The Economic Benefits of Generation Revenue and Demand Payment Assessment in Pool-based Market Model: The Case of Malaysia

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CONTENTS

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Abstract—In Malaysia, as the Power Purchased Agreement is coming toward the end, pool market model is recognized as a conceivable model to overcome the shortcomings of the single buyer market. However, there are issues on the welfare of the generators involved. In context of Malaysian Electricity Supply Industry, this paper proposes a model, a pool hybrid introducing the minimum capacity payment involving the efficiency of the generators and base load sharing approaches. Under single auction power pool, a case study is conducted for the generators in Peninsular Malaysia for an economic analysis to highlight the merits of the proposed model compared with other pool-based market models in terms of generation revenue and demand payment. The load demand curves, the details of the MW-installed capacity, energy prices, capacity prices, and efficiency of the generators are the parameters taken into account in carry out analysis on each generator revenue. Results have shown that pool hybrid market ensures the intermediate value of generation revenue with all Independent Power Producers participation even at the lowest demand and decreased the demand payment.

I. INTRODUCTION

Theoretically, there are no additional mechanism needed due to efficiency of energy-only markets, but without proper design, the energy-only market will suffer from serious drawbacks. According to [1], this short-term price volatility has given a number of market efficiency enhancing benefits. First, it provides strong incentives for generation unit owners to maintain their generation units in top working order. Then, these volatile short-term prices provide strong economic signals to loads to reduce their consumption during high-price periods and increase their consumption during low-price periods. Finally, this price volatility can provide a stronger economic case for storage and other fast-ramping technologies necessary for electricity supply industry's energy mix. Concerning about energy only markets is that they may not adequately compensate the peaking units that run occasionally. Nevertheless, according to [2], the limitations of the energy-only market are the design vulnerable to market power, need reliable estimation of value of lost load (VOLL), which can supply adequacy provisions, and the design prone to suffer investment cycles.

The participation of generation companies (GENCO) and large consumers in bidding methodologies is for their own benefits, as the electricity generation companies expect to maximize their profits and control the market price by strategically bidding, despite the fact that their offers will deviate from the true marginal costs and would result in great losses of market efficiency. In oligopoly market structure, GENCOs tries to maximize their profit and minimize the risk factor [3]. In order to achieve a maximum return, it is very important for the GENCOs to formulate optimal bidding strategies with risk terminology before stepping into the electricity market, as the market clearing price (MCP) in this landscape is flexible [4].

Under deregulation, there are many uncertainties in the power system, such as those related to electrical demand, price variations and generation, and also branch outages [5]. Risk management can be serious challenge for market participants, especially for small-sized electric companies. At least two aspects are included in risk management, risk assessment and risk control, where reliable and efficient assessment method is the basis for risk control [6]. Electricity spot prices show unique properties of high volatility for many reasons, while electricity demand is extremely inelastic in the short period, but due to unexpected demand shocks for example, extreme weather condition, it is fully regulated through price jump [7]. Forward contracts allow selling production in advance at a given price but do not hedge against cost volatility. Thus, the total risk can be reduced by selling energy in the spot market, which justifies, economically, the existence of electricity spot markets as a place to provide diversification opportunities to producers [7].

The pool market model is a standout among the most preferred power market model actualized in many developing countries. Regardless of being the sensible and safe choice for a more competitive and straightforward power supply industry, there are issues on the welfare of the generators included. As reported in [8], the analytical paradigm of economic mechanism design theory is to deduce and design a customized pool-based market mechanism to fulfill three major properties: incentive compatibility, individual rationality, and payment cost minimization.

Most of the implementations of the capacity payment approach have shown a number of drawbacks [2]. Capacity payments are often fixed and do not reflect the prevailing adequacy of the generation system. The capacity product to be exchanged for these payments is usually defined in terms of the generator´s “firm capacity”, which is normally estimated by means of very arguable procedures. Payments resulting from such methods often do not necessarily correlate with actual contributions of generating units to system reliability and its ability to deliver energy during scarcity. Therefore, the authors in [2] proposed a new reliability payment mechanism to replace the fixed capacity payment, which comprises fairness, incentive compatibility, and market power mitigation, where capacity of each generating unit is paid according to its effective contribution to overall system reliability.

This paper proposes a novel generation pricing approaches for pool-based market model. The aim of this research study is to improve the pool-based market model, which is useful for Malaysian Electricity Supply Industry (MESI) in order to enhance efficiency, to promote competition in order to lower costs, to increase customer choice, to assemble private investment, and to merge public finances. The proposed model; pool hybrid introducing the minimum generation capacity payment involving the efficiency of the generator and base load sharing approaches, could be applied as an alternative electricity market model to carry on the MESI previous plan toward restructuring, and to accommodate a fair competitive trading between power producers and all involved parties, especially to the Independent Power Producers (IPPs). This minimum generation capacity payment involving the efficiency of the generator is to educate the IPPs to bid and sell their electricity produced at a lower price. Meanwhile, the base load sharing approach helps to reduce the market power exercises and price fluctuations. The proposed model is compared with other pool-based models in a case study to identify which market model is superior. This study can be some form of help in assisting in new policy setup and further research works to overcome this crisis. In this research, economic analysis is performed in terms of generation revenue and demand payment investigation, due to the pricing issue in pool model by extending the capacity payment mechanism in the single auction power pool and generation adequacy. It is demonstrated without considering transmission flow constraints in the problem.

This paper is organized as follows: Section II briefly presents the history and current situation in MESI. Section III describes the basic concept and formulation of pool-based market model. Section IV presents the formulation of the proposed model. Section V elaborates on the results and discussion of the case study. Finally, Section VI concludes the paper.

II. MALAYSIA ELECTRICITY SUPPLY INDUSTRY (MESI)

In 1993, the introduction of IPPs was of one of the initial steps taken to urge the private investors to participate in the generation sector, where five companies were granted licenses to build, operate, and own power plants in Peninsular Malaysia [9], [10]. The introduction of IPPs and competitive bidding allows a level playing field in the generation sector. There is no competition in other areas, as Tenaga Nasional Berhad (TNB) fully controls the other aspect of the electricity business from transmission down to distribution and retail. However, numerous opinions have contended that the IPPs have been a major weight to the economy, given the lucrative quantifiable profit by method for specifically arranged Power Purchase Agreements (PPA). Obviously, the PPAs have experienced a noteworthy move throughout the years with the presentation of demand risk sharing, where IPPs sharing expenses among each other and the end of the basic event of some IPPs is getting monetary profit among disparities.

The single buyer model has raised concerns and drawbacks on how this model may backfire, as it lacks transparency and fairness, poor system planning, and non-competitive procurement. Several observers cite conflict of interest, duplication of cost, and tariff hikes. 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 maximize return [11], [12]. In MESI, after several processes of evolution, the existing single buyer model is still a form of imperfect competition and yet does not provide any competition due to the long-term agreement; that simplify the electricity trading under one company, which is TNB transmission and distribution [13], [14]. Consumers also faced risks as they depend on current market situation. Hence, a new market design is required so that the consumers pay reasonable price and TNB and IPPs also make reasonable profit.

Toward restructuring, MESI had planned to change from single buyer model to a wholesale market, but had been put on hold since 2005. In 2009, MESI transformation programme was launched, which aimed at delivering a reliable, transparent, efficient and sustainable, where two points were highlighted under industry structure; competitive bidding and PPA re-negotiation [15]. Therefore, the aim of this research study is to improve the pool-based market model, which is useful for MESI. In the competitive markets, GENCOs can sell energy through both private agreements with customers or load serving entity and in an organized pool auction [16]. In MESI, the proposed model will be implemented at the generation sector only, as the IPPs and competitive bidding play only at the generation sector and TNB fully controls the transmission to distribution of electricity businesses. The objectives of this study are to enhance efficiency, to promote competition in order to lower costs, to increase customer choice, to assemble private investment, and to merge public finances. The tools of achieving these objectives are the introduction of competition, which is supported by regulation and the encouragement of private participation. Currently, the IPP plants provide 70% of the nation's electricity demand [17]. Future challenges might expense the cost of supply and subsidy, due to volatile fuel prices and IPP payments, as well as earnings below cost of capital. Therefore, the pool-based market model could be applied as an alternative electricity market model to carry on the MESI previous plan toward restructuring, which can accommodate a fair competitive trading to all involved parties and guarantee incomes for all IPPs; it might as well also influence them to renegotiate the terms in the agreement.

III. ELECTRICITY MARKET MODEL

For many years, the electricity industry throughout the world has been vertically integrated. Many countries are encouraged to perform a huge transformation in the electricity supply industry toward deregulation. There are several factors that influence the deregulation of the electricity industry, for example politics, economics, and regulatory needs [18]. Meanwhile, the reason for restructuring is to introduce competition, and the utilities are required to unbundle the retail services and form three separated groups: GENCOs, transmission companies (TRANSCOs), and distribution companies (DISCOs).

Multiple electricity trading arrangements are available in deregulated structure, such as single buyer market, pool market, bilateral contract, and hybrid/multi-lateral contract, which have their own distinct characteristic. This section describes the basic concept and formulation of pool-based market model. The pool model is designed to promote a competitive environment, yet some functional applications have demonstrated the downsides of the model. Therefore, some researchers have developed hybrid model 1 (HM 1) and hybrid model 2 (HM 2) for MESI. Despite this, the proposed market is derived to overcome the weaknesses for both market models.

A. Pool Trading

Pool model is one of the most preferred electricity market model implemented in many developing countries. In the pool model, the generators are placed according to their bidding price, yet the cheaper generator has bigger opportunity to be selected to meet electricity demand. Normally, all generators have the opportunity to supply power during high electricity demand, but instead during low load demand, expensive generator has less opportunity to supply electricity. The last generator being dispatched will determine the system marginal price (SMP) according to its bid. Unfortunately, as energy-only market, attention has been given on the pricing issue where the generators are paid solely on the basis of the volume of electricity generated, resulting in the expensive generator eceiving zero revenue during low electricity demand. Power pools oblige generators to submit offers exhibiting the measure of power they can deliver at a given cost. The generators can offer at any value they like or could be founded on cost-based pools. The equation for pool purchased price, C_{PP}, is based on the SMP regardless of the energy bid price [19].

$$C_{PP} = SMP(1 - LOLP) + VOLL(LOLP) \tag{1}$$

The final price paid to the generators is a combination of the SMP, loss of load probability (LOLP), and the VOLL, which is fixed annually. All in-merit generators will be paid based on uniform price. It is clear the essential elements of the pool will dependably be required in one form or the other. The total generator revenue, G_T, with power generated of P_i for all power producers in Ringgit Malaysia per hour (RM/h) can be mathematically expressed as [19]

$$G_T = \sum_{i=1}^{k}(P_{Gi} \times C_{PP}) \tag{2}$$

Still, there are few issues of introducing the pool model such as price fluctuation and market power exercises. Thus, it is important to modify he existing pool model so that it can provide a fair market to the supplier and user. Therefore, the pool-based market model, hybrid market 1 (HM 1), and hybrid market 2 (HM 2) developed by [20], [21] are taken into account. Both models are developed to overcome the pool model issues.

B. Hybrid Model 1 (HM 1)

The HM 1, which combines the pure pool market and pro-rata base load, consists of two properties: base load demand and peak load demand [20]. For base load demand, the base load sharing allows all generators to get their revenue regardless of the current demand and their energy bid price, while a pro-rata basis approach has been used to divide the base load fairly to all power producers. There is no competition among the generators at this level. The portions of supply that is obtained by each generator will be proportional to its installed capacity, *i.e.*, generators with higher available capacity will have high percentage share of the base load demand. Instead, the remaining high load demand will be traded through competition of the energy bid price offered by each generator. Generator with a lower energy bid price has the priority to supply the remaining demand. The generator's payment for the base load demand would be based on the SMP, while for the remaining load, the demand would be based on their energy bid price. The MW level of base load demand will be determined from the daily load curve, which is the minimum load demand in 24 h. The mathematical equation that represents each generator's contribution, P_{GiBL}, to the base load demand can be written as [20]

$$P_{GiBL} = \frac{P_{Gi}}{\sum_{i=1}^{k} P_{Gi}} \times P_{GTbl} \tag{3}$$

Therefore, the revenue during base load sharing, G_{BLi}, can be calculated by replacing the SMP at the minimum load in 24 h in Eq. (1) and the mathematical equation can be referred as [20]

$$G_{BLi} = P_{GiBL} \times C_{PP} \tag{4}$$

Meanwhile, for peak load demand, the remaining capacity from each generator is traded in pool market model based on energy bid price [20]. As the remaining capacity for each generator is less, it is difficult for generators with higher installed capacity to have a monopoly on the electricity market and the SMP can be reduced due to less remaining demand required for the pool market model.

C. Hybrid Model 2 (HM 2)

The HM 2 with electricity demand sharing and capacity payment approaches has categorized the electricity demand into two areas, *i.e.*, as high demand area and low demand area [21]. The low demand and high demand areas are determined from the daily electricity demand curve, which is constructed using the demand forecasting data. A reference line is drawn on the hourly electricity demand curve at 80% of the highest demand forecasted to distinguish the low demand and high demand areas on the electricity demand curve [21]. The low demand area is represented by the electricity demand below the reference line, which consists of the hourly electricity demand below the 80% of peak demand value and will be traded through bidding competition as in the pool market. All IPPs involved in generation dispatch at low demand area will be paid based on C_{PP} as in Eq. (1), neglecting their initial bidding price. Thus, the revenue for IPP at low demand area, G_{LHi} with power generated P_i, can be mathematically expressed as [21]

$$G_{LHi} = P_i \times C_{PP} \tag{5}$$

Due to a majority of high costs, IPPs will experience low or even zero revenue at the low demand period; full capacity payment is given as compensation for the remaining IPPs which lost the opportunity to be selected in the bidding competition. The mathematical equation for capacity payment, G_{LCPj}, and the revenue under low demand area, G_L, is written as [21]

$$G_{LCPj} = P_j \times C_{CPj} \tag{6}$$

$$G_L = \sum_{i \neq j}^{k} [(P_i \times C_{PP}) + (P_j \times C_{CPj})] \tag{7}$$

where P_j signifies the capacity of the non-selected IPPs in MW, and C_{CPj} addresses the corresponding capacity price of the non-selected IPPs.

The high demand area consists of electricity demand at certain hour, which exceeds the reference line. The 80% from peak demand reference line will split electricity demand in the high area into two parts. Firstly, the electricity demand below the 80% reference line will be traded equally among the IPPs through demand-sharing approach [21]. The electricity demand at the lower part of the high demand area will be equally shared by all IPPs using Eq. (8) below [21].

$$P_{Si} = \frac{P_i}{\sum_{i=1}^{k} P_i} \times P_{80} \tag{8}$$

Here, k signifies the numbers of IPPs in the system, P_{Si} is the IPP electricity demand shares, P_i is the generation capacity of ith IPP, and P_{80} is the 80% of the peak electricity demand in MW. Secondly, the IPPs will compete against each other to supply the remaining demand in the area above the 80% reference line [21]. The upper part of the high demand area will be put under bidding competition using the energy bid prices submitted by the IPPs.

However, both models HM 1 and HM 2 did not consider the efficiency and the electricity price offered by the generators in the base load sharing. Theoretically, the base load power plants are designated based on their efficiency, low cost generation, and safety at rated output power levels. Thus, to overcome the drawbacks, pool hybrid, which introduces the approach of base load sharing and minimum capacity payment involving the efficiency of the generators, is developed. A case study is conducted for the generators in Peninsular Malaysia to analyze and compare the proposed model performance with pure pool model, HM 1, and HM 2.

IV. PROPOSED MARKET MODEL

This study emphasises on the economic aspect from the point of view of the generators. Under single auction power pool, the proposed model is designed to overcome several disadvantages of the pool-based market model discussed earlier. The actual load profile of Peninsular Malaysia, which is based on information provided by N. Othman, 2014, on Monday and Sunday, as shown in Figure 1, will be used as an hourly load demand that IPPs must meet [21]. This proposed market model has categorized the electricity demand into two areas, high demand area and low demand area, as shown in Figure 2. Case studies are carried out to compare the generators' revenue, hourly generation revenue, and demand payment in MESI under pure pool model, HM 1, HM 2, and the proposed model, pool hybrid. In this paper, the generators bid the same price for the 24 h. Transmission charges and losses for all resources are negligible because this research study is focusing on generation pricing only.

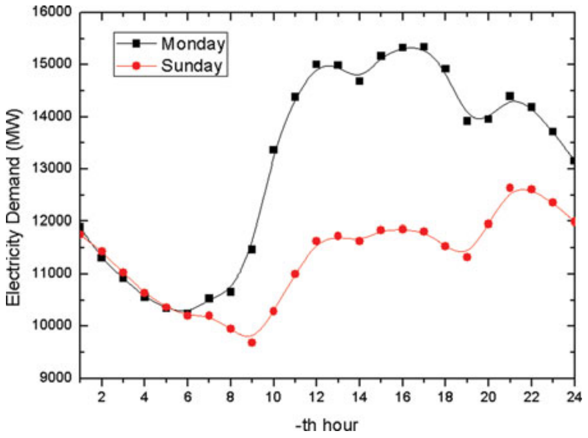

FIGURE 1. Diagram of Malaysia load profile curves.

Sixteen selected generators from thermal and combined cycle plant type are used as the test system. Only combine cycle gas turbine (CCGT) and thermal plant types are chosen

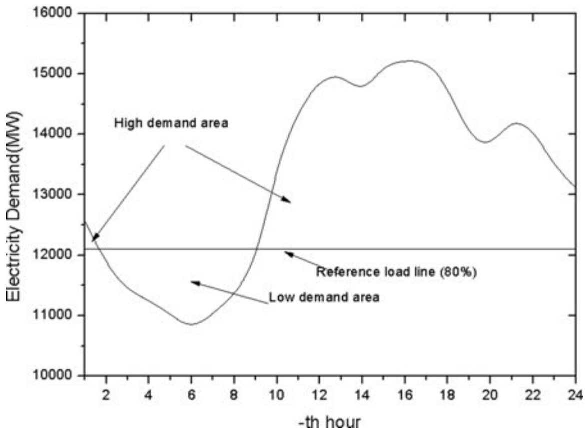

FIGURE 2. The high demand and low demand areas on hourly electricity demand curve.

Gen	Plant Type	Installed Capacity (MW)	Energy/Bid Price (RM/MW/h)	Capacity Price (RM/M/month)	η (%)
1	CCGT	720	120	30,000	46.91
2	CCGT	640	130	30,000	40.82
3	CCGT	334	130	35,000	43.64
4	CCGT	650	140	35,000	43.64
5	CCGT	350	145	35,000	43.64
6	Thermal	2420	150	20,000	39.03
7	CCGT	1170	150	30,000	45.62
8	CCGT	762	150	45,000	44.22
9	CCGT	1136	160	30,000	40.74
10	Thermal	2100	160	30,000	20.91
11	CCGT	440	165	35,000	43.64
12	CCGT	100	175	35,000	43.64
13	Thermal	100	175	30,000	35.99
14	CCGT	1303	180	40,000	42.09
15	Thermal	1400	190	25,000	35.91
16	Thermal	2100	200	55,000	25.82

TABLE 1. Details on plants types, MW installed capacity, bid price, capacity price, and efficiency for 16 generators in Peninsular Malaysia.

due to the efficiency and price offered by the generator. This is because generation costs of open cycle gas turbine (OCGT) are much higher; the fuel cost may be up to 50% higher than in CCGT as the efficiency is about two-third that of a combined cycle, yet still, the main reason for the OCGT high generation cost is the low load-factor of the peak-load services [22]. Based on information provided by N. Othman, 2014, Table 1 shows the details of the 16 generators in MW-installed capacity, bidding prices, and capacity prices [21]. Meanwhile, the efficiency of the generators is based on the calculations. As the monetary values involved in this paper are confidential, therefore estimated values are used.

The purpose of the proposed model is to introduce a price mechanism that can secure the revenue for the generator, although during low demand. The proposed market model is an improvement over pool-based market model by adding two properties: 1) minimum generation capacity payment and 2) base load sharing mechanism. The introduction of minimum generation capacity payment based on the efficiency of the generator is to ensure continuous remuneration for all IPPs regardless of their submitted energy, bid prices, and the fluctuating electricity demand. This is because pool market cannot guarantee continuous remuneration for IPPs when the electricity demand is low; numerous of high costs IPPs will experience low or even zero revenue during low demand period. Thus, this new mechanism for capacity payment is proposed to solve the capacity payment issue. Capacity payment mechanisms are required in electricity markets to ensure security of electricity supply and to fill the so-called “missing-money” gap. Instead of paying full capacity payment to the generator, minimum generation capacity payment based on generator efficiency is introduced as compensation because the possibility of expensive generators not being selected in the bidding competition is high. The same type of capacity payment will be given to the IPPs that have won in the bidding competition as an incentive in order to educate the IPPs to bid and sell their electricity produced at a lower price.

Meanwhile, the new concept of base load sharing approach in the proposed model ensures the participation of least cost generators for all trading period. This market could also reduce the market power exercise as a part of the generators’ available capacity has been used to supply the base load demand. The electricity demand sharing is applied under high demand area. Meanwhile, the capacity payment is added for low demand area.

A. Low Demand Area

The low demand area will be traded through bidding competition as in the pool market. Though, when the electricity demand is low, pool market cannot guarantee continuous remuneration for the IPPs. Thus, the IPPs lose the opportunity to fulfill the hourly electricity demand, which is the hourly income. Due to numerous high costs, IPPs experience low or even zero revenue at the low demand period; therefore, capacity payment with minimum generation based on generator efficiency is introduced. Similar to bidding system applied in the pool model, the payment for power generated is affected by the SMP determined from the last IPPs being dispatched at that period of time. The pool purchase price, C_{PP}, at low demand area is paid to the IPPs for the power generated in an hour. For more precise valuation, the values for LOLP and

VOLL from Eq. (1) were set at 1/365 and RM 10,000/MWh, respectively [21]. Therefore, all IPPs involved in generation dispatch will be paid based on C_{PP}, neglecting their initial bidding price. Thus, the revenue for IPPs at low demand area with power generated P_i can be mathematically expressed as Eq. (2).

In this model, the energy price is the key to pattern dispatch, which the IPPs submit energy/bids price and capacity available to be supplied for the period under consideration. Then, these bids are ranked in order of increasing price, from the least price up to the highest price. The cheapest or lowest running cost generator should be generating to meet demand. Since the probability of expensive generators for not being selected in the bidding competition is high, capacity payment based on generator efficiency will be given as compensation for the remaining IPPs which have lost in the bidding competition. This capacity payment will also be given as an incentive to the IPPs that are involved in the bidding competition to ensure continuous remuneration for all IPPs regardless of their submitted energy bid prices and the fluctuating electricity demand as an effort to educate the IPPs to bid and sell their electricity produced at a lower price. The electric power plant efficiency, η, is defined as the ratio between useful electricity output from the generating unit, in a specific time unit, and the energy value of the energy source supplied to the unit, within the same time [22]. The generator's efficiency, η_i, can be mathematically expressed as [23]

$$\eta_i = \frac{G_{Tout}}{E_{Ti}} \tag{9}$$

where G_{Tout} is the total generation output in Btu and E_{Ti} is the total fuel energy input in Btu. Thus, the mathematical equation for minimum generation based on efficiency, P_{MGi}, can be written as

$$P_{MGi} = P_i \times \eta_i \tag{10}$$

where P_i and η_i represent the output power generated and efficiency of the IPPs, respectively. Therefore, the mathematical equation for capacity payment with minimum generation, G_{MCPi}, for each IPP can be written as

$$G_{MCPi} = P_{MGi} \times C_{CPi} \tag{11}$$

where P_{MGi} and C_{CPi} represent the minimum generation capacity and capacity price offered by generator in RM/MWh, respectively. Hence, the total revenue at low demand area in RM/h for participated IPPs, G_L can be mathematically expressed as follows:

$$G_L = \sum_{i \neq j}^{k} [(P_i \times C_{PP}) + (P_{MGi} \times C_{CPi})] + (P_{MGj} \times C_{CPj}) \tag{12}$$

Here, k is the numbers of IPPs in the system, P_{MGj}, is the minimum generation capacity of the non-selected IPPs in MW, and C_{CPj} is the corresponding capacity price of the non-selected IPPs in RM/MWh.

B. High Demand Area

The electricity demand under high demand area will be traded through demand sharing and bidding competition. The 80% from peak demand reference line will split electricity demand in the high area into two parts. Firstly, the electricity demand below the 80% reference line will be traded equally among the IPPs through demand sharing approach in order to reduce market power exercises, due to high SMP during peak demand and no revenue during low electricity demand in pool model. The electricity demand at the lower part of the high demand area will be equally shared by all IPPs using Eq. (13):

$$P_{Si} = \frac{P_i}{\sum_{i=1}^{k} P_i - P_k} \times P_{80} \tag{13}$$

where P_k is the generation capacity for the most expensive generator, and other terms are same as defined in Eq. (8). The distribution of the shared electricity demand relies on the IPPs accessible capacity. IPPs with the highest capacity will have the biggest share of the electricity demand. The payment during electricity demand sharing will be determined by two factors, *i.e.* the SMP of the sharing demand and the amount of electricity demand shares of each IPP. The SMP during electricity demand sharing is decided from the aggregated generation curve graph. Figure 3 shows the aggregated generation

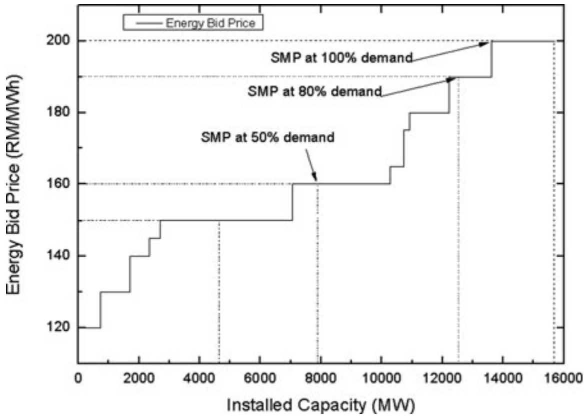

FIGURE 3. The aggregated generation curve and the SMP at 30, 50, 80, and 100%.

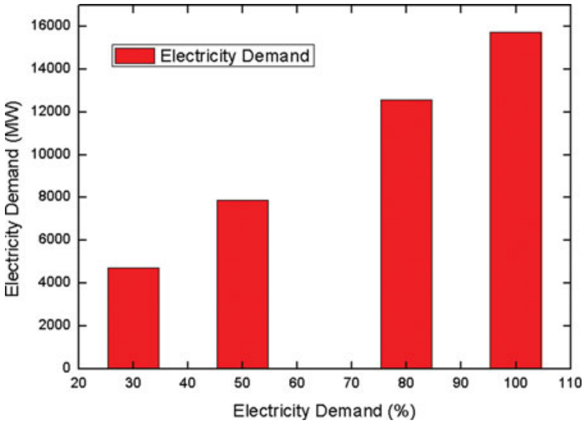

FIGURE 4. The analysis of the electricity demand values in MW.

curve and the SMP at 30, 50, 80, and 100% demand. Meanwhile, Figure 4 shows the analysis of the electricity demand values in MW.

Pool purchased price, C_{PP80}, is the sharing price calculated utilizing mathematical statement in Eq. (1) but with the SMP value at the total shared demand (80% of peak electricity demand). The resulting SMP will make the production cost of electricity will be lower, in order to control the price fluctuations during high demand. Indeed, even with the same SMP, each IPP will receive different payment relying upon their energy commitment at this level. The revenue for IPPs during electricity demand sharing, G_{Si} can be calculated using mathematical equation

$$G_{Si} = P_{Si} \times C_{PP80} \tag{14}$$

Secondly, the IPPs will compete against each other to supply the remaining demand in the area above the 80% reference line. As discussed earlier, the upper part of the high demand area will be put under bidding competition using the energy bid prices submitted by the IPPs. During this time, all IPPs are involved, from the less expensive to the costly generators, yet the IPPs with the least-expensive energy bid price will have the priority to be chosen to satisfy this remaining demand. The IPPs are being paid according to the remaining power generated, $P_{Ri,}$ and their own energy bid price, C_{Bi}. The revenue for IPPs for the remaining electricity demand generated, G_{Ri}, can be mathematically expressed as

$$G_{Ri} = P_{Ri} \times C_{Bi} \tag{15}$$

Therefore, the total revenue for all IPPs in the proposed model, G_T, can be expressed as the summation of the total revenue at low demand area, G_L, and high demand area. The revenue for proposed model is as follows:

$$G_T = G_L + G_{Si} + G_{Ri} \tag{16}$$

Thus, the total revenue for all IPPs can be mathematically written as

$$\begin{aligned} G_T = \sum_{i\neq j}^{k} G_{PH} = \sum_{i\neq j}^{k} [(P_i \times C_{PP}) + (P_{MGi} \times C_{CPi})] \\ + \left(P_{MGj} \times C_{CPj}\right) + (P_{Si} \times C_{PP80}) + (P_{Ri} \times C_{Bi}) \end{aligned} \tag{17}$$

V. RESULT AND DISCUSSION

A. Power Contributions

Based on the analysis of the electricity demand values in MW, as shown in Figure 4, there are four categories of demand, *i.e.*, 30, 50, 80, and 100%. In order to be chosen in the generation dispatch, IPPs must win in the energy bidding. The IPPs with lower energy bid price contrasted with the hourly SMP will be chosen to satisfy the power demand for that hour. The SMP at specific hour is determined when the load curve and supply curve intersect to influence the payment for all in-merit generators. All participated IPPs in the electricity dispatch will be paid according to the C_{PP}, which is determined from hourly SMP, rather than the initial bid. The non-participated IPPs are exposed to the risk of losing their revenue, because only at 100% demand, all IPPs receive the revenue. Hence, more IPPs will lose their revenue as the electricity demand keeps reducing, but the IPP revenue in the pool market continues to strike as the demand keeps increasing due to most IPPs being paid at higher price compared to their own bid price. For example, IPP 1 is paid with RM 200 for every MW power produced at 100% demand, which is RM80 higher compared to its initial bid price. Therefore, in this pool hybrid, power contribution is chosen at 80% for demand sharing approach resulting the SMP at RM 190; where the production cost of electricity will be lower, in order to control the price fluctuations during high demand.

B. IPPs' Generation Revenue

Figures 5 and 6 show the generation revenue of 16 generators during Sunday and Monday, respectively. On Monday, all 16 generators are able to supply electricity regardless of their bid prices. For overall total, the cheapest generator, Gen 1 manages to supply its full capacity and received RM 13.4 million. Meanwhile, the expensive generator, Gen 16 supplied and earned RM 18.2 million. However, on Sunday, according to pure pool market system, Gen 16 has lost its opportunity to

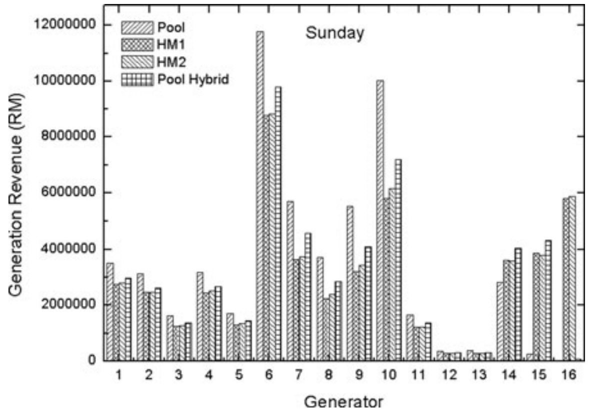

FIGURE 5. Comparison of generator's revenue on Sunday.

generate electric power and received zero revenue due to low load demand. Meanwhile, the generation revenues for HM 1, HM 2, and pool hybrid are RM 5.8, 5.87, and 82, 839 million, respectively. It indicates that expensive generators are able to gain revenue due to base load sharing. Even more, the capacity payment mechanism will increase the generation revenue in fair manner. For Gens 14 and 15, the proposed pool hybrid model received the highest revenue compared to other models because the most expensive generator, Gen 16, is not involved in the base load sharing in order to maximize the use of base load plants with cheaper prices. The available capacity from the remaining generators is divided fairly, which offered more capacity, will receive more share in the base load sharing, and gain more revenue. As a result, RM 5.7 million for HM 1 and RM 5.78 million for HM 2 are saved due to this change.

From HM 1, HM 2, and pool hybrid perspective, all 16 generators had the opportunity and managed to supply electricity and obtained their generation revenue on Monday, and Sunday, whereas the revenue was slightly lower compared to pure pool due to the added properties that have reduced the revenue for the generators. The pool hybrid model guarantees the welfare of all generators regardless of the variation of electricity demand. Indeed, the generation revenue for cheaper generator is slightly higher compared to HM 1, and HM 2, but slightly lower compared to pure pool. Instead of giving full capacity payment, thus it is reasonable to introduce the minimum generation capacity payment based on the efficiency of the generators, which helps to educate the generators to bid at cheaper prices.

The other merit for pool hybrid is the generator efficiency at the sufficient level despites the base load sharing mechanism. There is no competition among the generators at this level, and the generators share this load proportional to their available capacity. The generator with higher available capacity has high percentage share of the base load demand. However, the generator with the highest price is not allowed to involve in this base load sharing in order to optimize the available capacity from the cheaper generators. Although Gen 16, the expensive generator, is not involved in the base load sharing, yet it still had the opportunity to gain the revenue through the remaining load above the 80% reference line that will be put under bidding competition using the energy bid prices during high demand, and the minimum generation capacity payment during low demand.

C. Hourly Generation Revenue

Figures 7 and 8 show the hourly generation revenue on Sunday and Monday, respectively. As expected, the generation revenue is high on Monday compared to Sunday, due to the load demand decreasing on the weekend. Pure pool indicates the highest generation revenue due to the SMP changes according to the hourly demand. Meanwhile, for

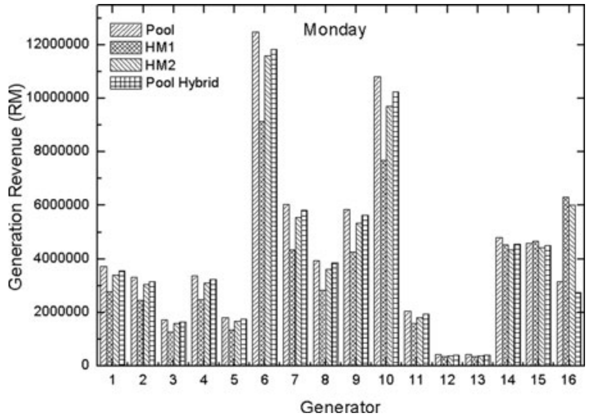

FIGURE 6. Comparison of generator's revenue on Monday.

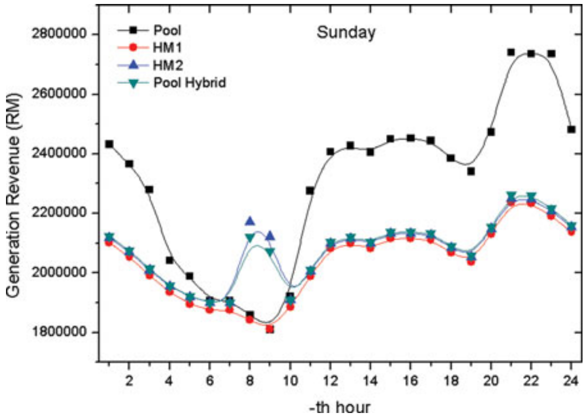

FIGURE 7. Comparison of hourly generation revenue on Sunday.

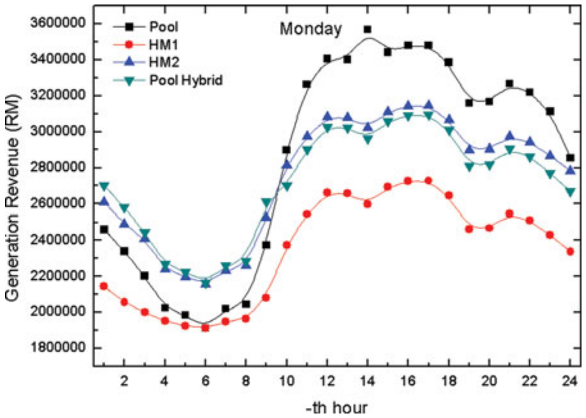

FIGURE 8. Comparison of hourly generation revenue on Monday.

HM 1, HM 2, and pool hybrid, the generation revenue is lower due to only one SMP during the base load sharing. According to pure pool, the highest revenue on Monday falls at 2.00 pm with RM 3.57 million, and the lowest revenue on Sunday at 9 am with RM 1.8 million. On Monday, total revenue for HM 2 is 3.7% lower than pure pool, but 2.4% higher than pool hybrid. The revenues for pool hybrid are lower influenced by the minimum generation capacity payment and changes have been made in base load sharing. During the lowest demand, the revenue for pure pool and HM 1 is the same with RM1.8 million, HM 2 is RM 2.1 million, and pool hybrid is RM 2.07 million. In pool hybrid, due to minimum generation capacity payment given as remuneration for participated IPPs, led to the competition between the generators, where all generators compete to reduce the generation costs and at the same time increasing the market efficiency. Consequently, the generators are able to compete for more dispatch and increase their revenues. On Monday, during low demand, hourly generation revenue for pool hybrid is slightly higher compare to HM 2 because of the minimum generation capacity payment based on generator efficiency given to the participated and non-participated IPPs, also influenced by the load demand, which increased on the weekday. However, during the high demand the situation is inverse effect from the base load sharing which are able to reduce market power exercises. On Sunday, during low demand, pool hybrid is slightly lower compared to HM 2 because of the reduction of full capacity payment to minimum generation capacity payment and affect from the decreasing loads demand.

Consequently, the results have shown that the pool hybrid has merit over the pool market in providing fair and adequate generator revenue over trading hours. Table 2 shows the percentage improvement in terms of generation revenues for HM 1, HM 2, and proposed model compared to pure pool model for Sunday and Monday in 24 h, while highlighted data are referred to low demand area. Instead of improvement percentages, negative data indicate the reduction percentages. The following explanations are based on the average percentage using data from Table 2 during low and high demand. On Sunday, the average percentage improvement of generation revenues for HM 2, and the proposed model in order to secure the expensive generator revenue during low demand area are 17 and 14.32%, respectively. In this case, pool hybrid is 2.68% lower than HM 2 due to the changes of capacity payment from full capacity payment to the minimum generation capacity payment. Meanwhile, the average percentage reduction of generation revenue during high demand area for HM 2, and the proposed model are reduced to 10.96 and 10.77%, respectively. In addition, the percentages data on Sunday are also affected from the decreasing load demand during weekend. On Monday, the average percentage improvement during low demand area for HM 2, and the proposed model are 9.27 and 11.38%, respectively. Temporarily, the average percentage of generation revenue during high demand area for HM 2 and the proposed model are reduced to 8.57 and 10.38, respectively.

In the meantime, the reduced percentages indicate that the improvement in lowering the demand payment. Furthermore, for base load plant, two important points are taken into account: i) efficiency of the generator and ii) cheaper price generator. According to these points, the base load demand sharing approach in pool hybrid market has equal opportunities to participate in the trading and receive some revenue for their contribution and guarantees the participation of all IPPs in the hourly trading period excluding the highest price generator.

D. Demand Payment

Figures 9 and 10 show the results for the analysis of the demand investigation. This demand investigation is to analyze the amount the purchasers have to pay to the producers for the electricity generated in 24 h. The mathematical formulation for hourly demand payment, DP_i can be expressed as

$$DP_i = \frac{LD_i}{LD_T} \times G_T \tag{18}$$

where LD_i is load demand for ith hour, LD_T is total load demand in 24 h, and G_T is the total generation revenue in 24 h. On Sunday, taking the pure pool as the base, the payment to be made for HM 1, HM 2, and pool hybrid have decreased as 11.52, 9.63, and 9.62 respectively. Meanwhile, on Monday, the payments to be made for HM 1 and pool

Day	Sunday			Monday		
Hour	HM 1 (%)	HM 2 (%)	Pool Hybrid (%)	HM 1 (%)	HM 2 (%)	Pool Hybrid (%)
1	– 13.57	– 12.87	– 12.66	– 12.81	6.13	9.84
2	– 13.18	– 12.46	– 12.25	– 12.06	6.44	10.34
3	– 12.64	– 11.88	– 11.68	– 9.22	9.30	10.98
4	– 5.23	– 4.20	– 4.12	– 3.61	10.60	11.94
5	– 4.66	– 3.45	– 3.42	– 2.95	10.82	12.18
6	– 1.69	– 0.33	– 0.33	0.00	12.71	13.17
7	– 1.69	– 0.33	– 0.33	– 3.54	10.62	11.97
8	– 0.94	16.77	14.13	– 3.88	10.50	11.82
9	0.00	17.23	14.51	– 12.28	6.35	10.19
10	– 1.91	– 0.60	– 0.60	– 18.14	– 2.90	– 6.76
11	– 12.61	– 11.85	– 11.65	– 22.03	– 8.88	– 11.04
12	– 13.42	– 12.71	– 12.51	– 21.82	– 9.49	– 11.07
13	– 13.54	– 12.84	– 12.63	– 21.83	– 9.49	– 11.07
14	– 13.41	– 12.71	– 12.50	– 27.14	– 15.30	– 16.97
15	– 13.67	– 12.97	– 12.78	– 21.72	– 9.56	– 11.08
16	– 13.68	– 12.99	– 12.79	– 21.61	– 9.62	– 11.09
17	– 13.64	– 12.94	– 12.74	– 21.60	– 9.62	– 11.09
18	– 13.30	– 12.58	– 12.38	– 21.86	– 9.44	– 11.07
19	– 13.03	– 12.30	– 12.09	– 22.04	– 8.20	– 11.02
20	– 13.80	– 13.11	– 12.90	– 22.05	– 8.26	– 11.02
21	– 18.38	– 17.84	– 17.41	– 22.03	– 8.91	– 11.04
22	– 18.36	– 17.82	– 17.39	– 22.05	– 8.60	– 11.03
23	– 19.87	– 19.24	– 18.91	– 21.94	– 7.85	– 11.00
24	– 13.84	– 13.16	– 12.94	– 18.02	– 2.46	– 6.47

TABLE 2. Percentages improvement and reduction in term of generation revenue in 24 h.

hybrid have decreased by 17.65 and 4.67%, respectively. However, the payment for HM 2 is 1.6% higher compared to pool hybrid with the total amount of saving of RM 1.05 million.

Even the payment made by purchasers for HM 1 is the lowest, but this market model cannot guarantee reasonable income for low and medium price generator, as shown in Tables 3 and 4. Even more, higher price generators manage to gain more revenue. This situation will not help to encourage the competition. However, the total generation revenue for pool hybrid at intermediate value indirectly reduces the demand payment, which creates a win-win situation for the producer and the buyer.

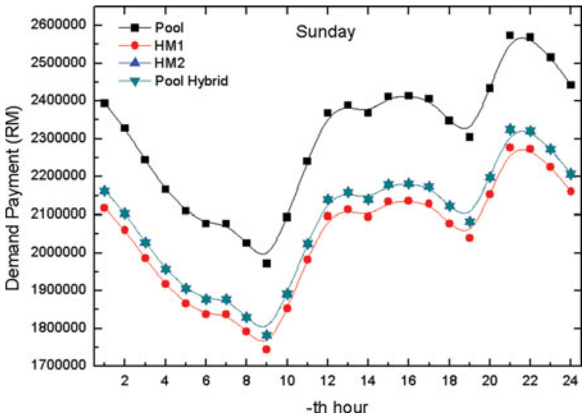

FIGURE 9. The analysis of the demand side investigation on Sunday.

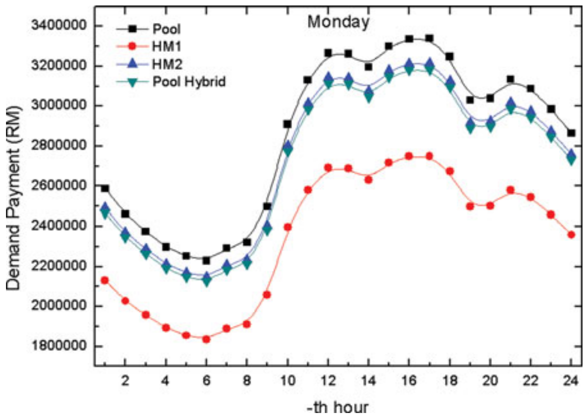

FIGURE 10. The analysis of the demand side investigation on Monday.

Sunday

IPP	Pool	HM 1	HM 2	Proposed Model
1	3,503,500	2,751,123	2,801,855	2,961,281
2	3,114,222	2,470,542	2,466,285	2,609,172
3	1,625,235	1,249,363	1,277,423	1,359,931
4	3,162,882	2,428,956	2,514,109	2,666,366
5	1,703,090	1,306,417	1,347,374	1,436,374
6	11,775,654	8,760,678	8,824,993	9,792,547
7	5,693,188	3,644,281	3,729,877	4,581,285
8	3,707,871	2,231,546	2,379,340	2,850,633
9	5,527,745	3,213,209	3,429,528	4,084,661
10	10,012,888	5,802,244	6,161,964	7,204,625
11	1,644,111	1,215,708	1,205,997	1,361,173
12	354,729	276,297.3	274,090.3	309,357.5
13	375,212.3	276,297.3	272,701.4	308,113.9
14	2,809,429	3,600,154	3,589,494	4,036,582
15	256,565	3,868,162	3,798,376	4,306,519
16	0	5,802,244	5,872,563	82,839
Total	55,266,321	48,897,222	49,945,970	49,951,458

TABLE 3. Comparison data on generation revenue in RM on Sunday.

Monday

IPP	Pool	HM1	HM2	Proposed Model
1	3,715,318	2,779,064	3,392,122	3,547,615
2	3,302,505	2,456,362	3,036,309	3,148,364
3	1,723,495	1,263,634	1,584,574	1,655,695
4	3,354,107	2,481,848	3,105,171	3,231,853
5	1,806,058	1,341,262	1,677,782	1,742,839
6	12,487,598	9,138,447	11,600,373	11,842,622
7	6,037,392	4,336,703	5,550,753	5,811,560
8	3,932,045	2,824,417	3,599,608	3,844,144
9	5,861,947	4,270,127	5,340,399	5,638,829
10	10,828,306	7,694,796	9,704,004	10,248,086
11	2,033,503	1,575,724	1,791,979	1,947,932
12	420,542.5	353,214.8	387,327.5	405,214
13	418,321.4	353,214.8	385,106.4	399,646
14	4,799,658	4,526,685	4,329,381	4,543,956
15	4,577,592	4,665,750	4,425,593	45,081,72
16	3,153,205	6,308,714	6,015,180	2,740,244
Total	68,451,593	56,369,962	65,925,661	65,256,770

TABLE 4. Comparison data on generation revenue in RM on Monday.

VI. CONCLUSION

This paper has proposed a pool hybrid market model introducing base load sharing mechanism and minimum generation capacity payment to satisfy the generator revenue adequacy under competitive electricity market environment. Base load sharing approach is able to reduce the market power exercises. The advantage of minimum generation capacity payment is that it can guarantee continuous remuneration for all IPPs regardless of their submitted energy bid prices and fluctuating electricity demand, even the fact that all generators could recover their operation and maintenance costs by bidding higher price during peak load demand. Subsequently, the pool hybrid positively defeats the downsides of the existing single buyer market due to capacity payment obligation without overlooking the pool market, in order to guarantee revenue remuneration for the generator. In conclusion, pool hybrid is superior to other models as the model is able to provide competitive and effective environment with efficient electricity supplies, and constrained cases will be included for further research.

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