SUPERSTRUCTURE OPTIMIZATION AND FORECASTING OF DECENTRALIZED ELECTRICITY GENERATION BASED ON PALM OIL BIOMASS

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To my real and spiritual parents and all those who loved and encouraged me

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ABSTRACT

Malaysia realizes the importance of addressing the concern of energy security to accomplish the nation's policy objectives by mitigating the issues of security, energy efficiency and environmental impacts. To meet the rising demand for energy and incorporation of Green Technology in the national policy, Malaysian government during the last three decades has developed several strategies and policies. National Green Technology Policy was an initiative, which marked the firm determination of the government to incorporate Green Technology in the nation's economy policy. Malaysia has abundant biomass resources, especially oil palm residues with power generation potential of about 2400 MW, which is promising for decentralized electricity generation (DEG). The aim of this study is to determine the best location to install appropriate biomass electricity generation plant in Johor and forecasting the electricity market (i.e. electricity demand) in order to provide a strategic assessment of measures for the local energy planners of Malaysia, as an optimization bottom-up model. A superstructure was developed and optimized to represent DEG system. The problem was formulated as Mixed Integer Nonlinear Programming (MINLP) and implemented in General Algebraic Modeling System (GAMS). Electricity demand was modeled using Adaptive Neuro Fuzzy Inference System (ANFIS). Based on GAMS and ANFIS models, palm oil biomass based DEG system and distribution network scenarios for current as well as next ten, twenty and thirty years have been proposed for State of Johor, Malaysia. Biomass from sixty six Palm Oil Mills (POMs) would be collected and transported to eight selected locations. Empirical findings of this study suggested that total production cost is minimized by placing biomass gasification based integrated combine cycle (BIGCC) power plant of 50MW at all eight locations. For 2020 Scenario, no additional infrastructure will be required. For 2030 Scenario, additional units of BIGCC of 50MW will be required at five out of eight locations. While for 2040 Scenario, again no additional infrastructure development will be needed. Total minimum cost varied from 6.31 M$/yr for current scenario to 22.63 M$/yr for 2040 scenario.

ABSTRAK

Malaysia menyedari kepentingan dalam menangani keprihatinan bekalan tenaga yang terjamin untuk mencapai objektif polisi negara dengan menangani isu-isu keselamatan, kecekapan tenaga dan impak alam sekitar. Untuk memenuhi permintaan yang semakin meningkat terhadap tenaga dan penubuhan Teknologi Hijau dalam polisi kebangsaan, kerajaan Malaysia dalam tempoh tiga dekad yang lalu telah membangunkan beberapa strategi dan dasar. Dasar Teknologi Hijau Negara adalah satu inisiatif, yang menandakan kesungguhan teguh kerajaan untuk menggabungkan Teknologi Hijau dalam polisi ekonomi negara. Malaysia mempunyai sumber biojisim yang banyak, terutama sisa kelapa sawit dengan potensi penjanaan kuasa kira-kira 2400 MW, yang menjanjikan untuk desentralisasi penjanaan elektrik (DEG). Tujuan kajian ini adalah untuk menentukan lokasi terbaik untuk memasang loji penjana elektrik biojisim yang bersesuaian di Johor dan meramal pasaran elektrik (iaitu permintaan elektrik) untuk menyediakan penilaian langkah strategik kepada jururancang tenaga tempatan Malaysia, sebagai pengoptimuman model bawah ke atas. Struktur utama telah dibangunkan dan dioptimumkan untuk mewakili sistem DEG. Masalah itu telah dirumuskan sebagai Pengaturcaraan Campuran Integer Bukan Linear (MINLP) dan dilaksanakan dalam Sistem Pemodelan Umum Algebra (GAMS). Permintaan elektrik yang telah dimodelkan menggunakan Adaptif Neuro Inferens Sistem Fuzzy (ANFIS). Berdasarkan GAMS dan model ANFIS, biojisim minyak sawit berasaskan sistem DEG dan senario rangkaian pengedaran terkini serta sepuluh, dua puluh tiga puluh tahun seterusnya telah dicadangkan bagi Negeri Johor, Malaysia. Biojisim dari Kilang Kelapa Sawit (POMs) akan dikumpulkan dan dihantar ke lapan lokasi terpilih. Penemuan empirikal kajian ini mencadangkan bahawa jumlah kos pengeluaran dapat dikurangkan dengan meletakkan gasifikasi biojisim berasaskan gabungan kitaran bersepadu (BIGCC) loji kuasa 50MW di kesemua lapan lokasi. Senario bagi tahun 2020, tiada infrastruktur tambahan dikehendaki. Senario bagi tahun 2030, unit tambahan BIGCC daripada 50MW diperlukan pada lima daripada lapan lokasi. Sementara senario bagi 2040, sekali lagi tiada pembangunan infrastruktur tambahan akan diperlukan. Jumlah kos yang minimum berubah dari RM 6.31 /tahun untuk senario semasa kepada RM 22.63 /tahun bagi 2040 senario.

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LIST OF SYMBOLS AND ABBREVIATIONS

AI	-	Artificial Intelligence
ANN	-	Artificial Neural Networks
ANFIS	-	Adoptive Neuro Fuzzy Inference System
ARDL	-	Autoregressive Distributed Lag
ARIMA	-	Autoregressive Integrated Moving Average
BCHP	-	Building Cooling Heating and Power
CCHP	-	Combined Cooling Heating and Power
CCS	-	Carbon dioxide Capture and Storage
CEB	-	Central Electricity Board
CHP	-	Combined Heat and Power
CO_2	-	Carbon Dioxide
EC	-	Energy Commission
etc.	-	et cetera
FALCON	-	Fuzzy Adaptive Learning Control Systems
FBPN	-	Fuzzy Back-Propagation Network
FHRCNNs	-	Fuzzy Hyper Rectangular Composite Neural networks
FNN	-	Fuzzy neural network
FELDA	-	Federal Land Development Authority
FL	-	Fuzzy Logic
GAMS	-	General Algebraic Modeling System
GC	-	Grid-connected
GDP	-	Gross Domestic Product
GIS	-	Geographical Information System
GNP	-	Gross National Product
GHG	-	Green House Gas

i.e.	-	id est
LCE	-	Low-Carbon Economy
LEAP	-	Long-Range Energy Alternatives Planning System
LP	-	Linear Programming
MILP	-	Mixed Integer Linear Programming
MINLP	-	Mixed Integer Nonlinear Programming
MIP	-	Mixed Integer Programming
NARX	-	Nonlinear Autoregressive Exogenous
NEB	-	National Electricity Board
NLP	-	Non-Linear Programming
OR	-	Operations Research
PCA	-	Principal Component Analysis
POM	-	Palm Oil Mill
POME	-	Palm Oil Mill Effluents
PTM	-	Pusat Tenaga Malaysia
PV	-	Photo Voltaic
RE	-	Renewable Energy
Re	-	Relative Error
SA	-	Stand-alone
SO	-	System Operators
SREP	-	Small Renewable Energy Program
TCR	-	Total Capital Requirement
TMAX	-	Maximum Average Annual Temperature
TMIN	-	Minimum Average Annual Temperature

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CHAPTER 1

INTRODUCTION

Energy is one of the most critical international issues and most likely to be so for the years to come. It is becoming gradually accepted that current energy systems, networks encompassing everything from primary energy sources to final energy services, are becoming unsustainable. As a part of a national global warming mitigation strategy, nations are trying to achieve low-carbon economies through adoption of comprehensive strategies to manage global warming and carbon neutrality. Concerns over air pollution, global warming caused by greenhouse gas (GHG) emission make biomass, solar and wind power as attractive alternative energy sources. Besides that, this concern also has encouraged extensive energy conservation efforts to implement more efficient processing technique and equipment to increase efficiency.

1.1 Research Background

Progressive release of GHGs from increasing energy-intensive industries has eventually caused human civilization to suffer. There is an increasing interest emerged recently to promote Low-Carbon Economy (LCE), generally is referred as an economy with a minimal output of GHG emissions. The most of the established public as well as scientific opinion are based on the assumption that amassing addition of GHGs in the atmosphere makes drastic changing in the climate around the globe while producing global warming resulting in long-term climate variations imposing adverse impacts on human civilization in the foreseeable future. Nations are now determined to shift towards more modern concept of zero carbon society and renewable energy (RE) economy for which LCE's are considered as a precursor.

Currently, fossil fuels are serving as a primary energy source to meet the energy requirement of the world. Driving the global energy system into a sustainable path has been emerged as a major concern and policy objective. Although fossil fuels are still dominant among primary energy sources, however, the overwhelming scientific evidence is that the unfettered use of fossil fuels is causing the world's climate to change, with potential catastrophic effect. Malaysia is well endowed with both fossil and renewable energy resources. To cater the future energy requirement in line with growing trend in country's energy consumption pattern, Malaysia has set a sustainable development program. The diversification of energy sources has been included as the principle objective of country's energy policy. Malaysian Government's Five-Fuel Diversification Policy emphasizes, as a target, to generate 5% of the country's generation mix from RE. RE resources has been declared as the economy's fifth fuel, and 9th Malaysian Plan (2006–2010), focusing on the sustainable development of the energy sector of the country, put emphasis on the energy security, reliability, and cost-effectiveness [1].

RE provides an effective option for the provision of energy services from the technical point of view while biomass, a major source of energy in the world until before industrialization when fossil fuels become dominant, appears an important renewable source of energy and researches have proven from time to time its viability for large-scale production. Being a widely spread source, biomass offers the execution of decentralized electricity generation gaining importance in liberalized electricity markets. The decentralized power is characterized by generation of electricity nearer to the demand centers, meeting the local energy needs. Researchers envisaged an increasing decentralization of power supply, expected to make a particular contribution to climate protection. Decentralized Biomass Power is an attractive option for Malaysia to be adopted as RE [2].

1.2 Background of the Problem

Apart from vulnerability, centralized energy supply systems are losing its attractiveness due to a number of further alarming factors including the depletion of fossil fuels and their climate change impact, the insecurities affecting energy transportation infrastructure, and the desire of investors to minimize risks through the deployment of smaller-scale, modular generation and transmission systems. On the basis of type of energy resources used, decentralized power is also classified as non-renewable and renewable. These classifications along with an overabundance of technological alternatives complicated for decision making. Establishing local generation and a local network may be cheaper, easier and faster than extending the central-station network to remote areas of modest load. The rural areas of many developing and emerging countries are unlikely ever to see the arrival of classical synchronized electricity transmission lines. Decentralized local systems, including those using local resources of renewable energy such as wind, solar and biomass power, appear much more feasible.

Decentralized power technologies include Co-generation, Biomass power, Small and Mini-hydro power, Wind power and Solar Photo Voltaic (PV) power. Biomass, Solar, and Wind power are the low carbon power generation technologies. Malaysia generates a large amount of biomass per annum. The country has great potential to develop the biomass conversion setup and facilities to utilize biomass, especially abundantly available palm oil biomass, effectively and efficiently. The palm oil mills in the country are producing large amount of palm oil biomass which is not currently consumed on mill sites and available for utilization for energy purposes. Various well developed biomass conversion technologies are available to convert oil palm biomass to different types of value added products. Oil palm biomass being a renewable energy source also has a great potential to be used as feed stock to generate electricity [2].

1.3 Problem Statement

Progressive release of greenhouse gases (GHG) from increasing energy-intensive industries has eventually caused human civilization to suffer. Realizing the exigency of reducing emissions and simultaneously catering to needs of industries, researchers foresee the RE as the perfect entrant to overcome these challenges. RE provides an effective option for the provision of energy services from the technical point of view while biomass, a major source of energy in the world until before industrialization when fossil fuels become dominant, appears an important renewable source of energy and researches have proven from time to time its viability for large-scale production.

Since 2000, Malaysia has made efforts towards RE development through the five fuel policy where the principle adopted was using the market forces to deliver the intended outcomes towards electricity generation. The National RE Policy and Action Plan (NREPAP) was approved by Cabinet on 2nd April 2010 and it provides long-term goals and commitment which all stakeholders should strive to realize. The Policy charts the path of enhancing the utilization of indigenous renewable energy resources to contribute towards the national electricity supply, security and sustainable social-economic development. The Malaysian energy sector is still heavily dependent on non-renewable fuels, such as fossil fuels and natural gas, as sources of energy. In line with the objective of diversifying the sources of energy, renewable energy has been identified as an alternative source of energy which could have been promoted since the 8th Malaysian Plan, and while the Malaysian government has stimulated a variety of energy related policies and tried to sustain the energy demand the result is so far disappointing. In the 8th Malaysia Plan the Malaysian government fixed a target of 5% renewable energy of total energy in 2001-2005 but achieved only around 1%. Again in 2006, the government declared the 9th Malaysian Plan having the target of 5% renewable energy of total energy, but this target was not achieved either. The 10th Malaysian Plan has pointed out that "several new initiatives anchored upon the Renewable Energy Policy and Action Plan will be undertaken to achieve a renewable energy target of 985 MW by 2015, contributing 5.5% to Malaysia's total electricity generation mix." This target is approximately the same as the 8th Malaysian Plan target, which means that although Malaysia has implemented some incentive-led policies and projects in terms of renewable energy, and some progress of renewable energy has occurred; comparing target plans reveals a huge discrepancy [3].

Being a widely spread RE source, biomass offers the execution of decentralized electricity generation gaining importance in liberalized electricity markets. Growing populations and industrialization in countries create huge needs for electrical energy. Malaysia's electricity demand is expected to be tripled by 2020 and country's current electricity supply consists of long distanced transmission lines of centralized energy supply systems which offer more energy losses. According to 2009-estimates by IEA, Malaysia's electric power transmission and distribution losses during the year 2009 were 3992 GWh which is equivalent to 3.8% of output. According to clever estimate, saving just 1 % on the electrical energy produced by a power plant of 1000 MW means transmitting 10 MW more to consumers, which is far from negligible: with the same energy we can supply 1000 – 2000 more homes. In centralized energy systems, transmitting electricity over long distances via networks involves energy losses which make decentralized systems more attractive. So, with growing demand comes the need to minimize this loss to achieve two main goals: reduce resource consumption while delivering more power to users. Small-scale decentralized systems are emerging as a viable alternative as being less dependent upon centralized energy supply.

In this study, a biomass based decentralized electricity power generation and distribution network is proposed which is capable to generate electricity using local biomass resources to satisfy to local electricity demand. Which will eliminate the extension of national grid to remote areas overcoming the transmission and distribution losses as well as will remarkability contribute towards achieving the objectives National RE Policy. RE in the above mentioned context is assumed to be the utilization of biomass only, and other renewable energy sources are not considered in this research because, biomass has ample supply in the country. As most of the biomass in Malaysia is from the palm oil industry, and this industry is forecasted to be able to produce palm biomass sustainably and in a long term, the utilization of palm biomass is considered to be studied.

1.4 Objectives of the Study

This study aims:

- To develop a superstructure based mathematical optimization model that capable to determine the best generation mix of palm biomass in the energy field in terms of electricity generation as well as selecting best locations in State of Johor, Malaysia for processing facilities to be installed at minimum total generation cost.
- To forecast future electricity market of the State for next thirty years.
- To develop optimal decentralized biomass power generation scenarios for State of Johor for next ten, twenty and thirty years based on forecasted electricity demand.

1.5 Scope of the Study

A mathematical optimization model with the least error, relating the relationship of the proposed superstructure linking the palm biomass sources to the technologies for converting biomass to the electricity is formulated to determine the suitable ratio of allocation for each palm oil biomass source, number of plants of selected technology and possible best locations to install them. The palm oil industry and electricity generation and distribution related actors can benefit from this model, and palm biomass waste can be best utilized in order to provide for the energy industry by introducing a more environmentally friendly yet sustainable decentralized electricity system. An MINLP model was formulated and implemented in GAMS software to design an optimal DEG system. Electricity demand for future was forecasted by formulating an ANFIS model implemented in Matlab software. Based on forecasted demand, DEG scenarios for next ten, twenty and thirty years have been designed for State of Johor taken as case study for proposed model. All the data were collected from reviewing literature, journals, and official reports available on related websites like Malysian Palm Oil Board, Department of Statistics Malaysia, Johor State Investment Centre and Negeri Johor Darul Ta'zim, as well as from individual POMs.

In this study, two case studies have been made for the proposed work comprising of a pilot scale study for Iskandar Malaysia (IM) Region and a broader scale study for whole state of Johor. There are sixty six palm oil mils in Johor generating about 8.5 million ton per annum of palm oil biomass. Out of these, five mills are situated within IM region. In this study, palm biomass is categorized into two different categories, solid biomass as well as liquid biomass. Solid palm biomass is consisted of empty fruit bunch (EFB), palm fiber, and palm shell. Liquid biomass consists of palm oil mill effluent (POME). The other biomass from palm is not considered because they are not used for energy generation. Since the electricity generation facilities will be placed on different optimal locations in the locality, therefore, only solid palm oil biomass is considered and POME is assumed to be consumed on mill site. Three categories of solid palm biomass will be used to generate electricity. The energy in form of heat and other by-products are also not considered, as this study is focused on decentralized electricity generation scenario development from palm oil biomass. Only the electricity production lines are optimized because they are subjected to government policies as compared to other products used currently for other smaller usages. The solid biomass is assumed to undergo three types of biomass conversion technologies named direct combustion, gasification, and pyrolysis to produce electricity. For each type of processing technology the generation capacity is considered as comparison basis.

The generation costs of each undergoing technology are considered in terms of annualized capital costs, per annum operating costs, acquisition costs of the biomass, transportation costs, and electricity transmission costs. DEG system is optimized to obtain highest possible economic value at the lowest production cost. The system is subjected to several constraints such as the availability of each of the solid biomass, the minimum production rate to meet government's policies on electricity generation from RE, the lower and upper limit of the biomass boilers capacity, the upper maximum boilers production capped.

In order to identify the amount of each biomass to produce the end product as well as which technology to undergo at the minimum cost while fulfilling all the constrains, the problem will be formulated in mathematical modeling and programmed in General Algebraic Modeling System (GAMS), an optimizing tool. The optimizer was able to produce a result that shows the best mix of palm biomass to produce electricity, best locations to install the selected technologies. The developed model can be used as a guide for policy makers to plan for biomass utilization for future energy usage purposes. The electricity market (i.e. electricity demand) was forecasted using ANFIS Network. Based on GAMS and ANFIS models, palm oil biomass based DEG system and distribution network scenarios for current as well as next ten, twenty and thirty years have been proposed for State of Johor, Malaysia.

1.6 Research Outcomes

The research conducted in this study is envisaged to provide a sustainable solution for:

- Efficient utilization of Renewable Energy Recourses
- Low-Carbon Economy shift
- Enhancement of energy efficiency
- Eradication of GHG emission
- Improvement in rural electrification
- Improving and imparting energy policies
- Decision making by energy planners
- Effective waste management
- Step towards achieving MDGs

1.7 Report outline

This report contains five chapters:

Background of the research and problem at hand, the objective and scope of this study is discussed in Chapter 1. Chapter 2 gives literature survey of palm oil biomass starting from its historical growth with especial emphasis on its conversion to electricity, operation research and role of optimization in power sector. Chapter 3 discusses about the research methodology including road map for the research and planning, model development and implementation. Description about the results is presented in Chapter 4. Finally, Chapter 5 contains the overall conclusion of this study and recommendations for future research.

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