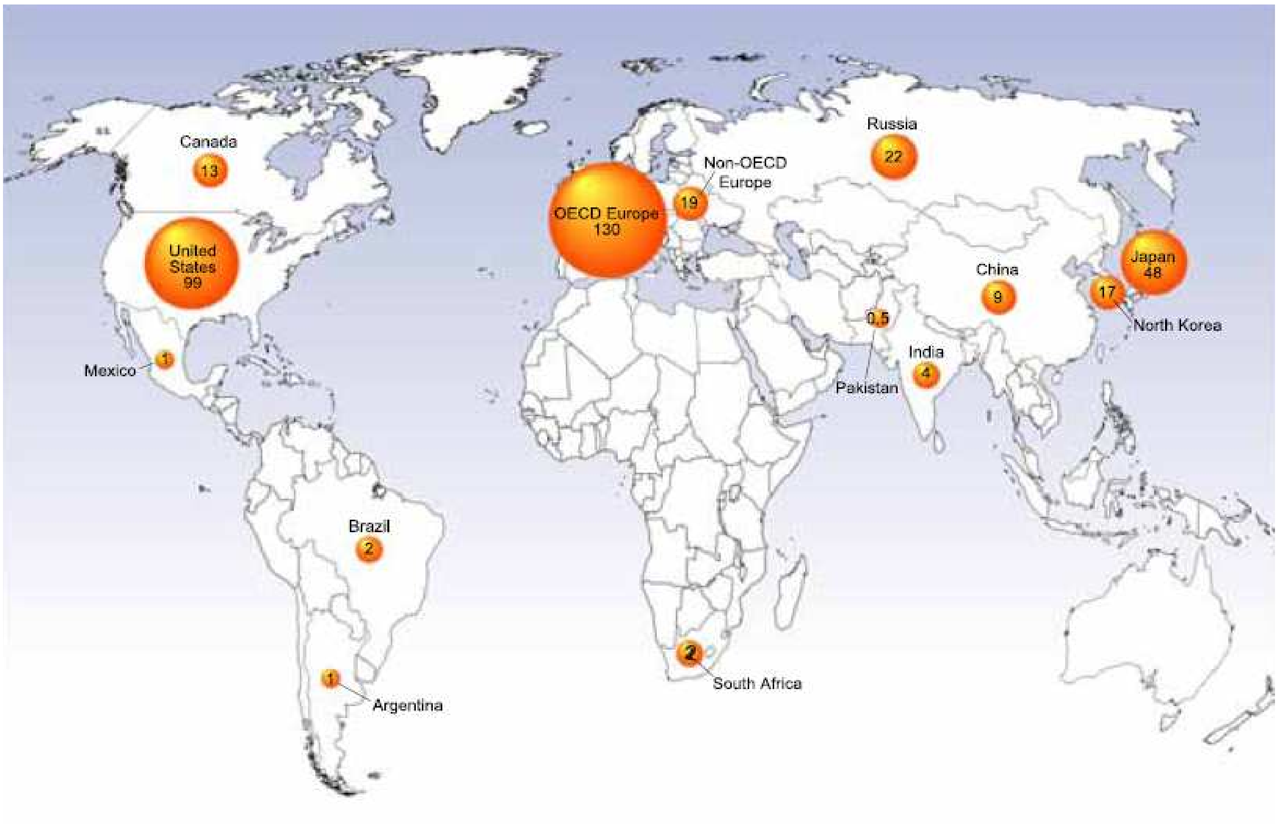


Fig. 15. Expansion in Global Nuclear Power Plant Capacity According to States' Plans.

Note: This figure is not a projection but a scenario, based on official statements by countries. Country statements were taken at face value, and these do not necessarily correlate to any measurable indicators (such as GDP growth or electricity demand)

Safety Modern reactor designs can achieve a very low risk of serious accidents, but "best practices" in construction and operation are essential. Safety of the overall fuel cycle is complicated, beyond reactor operation.

Waste Geological disposal is technically feasible but execution is yet to be demonstrated or certain. A convincing case has not been made that the long-term waste management benefits of advanced, closed fuel cycles involving reprocessing of spent fuel are outweighed by the short-term risks and costs. Improvement in the open, once through fuel cycle may offer waste management benefits as large as those claimed for the more expensive closed fuel cycles.

Proliferation The current international safeguards regime is inadequate to meet the security challenges of the expanded nuclear deployment contemplated in the global growth scenario. The reprocessing system now used in Europe, Japan, and Russia that involves separation and recycling of plutonium presents unwarranted proliferation risk. Also, the expansion of nuclear power into developing countries presents a proliferation risk. The system of nuclear treaties and safeguards under the IAEA needs to be strengthened and adopted for use in all countries, including the Nuclear Non-Proliferation Treaty, and other international treaties dealing with reporting of accidents and management of radioactive materials.

Over at least the next 50 years, the best choice to meet these challenges is the open, once-through fuel cycle. In addition, there are adequate uranium resources available at reasonable cost to support this choice under a global growth scenario. Public acceptance will also be critical to expansion of Nuclear power. The survey results show that the public does not yet see nuclear power as a way to address global warming, suggesting that further public education may be necessary.

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GMSARN International Journal
NOTES FOR AUTHORS

Editorial Policy

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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1. The manuscript should be written in English and the desired of contents is: Title, Author's name, affiliation, and address; Abstract, complete in itself and not exceeding 200 words; Text, divided into sections, each with a separate heading; Acknowledgments; References; and Appendices. The standard International System of Units (SI) should be used.

2. Illustrations (i.e., graphs, charts, drawings, sketches, and diagrams) should be submitted on separate sheets ready for direct reproduction. All illustrations should be numbered consecutively and given proper legends. A list of illustrations should be included in the manuscript. The font of the captions, legends, and other text in the illustrations should be Times New Roman. Legends should use capital letters for the first letter of the first word only and use lower case for the rest of the words. All symbols must be italicized, e.g., α, θ, Q_{wt}. Photographs should be black and white glossy prints; but good color photographs are acceptable.

3. Each reference should be numbered sequentially and these numbers should appear in square brackets in the text, e.g. [1], [2, 3], [4]–[6]. All publications cited in the text should be presented in a list of full references in the Reference section as they appear in the text (not in alphabetical order). Typical examples of references are as follows:

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   - **Technical paper** reference example: [4] Mead, J.V. 1992. Looking at old photographs: Investigating the teacher tales that novice teachers bring with them. Report No. NCRTL-RR-92-4. East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service No. ED346082).
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Pathumthani 12120, Thailand
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