POOL-BASED ELECTRICITY MARKET MODEL FOR MALAYSIA ELECTRICITY SUPPLY INDUSTRY CONSIDERING MINIMUM GENERATION CAPACITY PAYMENT

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To my caring and beloved husband,

Amir,

To my dearest sons and daughter

Afiq, Afif, Affan and Azalea

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ABSTRACT

Malaysia is improving its electricity supply industry to become more transparent, productive and competitive with the introduction of the single buyer market model. However, since the electricity demand is lower than the reserved capacity, the implementation of this market model does not provide transparent competition as Tenaga Nasional Berhad (TNB) has suffered massive profit erosion because of monthly capacity payment that should be paid to Independent Power Producers (IPP) regardless of electricity usage. Since 2005, the Malaysia Electricity Supply Industry (MESI) has planned to change to the pool market model as it is recognized as a model which could overcome the shortcomings of the single buyer market model. However, there are a few issues on introducing the pool model such as price fluctuation and market power exercises which could influence the welfare of generators as well as the consumers. Some researchers have developed pool-based market models with the aim to overcome the aforementioned issues, but the efficiency and the energy price offered from the generators are not considered. Therefore, this research developed a model introducing the minimum generation capacity payment involving the efficiency of the generators and base load sharing approaches. The proposed model was tested using the 2, 16 and 24 generator test systems involving IPPs and Tenaga Nasional Berhad Generation (TNBG) around Peninsular Malaysia for an economic analysis to highlight the merits of the proposed model in terms of generation revenue and demand payment. The results have shown that the proposed market model ensures the intermediate value of total generation revenue which decreased from 1.99% to 4.67% and 3% to 9.62% during the weekday and weekend, respectively. The demand payment decreased as it is proportional to the generation revenue. However, this proposed model did not consider market uncertainties. This findings can be applied for MESI and globally, in assisting and creating a new policy to achieve a better electricity market model.

ABSTRAK

Malaysia sedang meningkatkan industri bekalan elektrik untuk mewujudkan persekitaran yang lebih telus, produktif dan berdaya saing dengan pengenalan model pasaran pembeli tunggal. Disebabkan permintaan elektrik yang lebih rendah berbanding kapasiti simpanan, pelaksanaan model pasaran ini tidak memberikan persaingan yang telus kerana Tenaga Nasional Berhad (TNB) telah mengalami kerugian yang besar kesan pembayaran kapasiti bulanan kepada Pengeluar Tenaga Bebas (IPP) tanpa mengira penggunaan elektrik sebenar. Semenjak 2005, MESI merancang untuk bertukar ke model pasaran *pool* kerana menganggap model tersebut dapat mengatasi kelemahan pasaran pembeli tunggal. Terdapat beberapa isu dalam memperkenalkan model *pool* seperti turun naik harga dan penguasaan pasaran tenaga yang memberi kesan kepada penjana juga pengguna. Beberapa penyelidik telah membangunkan model berasaskan pasaran *pool* bertujuan untuk mengatasi isu-isu tersebut tetapi tidak mengambil kira kecekapan dan harga tenaga yang ditawarkan daripada penjana. Kajian ini mencadangkan model pasaran yang memperkenalkan bayaran penjanaan kapasiti minimum melibatkan kecekapan penjana dan perkongsian beban asas. Model yang dicadangkan diuji menggunakan 2, 16 dan 24 sistem pengujian penjana yang melibatkan IPP dan Tenaga Nasional Berhad Generasi (TNBG) di sekitar Semenanjung Malaysia untuk analisis ekonomi bagi menunjukkan kelebihan model tersebut dari segi pendapatan penjanaan dan pembayaran permintaan. Keputusan menunjukkan jumlah keuntungan penjanaan model pasaran yang dicadangkan berada pada nilai pertengahan dengan peratus penurunan dari 1.99% kepada 4.67% pada hari bekerja dan 3% kepada 9.62% pada hujung minggu. Pembayaran permintaan menurun kerana berkadar langsung dengan keuntungan penjanaan. Model yang dicadangkan ini tidak mengambil kira ketidaktentuan dalam pasaran. Penemuan ini boleh digunakan oleh MESI dan global dalam mewujudkan dasar baharu untuk model pasaran elektrik yang lebih baik .

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LIST OF SYMBOLS AND ABBREVIATIONS

$	-	Australian Dollar
Btu	-	British Thermal Units
MW	-	Megawatt
MWh	-	Megawatt hour
RM	-	Ringgit Malaysia
RM/h	-	Ringgit Malaysia per hour
RM/MW/month	-	Ringgit Malaysia per Megawatt per month
RM/MWh	-	Ringgit Malaysia per Megawatt hour
η	-	Efficiency
AEMO	-	Australian Electricity Market Operator
CCGT	-	Combined Cycle Gas Turbine
CEB	-	Central Electricity Board
DistCo	-	Distribution company
EIA	-	Energy Information Administration
EC	-	Energy Commission
ESI	-	Electricity Supply Industry
GENCO	-	Generation company
GSO	-	Grid System Operator
HM	-	Hybrid Model
ICAP	-	Installed Capacity
ISO	-	Independent System Operator
IMO	-	Independent Market Operator
IPP	-	Independent Power Producer
KED	-	Kinta Electrical Distribution Co. Ltd.
LLN	-	Lembaga Letrik Negara
LOLP	-	Loss of Load Probability
M3	-	Managed Market Model

MCP	-	Marginal Clearing Price
MESI	-	Malaysia Electricity Supply Industry
NEM	-	National Electricity Market
NEB	-	National Electricity Board
NEDA	-	New Enhanced Dispatch Arrangement (NEDA)
NEMMCO	-	National Electricity Market Management Company
OCGT	-	Open Cycle Gas Turbine
PAB	-	Pay as Bid
PJM	-	Pennsylvania-New Jersey-Maryland
PPA	-	Power Purchase Agreement
PPP	-	Pool Purchase Price
PRHEP	-	Perak River Hydro Electric Power
RE	-	Renewable energy
SB	-	Single Buyer
SESB	-	Sabah Electricity Sdn. Bhd.
SMP	-	System Marginal Price
SLA	-	Sevice Legal Agreement
SO	-	System Operator
TNB	-	Tenaga Nasional Berhad
TNBD	-	Tenaga Nasional Berhad Distribution
TNBG	-	Tenaga Nasional Berhad Generation
TRANSCO	-	Transmission company
UP	-	Uniform Price
VOLL	-	Value of Lost Load

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CHAPTER 1

INTRODUCTION

The deregulation of electricity market is required to replace the vertically integrated utility which monopoly in selling and distribution of electricity into a more competitive market. Cost efficiency, the increased public awareness of the environmental impact of energy production, and the improved technological performance of peaking units, also the development of combined cycle gas turbines have been the drivers for the restructuring [1]. Therefore, the restructuring of electricity supply industry in developing countries has provide the consumers lower prices electricity and to open the market for competition by allowing the smaller players to get access to the electricity market by reducing the share of large state owned utilities. As a matter of fact over various countries, there exists diversity in the wholesale electricity market operation. A transparent, open marketplace would encourage competition generators and reveal the inefficiencies of the current system to improve the efficiency of the electricity sector.

1.1 Research Background

In 1992, MESI took its first step towards becoming a competitive electricity market by introducing the Independent Power Producers (IPPs). The introduction of IPPs came after the national power outage in 1992 and a series of interruptions and rationing caused the government to conduct an immediate assessment of the nation's power generation industry [2]. During that time, the country was unable to cater for the growth in demand for power due to the rapid development of the national economy in the previous years. The IPPs' program is to restore an adequate safety

margin of power capacity and to ensure that it could meet the country's anticipated future power needs [3]. As a result, the government pushed forward the IPPs permit activity to break TNB's domination in the MESI, as well as to transfer the government-owned electricity utility's financial burden to build power plants. The introduction of IPPs and competitive bidding allowed for a level playing field in the generation sector. There is no competition in other areas as TNB fully controls the other aspects of the electricity business from transmission down to distribution and retail. The IPPs investments bring the implementation of a single buyer market model.

The Power Purchased Agreements (PPA), which has lasted for 21 years, is signed by TNB and IPPs for the purpose of market risk protection [4]. The electrical energy is sold to TNB on a fixed rate based on the PPA, providing 70% of the nation's electricity demand. The first batch of IPPs granted licenses to build, operate and own power plants in Peninsular Malaysia. For instance YTL Power, Malakoff, Genting Sanyen Sdn. Bhd., Powertek Bhd and PD Power Sdn. Bhd. received between 18% and 25% internal rate of return as the PPAs were signed in 1993 and 1994 for the first-generation IPPs, handled by the Economic Planning Unit (EPU) [3]. YTL Power had the best deal with its first PPA with TNB, which was reported as being the only PPA that was based on a take-or-pay mechanism, where TNB had to take at least 75% of the electricity generated by YTL Power at a fixed price for a period of 21 years. This is a biased agreement because even if the former did not need the electricity, it would still need to pay compensation to YTL Power [2]. The second and third-generation PPAs were signed a few years later. For the first quarter of year 2014, 52.7% installed capacity was from TNB and 47.3% were produced by IPPs with fuel sources, 58% used gas and liquefied natural gas (LNG), 33% for coal and 9% for hydro and others [5]. As of December 2015, the installed generation capacity in Peninsular Malaysia was 20,710 MW, and the peak demand for 2015 as forecasted by TNB was at 16,901 MW [6].

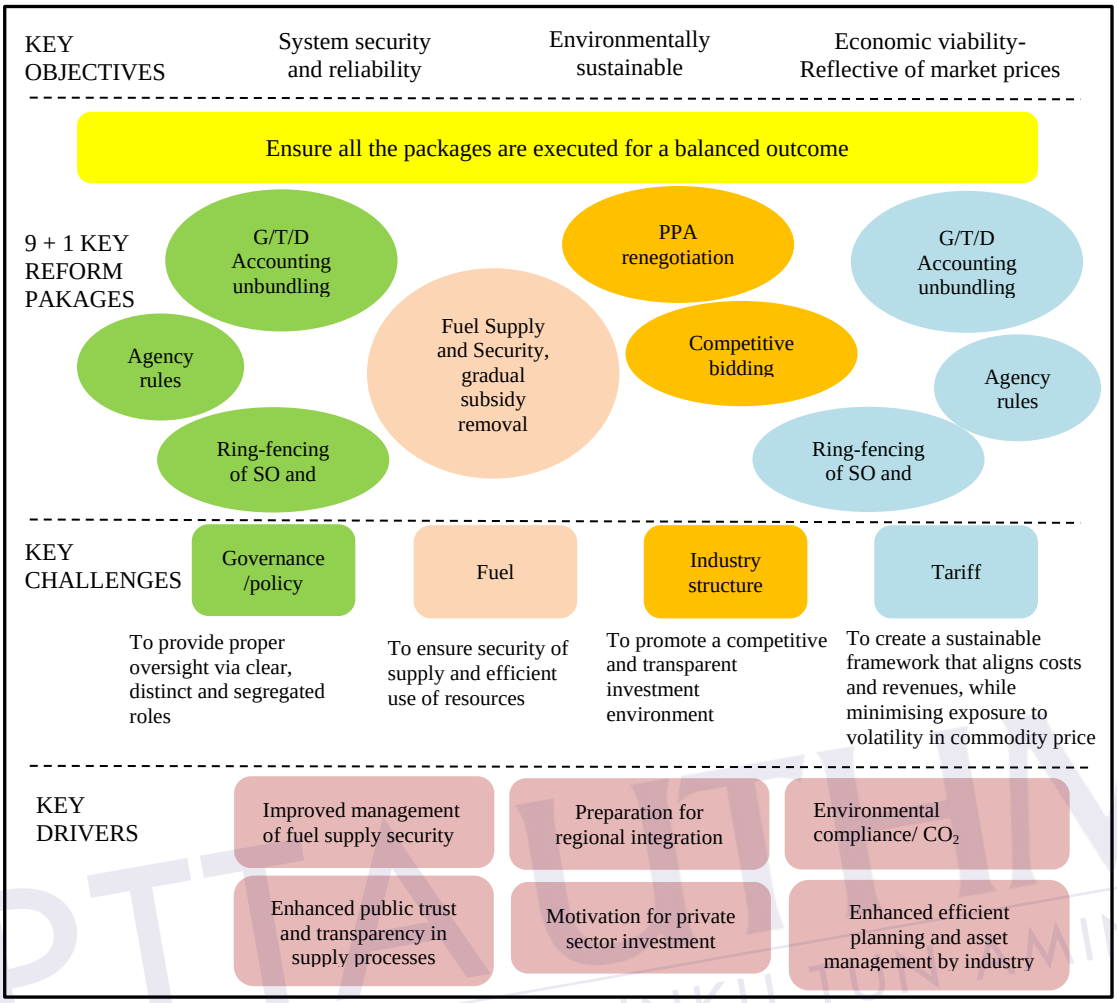

Figure 1.1: Malaysia ESI reform

The restructuring is supported by the existence of the Energy Commission (EC), which is an electrical regulator in Malaysia. EC is obliged to not only design an appropriate electricity market model, but also to set up suitable policies and regulation related to the electricity industry [2]. According to the Energy Commission Act 2001, the role of EC in the competitive bidding process is to promote and safeguard competition, and to enable fair and efficient market conduct or, in the absence of a competitive market, to prevent the misuse of monopoly or market power. In 2005, the MESI transformation program was launched which aimed to deliver a reliablility, transparency, efficiency and sustainability, where two points were highlighted under the industry's structure: competitive bidding and PPA renegotiation as shown in Figure 1.1 [7].

Competitive bidding was introduced following by the government's decision for future generation capacity requirement to ensure independence, credibility and

transparency in procuring all new capacity requirements, which will include a price discovery mechanism that ensures only qualified parties will be tasked with the country's future electricity requirements [8]. The EC has been entrusted by the government to conduct the competitive bidding exercise since 2010 [3, 9].

MESI had planned to change from a single buyer model to a wholesale market due to capacity payment in the single buyer model where the capacity payment was paid regardless of the energy usage to cover the fixed cost. During that time, the demand and reserve capacity gap were far different, which was almost 50%. Consequently, TNB had to bear higher expenses for capacity payment due to the high reserve margine. However, this plan had been put on hold since 2005 following the California crisis, and MESI had taken precautionary steps in the process of privatizing electricity. In order to carry out MESI's previous plan of restructuring, the pool-based market model could be applied as an alternative electricity market model as it accommodates fair competitive trading between power producers and power purchasers.

Therefore, this research proposes novel generation pricing approaches for the pool-based market model. The aim of this research study is to improve the pool-based market model which is useful for MESI to enhance efficiency, promote competition to lower costs, increase customer choice, assemble private investment and merge public finances. The proposed market model introduces the minimum generation capacity payment involving the efficiency of the generator and base load sharing approaches. This minimum generation capacity payment mechanism involves the efficiency of the generators to educate the IPPs to bid and sell their electricity produced at a lower price. Meanwhile, the base load sharing approach helps to reduce market power exercises and price fluctuations. The proposed model is compared with other pool-based models in three research cases to identify which market model is superior. This study also can be a reference to assist new policy set up. In this research, economic analysis is performed in terms of the generation of revenue and demand payment investigation, due to the pricing issue in the pool model by extending the capacity payment mechanism in the single auction power pool and generation adequacy. This is demonstrated without considering the transmission flow constraints.

1.2 Problem Statement

The initial IPPs were awarded licenses to govern the construction, purchase and/or use of fuel, operation and selling of the energy produced under them for up to 21 years [10]. In this agreement, TNB as the power off taker had agreed to pay two types of payment, which were energy and capacity payment. The energy payment is based on the electricity consumed by TNB, while the capacity payment, also known as availability payment, was paid monthly regardless of the electricity usage. This payment provides incentives for generators to be available at times when the system needs generation capacity and provide extra revenue to generators to cover the capital and other fixed costs which are not covered by the energy payment. However, due electricity demand being lower than the reserved capacity, TNB had suffered massive profit erosion because of capacity payment to IPPs. The cost of reserve capacity was borne by TNB, where the group bore RM 1.3 bilion spare capacity cost in financial year 2007 with a reserve margin at 45%. In 2008, the reserve margin was at 42% [6, 11]. Furthermore, after ten years of signing the PPAs, some IPPs had covered their capital and fixed cost. As a result, TNB as the power off taker has to bear high expenses and consumers also face risks as they depend on the current market situation. After passing several processes of evolution, the single buyer model is still a form of imperfect competition as there is only one buyer and many sellers of a product. The existing single buyer model does not provide any competition due to long-term PPAs, in which electricity trading only fall under one company, which is TNB transmission and distribution [12]. Therefore, a new market design is required so that TNB and IPPs receive reasonable profit and consumers pay an affordable price.

In a perfect competition, all participants are price-takers and no participant can influence the market price unilaterally because theoretically, suppliers should bid at or very close to their marginal production costs to maximise return [13-15]. In 2005, MESI aimed to change its structure to a wholesale market model [16]. In this research, the pool market model was proposed to carry out MESI's previous plan and overcome the drawbacks of the single buyer market model. However, there were a few issues of introducing the pool market model such as price fluctuation and market power exercises, which influenced the welfare of the generators. Consequently, the adoption of the pool market model in MESI will cause high cost IPPs to lose the

opportunity to be included in generation dispatch and eventually lose the revenue at low electricity demand. Conversely, the System Marginal Price (SMP) that cleared the market will become too high at peak electricity demand, providing excessive revenue for low cost IPPs. Therefore, some improvements should be made for the pool market model.

Some researchers have developed an improved pool market model called the hybrid model. The hybrid model is a pool-based market model, which combines the pure pool market model and pro-rata base load profile where base load sharing is introduced. However, the developed hybrid model did not consider efficiency and the electricity price offered by the generators during base load sharing. This is because aging generators are not able to provide full available capacity due to low efficiencies, while some generators offer expensive electricity prices to gain more profits. As a result, energy buyers have to pay more for the electricity purchased due to full capacity payment and high energy prices. Theoretically, the base load power plants are designated based on their efficiency, low cost generation, and safety at rated output power levels. Thus, it is important to modify the existing pool model, so it can provide a fair market to the supplier and user.

1.3 Research Objectives

The aim of this research is mainly to improve the pool based electricity market model for MESI in a deregulated market environment, focusing on the economic benefits. In summary, this thesis addresses the following main objectives:

(i) To solve unfair capacity payment in a single buyer model for MESI by proposing a new pool market model which incorporate the minimum generation payment mechanism and base load plant efficiency.

(ii) To overcome the problem of high cost IPPs from losing the revenue at low electricity demand by synthesising the minimum generation capacity payment mechanism in the pool model.

(iii) To validate the proposed market model by making a comparison with the spot market model applied by the Australian National Electricity Market (NEM) as a practical model from an economic view.

1.4 Scope of the Thesis

This research focuses on the future recommended electricity market not limited to MESI only, but also to other countries which aim to develop a competitive market model to satisfy both power producers and purchasers. This can be achieved by considering and improving the properties of pool market in the proposed market model to solve the capacity payment problem in a single buyer model. The additional approach is added to modify the pool market for the future electricity market by introducing a minimum generation capacity payment mechanism to overcome the problem of losing revenue during low electricity demand for high cost IPPs. Furthermore, in order to ensure continuous remuneration of IPPs, the proposed market model considered the minimum generation payment mechanism with the base load plant efficiency and demand sharing approaches.

The proposed market model is a single auction. The competition is only valid among generator companies, whereas customers do not know which generators succeeded in selling their output. The proposed market model was tested using two bus systems for conceptual analysis. Meanwhile, 16 and 24 generator test systems involving IPPs and Tenaga Nasional Berhad Generation (TNBG) around Peninsular Malaysia were tested for application analysis, which fully reflect the real situation in MESI. The parameters were taken into account; for instance, the load demand curves, the details of the MW installed capacity, energy prices, capacity prices, and efficiency of the generators were used for analysis in terms of generation revenue and demand payment. Considering the experience by the Australian National Electricity Market (NEM) in the pool market model, a comparison was carried out between the spot market model applied by the Australian NEM and the proposed market model from the view of the economic aspect. The MATLAB software was used to simplify the process of the analysis. The electricity trading that was considered was only up to the transmission level. Consequently, the business was only between the generators as the seller and distributor as the buyer or customers without taking into account the end user.

1.5 Significance of Research

This research is conducted as the existing single buyer affects the TNB revenue as the power of the taker and also due to unfair market aspects. Meanwhile, future pool market models affect the revenue of expensive generators and demand payment for consumers. Therefore, this research work has presented an improvement in the pool market model approach as it can solve the capacity payment problem in the single buyer model which has burdened TNB and the demand side. For this proposed market model, the generators will receive reasonable payment or revenue based on the electricity's power that they had produced. It will also reduce the demand payment for a win-win situation to power producers and energy buyers. However, this research work is not limited to MESI only, but is for global use. Other contributions of this thesis are identified as follows:

(i) To introduce the minimum generation capacity payment based on the generator's efficiency for the participated IPPs which have won the bidding competition as an incentive to educate the IPPs to bid and sell their electricity produced at a lower price. This approach enables the generators to compete for more dispatch and increase their revenues.

(ii) To introduce a minimum generation capacity payment based on the generator efficiency for the non-participating IPPs which had lost in the bidding competition as compensation to ensure continuous remuneration for the IPPs regardless of their submitted energy bid prices and the fluctuating electricity demand.

(iii) To introduce base load sharing demand among the generators involved. The efficiency and the price offered by the generators are taken into account. Therefore, the base load plant has equal opportunities to participate in the trading and receive revenue for their contribution.

1.6 Thesis Outline

This thesis is organised in six chapters.

Chapter 2 discusses the deregulated electricity market in brief, covering the before and after of the restructuring. In addition, the markets for electrical energy called

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