Impact of Reserve Margin Variance on Competition for Creating Price Efficiency and Investment Encouragement

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***Abstract*—The restructure of electricity market systems aims to achieve price efficiency and encourage new investment. However, these two intentions are contradictory with regard to the reserve margin level in the system. Hence, an 'optimum' reserve margin is sought that establishes a balanced condition that can create price efficiency and encourages investment. This research examines the optimum reserve margin of the Java-Bali prospective competitive market with energy-only and spot-price system, by simulations using PLEXOS® software. To reflect perfect competition in the market model, the short-run marginal cost (SRMC) simulation was used, while imperfect competition was attained by imposing a combination of game theoretic, Nash-Cournot and Bertrand simulations. The model was validated for both physical and competition conditions in order to ensure the accurate representation of real market conditions. Due to a lack of data for the Java-Bali spot-price market, the Australia's National Electricity Market (NEM) was used as a representative of the future spot-price market design of the Java-Bali system.**

The simulations yielded different levels of optimum reserve margin in perfect and imperfect competition conditions. Sensitivity analysis on the results concerning the existence of market power suggests that high reserve margin does not necessarily improve price efficiency.

***Index Terms*—reserve margin, competition, price efficiency, investment encouragement, company/generator behavior, SRMC, Nash-Cournot, Bertrand**

I. Introduction

The pursuit of economic efficiency and new capital investments leads countries to restructure their electricity markets [1]. In a restructured market system, liberalisation replaces the monopolistic system and introduces competition among all market players [2] and [3]. Some countries such as Australia, the United Kingdom and Nordic countries have successfully restructured their market systems by implementing electricity restructuring reform law or a process commonly referred to as 'deregulation' [2], [4] and [5]. An indication of the success is the economic efficiency gained by providing lower electricity prices and adequate electricity supply [5]. By applying deregulation, major changes in institutions and operations of electricity market are required to facilitate and accelerate the competition process [1]. The changes involve unbundling of vertically integrated electricity companies by separating management of generation, transmission and distribution [6]. It is expected that this effort could eliminate the inefficiency of the traditional system as well as encourage investors to participate in a competitive market created.

However, to establish a competitive electricity market, the physical condition of the electricity system should be identified as a significant concern. Issues arise with regard to reserve margin in the system. Intense competition in a high reserve margin condition increases price efficiency but reduces incentives for investors [7]. In an energy-only market, these incentives are required to compensate investment cost that is not guaranteed [8]. Failure to obtain them might discourage new investments. Conversely, a low reserve margin condition enables investors to control market prices that can lead to price inefficiency [9]. Therefore, to achieve the aims of deregulation, a balanced condition of reserve margin where both interests are satisfied should be analyzed.

This research was undertaken to analyze impacts of reserve margin on price efficiency and investment incentives in a competitive electricity market. It examines the case of the biggest Indonesian electricity system, the Java-Bali system where the reserve margin issues could emerge after the system is restructured due to a low reserve margin in the present condition. However, this issue may also be relevant to countries that have already restructured, or intend to restructure their electricity markets.

II. Methodology

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Reserve margin simulations in a competitive market model are utilized to determine an optimum reserve margin or reserve margin limit. The limit reflects a balanced condition of the market in maintaining price efficiency and attracting investments. The model uses a competitive spot-price market system, a prospective system for the Java-Bali market [10] and [11], since the existing system, pays-as-bid with take-or-pay contract [11], does not reflect a real competitive market. However, since specific rules and arrangements for the Java-Bali spot-price market are not available, adoption of rules and arrangements from other countries are required. Therefore, Australia's National Electricity Market (NEM) rules, particularly bidding rules and spot-price market arrangements are adopted for the Java-Bali model. Using the rules and arrangements, the Java-Bali market is modeled as if it were in a competitive spot-price market.

The basic approach of the simulation is divided into two stages. The first stage involves reserve margin simulation in a competitive market model built in PLEXOS. The following stage contains assessment of investment encouragement using Microsoft Excel, or post-processing calculation, which examines results obtained from the first stage.

The market model built in the first stage has to be able to maximize social benefit by obtaining price efficiency resulting from competition. In this case, social benefit is described as competition benefit [12]. Therefore, perfect and imperfect competitions are imposed in the model as a mechanism for maintaining price efficiency in the market. Imposing these two types of competition, high competition intensity in the market model is guaranteed [13]. Thus, it tends to result in lower market clearing prices or higher price efficiency [9]. For perfect competition, the short-run marginal cost (SRMC) simulation is used. For imperfect competition, this paper utilizes a combination of game theory with volume-based competition (Nash-Cournot) and game theory with price competition (Bertrand).

Expected results from the market simulation are optimum generators' offer prices and quantities, spot prices, revenues and profits. The profits are then assessed in the second stage. This assessment intends to find an optimum reserve margin of the market where investment is still attractive. Rational thought suggests that investors would not be interested in a market condition that results in losses due to not recovering investment costs.

A. Stage 1-Market Model Simulations

The simulations begin with establishing the Java-Bali physical market model in PLEXOS, which includes database of objects (generators, nodes, lines, regions and fuels) and the rules and bidding arrangements of the market. Competition behavior is then established by imposing the SRMC and Nash-Cournot (NC) and Bertrand competitions in separate simulations. To obtain different reserve margin conditions, half-hourly input demand is scaled to certain values, while total supply capacity remains constant. The scaling factor is adjusted based on the desired reserve margin value.

The model is required to imitate not only the physical condition of the market, but also the real bidding arrangements. In research using imperfect market competition, it is common to utilize only one attribute that is competing, price only or quantity only. However, in this paper, both attributes are controllable in order to capture the real bidding process. Using solely NC or Bertrand competition is not entirely realistic since in fact, generators have an ability to manipulate offer prices as well as quantities. For example, in the NEM bidding system, generators could continually set bid prices until the bidding time is closed [14]. This is analogous to Bertrand competition. After gate closure, the offer prices are locked. Generators could re-bid, but only to change the capacities offered. This is analogous to NC competition. Therefore, a combination of this game would reflect the real bidding process.

Combining NC and Bertrand games would yield mark-up prices that are different from those when each game is used independently. Fig. 1 shows shapes of price duration curves (PDCs) from the SRMC, NC and Bertrand simulations. By using only NC simulation (Fig. 1(a)), mark-ups above perfect competition occur mostly during peak load and off-peak load period with a bias towards peak times [15]. This indicates that a re-bid quantity enables generators to change their quantities in peak or off peak period in order to maximize profit. With only Bertrand simulation (Fig. 1(b)), generators tend to keep prices close to marginal cost in off peak period due to a large amount of supply available at low prices [15], while in peak period, generators would offer high prices that are close or equal to a cap price [16]. Therefore, in the Bertrand curve, the mark-up is significant in peak period and less significant in off-peak period. Fig. 1(c) shows PDCs from the combination of NC and Bertrand simulations. The area above the SRMC curve is the mark-up prices from these simulations. Combining these two games would result in more mark-up prices.

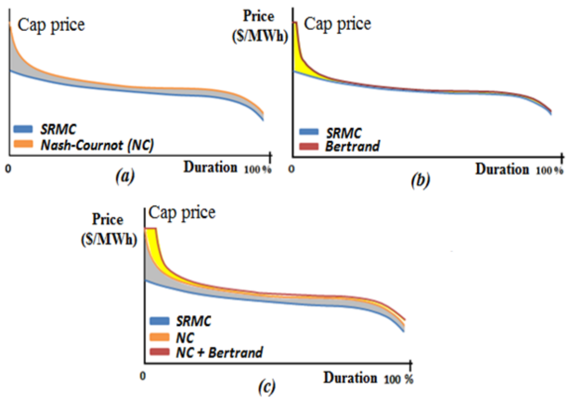

Figure 1. PDCs from the SRMC, NC and Bertrand simulations

Each simulation conducted in both perfect and imperfect competition conditions has the same objectives that relate to market operator objective, price efficiency, and company's objective, profit maximization. The objective of the market operator is organized by imposing competition in the model, hence, in the model created, generator's objective is left to be considered. Therefore, the objective function of the market model simulation is profit maximization function.

Objective Function - Max Profit per Generator (π_{if})

$$\sum_1^k \sum_1^d \{[g_{ifdk} \cdot U_{if} \cdot h_{dk} \cdot p_k \cdot MLF_{if}] - [g_{ifdk} \cdot h_{dk}] \cdot [FP_{if} \cdot HR_{if} + Vom_{if}] - Fom_{ifk}\} \quad (1)$$

Subject to constraints:

- Energy balance;
- Feasible dispatched capacity considering the minimum stable level and the maximum capacity;
- Feasible dispatched capacity considering the maintenance rate and the force outage rate (FOR);
- Feasible dispatched capacity considering the rating (maximum generated capacity in certain period);
- Feasible operation time considering maintenance time;
- Ramping up time;
- Ramping down time;
- Offer price limitation;
- Limitation for transfer capacity inter-region.

where π_{if} (\$) is profit obtained by generator *i* and company *f*. The profit is counted in a thirty-minute trading interval *k*. Each generator can re-bid the quantity every five minutes, hence, there will be quantity changes in each re-bid interval *d*. The trading is in units of energy purchased, therefore, the dispatched capacity of a generator is multiplied by hour *h* within each re-bid interval *d* to find the energy purchased. Each generator has a number of units installed, U_{if} that generates certain amount of capacity, g_{if} (MW). Cost of generators is derived from fuel cost (fuel price (FP_{if}) and heat rate (HR_{if})) (\$/kWh), and generator variable and fixed costs for maintenance and operation, VOM_{if} (\$/kWh) and FOM_{if} (\$/MW). The price received by a generator is market price, *p* (\$/kWh) that has been scaled by a transmission marginal loss factor (MLF). Ref. [14] provides explanation regarding MLF.

B. Stage 2- Post-Processing Calculation

This stage computes investment recovery using results derived from the previous stage to find the optimum reserve margin that balances the interests of investors and consumers. The concept employed is offsetting between trading profits, also known as premiums, and investment cost. An equilibrium of sorts could occur when the premium exactly offsets the investment cost.

For a condition of the adjusted reserve margin (n%), the profit per year is derived from competition simulation. Premiums and investment cost are calculated in \$/kW/year. The difference between investment cost and premium is the additional premium required to offset the investment cost. A positive value of this premium required indicates that the gain from trading could not offset the investment cost. If the premium required is zero, then the n% reserve margin is the optimum condition where investment is still attractive for the investors, otherwise, the simulation in stage 1 has to be repeated using a different reserve margin condition. This process is repeated until a zero-premium-required condition is found, or until there are enough points to make an equation in premium versus reserve margin curve that can be used for extrapolation to find premium required equal to zero. In the latter method, each simulation and calculation result is mapped in reserve margin versus required premium curve (see Fig. 2). The curve's equation is then found. In the figure, X_0 is the objective reserve margin point.

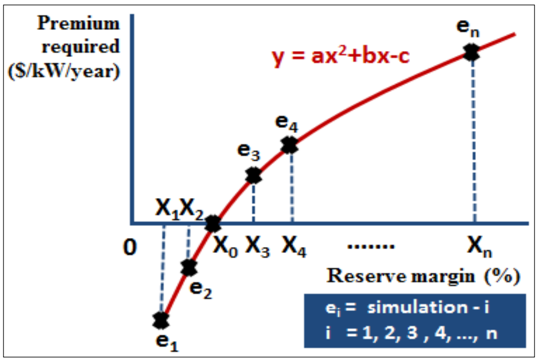

Figure 2. Premium required versus reserve margin curve

Equations (2), (3), (4) define the calculation to offset premium with investment cost.

Find condition of reserve margin (n %) where:

$$PReg_{ifn} = Inv\_annual_{if} - Prem_{ifn} = 0 \quad (2)$$

$$\forall,\ Inv\_annual_{if} = \frac{WACC \cdot (1+WACC)}{(1+WACC)^{Ec_{if}}-1} \cdot Invcost_{if} \quad (3)$$

$$\forall,\ Prem_{ifn} = \sum_1^k \pi_{ifk} / (\sum_1^k G_{if})/k \quad (4)$$

where:

- $PReg_{ifn}$ is premium required of a generator *if* in n(%) reserve margin condition (\$/kW/year);
- Inv_annual_{if} is investment cost per installed capacity per year of generator if (\$/kW/year);
- $Prem_{ifn}$ is premium of generator if in a condition of n (%) of reserve margin in the system (\$/kW/year);
- $WACC$ is weight averaged cost of capital (%);
- $Invcost_{if}$ is investment cost of generator *if* (\$/kW);
- Ec_{if} is economic life time of generator *if* (year);
- G_{if} is generated capacity of generator *if* (MW), which is $U_{if} \cdot g_{if}$.

C. Validation of the Model

In order to ensure that the model can imitate the real market condition both physical and competition conditions, validation with backcast approach was conducted using the Australia's National Electricity Market (NEM), which is considered to represent the Java-Bali future market system. In this approach, the results from the simulations are compared with some indicators from historical data. The validation focuses not only on the physical market model, known as base model, but also on the selection of types of competition imposed in the model. The base model is validated using indicators including the real capacity factor of each generator, real production (GWh), real flows in interconnectors among regions (MW) and real region spot prices ($/MWh). The ability of the selected types of competition (the SRMC, combined NC and Bertrand) to imitate the real market competition is assessed subsequently if base model has been considered valid. The indicator used is the historical spot prices in each Australia's NEM region.

Validation results for the NEM model indicate that the model and types of competition selected can capture the real market condition. However, an improvement of the model could be obtained by applying some additional constraints to hydro energy availability. Imperfect competition with NC and Bertrand simulation could accurately capture the real competition in the NEM market. Conversely, perfect competition with the SRMC model resulted in underestimated spot prices in all regions. For the Java-Bali system, however, perfect competition is still used as a comparison to determine how close the market can achieve maximum price efficiency.

III. Model Overview

The Java-Bali system consists of four regions in Java and one sub-region in Bali. The sub-region is a small region, and thus in the model, Bali is treated as a region. Hence the regions in the model are, R1-Jakarta & Banten, R2-West Java, R3-Central Java & Yogyakarta, R4-East Java and R5-Bali (see Fig. 3). The adjacent regions are interconnected via seven high-voltage 500 kV lines. No congestion in the transmission system limits the inter-region power transfer. The model includes 74 generators and 12 owners/companies. Based on the existing generation installed capacity and the peak demand, the reserve margin of 33.70% is imposed as a base condition in the model. Generators are divided into 11 groups based on technology and fuel used, which include open cycle gas turbine (OCGT) with fuel oil (OCGT-Oil), OCGT with gas (OCGT-Gas), combined cycle gas turbine (CCGT) with gas (CCGT-Gas), CCGT with liquid natural gas (LNG) (CCGT-LNG), steam power plant (PP) with coal (Steam PP-Coal), steam PP with fuel oil (Steam PP-Oil), steam PP with gas (Steam PP-Gas), diesel PP with fuel oil (Diesel PP), hydro PP using run of river (Hydro Run of River), hydro PP using pondage (Hydro Pondage) and Geothermal PP (Geothermal).

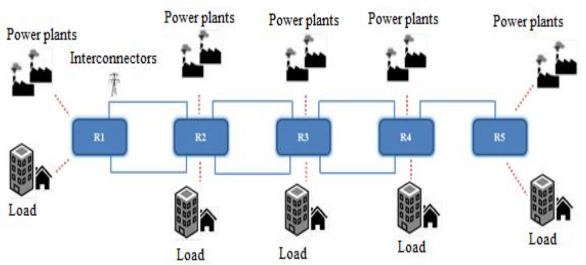

Figure 3. The overview of the Java-Bali model

IV. Simulation Results and Discussion

The results are assessed using three scenarios; scenario for overall system, scenario per type of generator and scenario per company.

A. Results for Scenario 1: Overall System

Optimal reserve margins of -9.44% and 67.44% are yielded from a perfect and an imperfect competition simulations respectively. The negative value indicates that generators could gain more profit to recover investment costs in a shortage capacity condition. This shortage condition could increase the probability of generators being dispatched and having more power to control market prices. However, the shortage condition in the system is clearly unacceptable due to the demand side costs. Therefore, even though a perfect competition condition leads to the most efficient market price for consumers, this condition does not appear to be a friendly condition for incentivizing investment. Above those reserve margin limits, premiums required are positive, implying there are excessive generators in the market, and thus new investment could not expect to make a profit. Conversely, below that reserve margin limit, most of the generators would create more profit than the amount that is required to recoup the investment cost. This condition would lead to price inefficiency for consumers, hence, the balanced condition that would be profitable for both consumers and investors is the reserve margin limit condition where the premium required is zero.

B. Results for Scenario 2:Per Type of Generator

This scenario enables the analysis of more profitable generator types. Table I shows optimum reserve margins for each type of generator. It is found that generators that have positive reserve margin limits are those that serve base and intermediate demand. None of peaking generators, have positive reserve margin limit, *i.e.* hydro pondage power plant. The results also indicate that the selection of generator type is crucial in determining reserve margin limits. Moreover, selection of fuel used can have an impact on the obtained profit.

TABLE I. Reserve Margin Limit Per Type of Generator

No.	Types of Generator	Perfect Competition (%)	Imperfect Competition (%)
1	OCGT-Oil	12.39	90.71
2	OCGT-Gas	-36.04	44.67
3	CCGT-Gas	-4.8	47.76
4	CCGT-LNG	-47.72	17.29
5	Steam PP-Coal	-6.91	67.62
6	Steam PP-Oil	-5,764.59	-224.21
7	Steam PP-Gas	-4,141.23	-717.22
8	Diesel PP	40.28	96.39
9	Hydro RoR	-35.56	58.27
10	Hydro Pondage	-88.96	-16.99
11	Geothermal	27.59	217.41
	Total system	**-9.44**	**67.44**

Concerning selection of fuel used, a unique result is found with regard to steam PP-Oil and steam PP-Gas in an imperfect competition simulation. In the dispatching system, steam PP should be operated as base generators [17]. Therefore, it should be that, as other types of base load generators in this simulation, steam PP-Oil and steam PP-Gas could cover their investment cost. However, the simulation results show that due to their inefficiency of fuel cost, these types of generators cannot compete with other generators and thus, they become the least prioritized generators to be operated. Moreover, due to slow-response towards demand volatility, it is unlikely to operate these generators for supplying peak demand [18]. Consequently, most of the time, they are not dispatched.

In order to assess the impact of fuel type on reserve margin limit, another simulation was conducted. In this simulation, all steam PPs use their original fuel, coal, and all OCGT PPs use gas. The simulation yields reserve margin limit of 48.69% in an imperfect competition condition, which is lower than initial reserve margin limit of 67.44%. A perfect competition condition shows a result of -25.59%. The result implies that by changing fuel used, a balanced condition can be obtained in a lower reserve margin level.

C. Results for Scenario 3: Per Company

The simulation in perfect competition resulted in positives reserve margins for only four out of 12 companies, while in imperfect competition all 12 companies achieved a positive reserve margin (see Table II). This indicates that an imperfect competition condition is preferable for most of the companies in the Java-Bali system.

TABLE II. RESERVE MARGIN LIMIT PER COMPANY

No.	Companies	Perfect Competition (%)	Imperfect Competition (%)
1	Geodipa Energy	-23.09	57.61
2	Indonesia Power	-2.01	65.09
3	IPP - Chevron G.S	63.71	211.43
4	IPP - Cikarang Listrindo	-59.9	27.74
5	IPP-PLTG	38.81	100.34
6	IPP-PLTU	-6.84	66.91
7	Jawa Power	-71.23	33.88
8	Paiton Energy	-74.23	37.73
9	Pertamina Group	36.43	223.64
10	Perum Jasa Tirta	5.88	135.61
11	PLN	-1.7	79.73
12	PT. PJB	-63.79	17.26
	Total system	**-9.44**	**67.44**

Even though all companies have positive reserve margin limits, the results show a tendency for large players to control the market in the Java-Bali system. The three biggest companies; Indonesia Power, PLN and PT PJB, dominate the supply side (see Fig. 4). Moreover, Indonesia Power, the biggest company, has a close reserve margin to that of the overall system. In this case, there is a possibility that the reserve margin limit of the overall system is significantly dependent on reserve margin limit of that company.

V. SENSITIVITY ANALYSIS ON MARKET POWER

In order to evaluate the effect of market power on reserve margin limits, a sensitivity analysis was performed. Each of the three biggest companies is divided into several companies. The segregation and the generator capacity ownership is based on the location of generators.

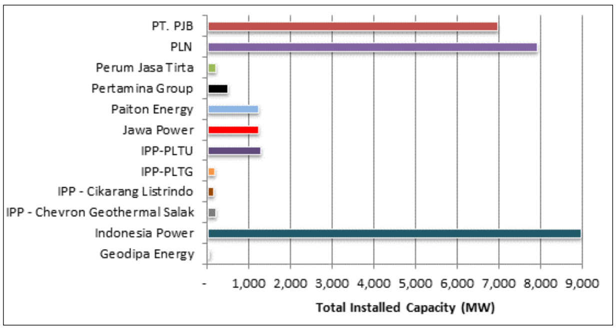

Figure 4. The generator ownership (in installed capacity (MW))

The results for perfect competition before and after the segregation are the same (see Fig. 5). All generators keep offering prices equal to marginal cost regardless the ownership. There is no market power that controls the price and the maximum price efficiency is obtained in this market condition. In imperfect competition, having less market power makes the market more competitive, hence, the control over prices and quantities by dominant companies can be reduced. This is characterized by the lower reserve margin limit that reflects less profit gained by companies and greater price efficiency. The new reserve margin limit is 22.41%.

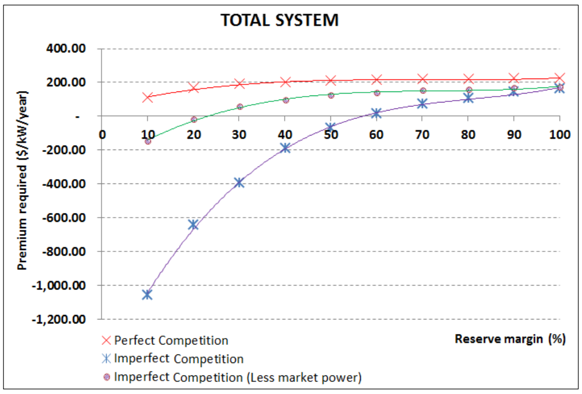

Figure 5. Reserve margin limits for power market analysis

From the simulation, it can be concluded that the more the companies are divided into smaller companies, the less the market power is and the more the market is close to a perfect competition condition. Moreover, reducing the market power, new investment can only be achieved by lowering reserve margin limit.

In order to provide technical reliability of supply in the Java-Bali system, reserve margin policy in Indonesia requires minimal 30% of reserve margin for yearly production, or a spare capacity of at least one biggest unit of generator per day production [19]. Considering this issue, the minimal reserve margin of 30% must be fulfilled. Thus, if the existing condition of reserve margin, 33.70% remains the same, the price efficiency in this condition could be obtained by separating the biggest companies to lessen market power.

However, the segregation of companies is not an easy approach to be applied since governments do not have an absolute control on that issue. Besides, in some cases, it is not feasible. For example, in Singapore, a company consists of one power station that cannot be physically separated [20]. Hence, in this case company segregation is not a feasible option to reduce market power. Nevertheless, company segregation is not the only option for altering market structure to reduce market power. Another common option is using vesting contracts with large incumbent companies [21]. With vesting contracts, a certain percent of the market volume is settled in the basis of specified price [22]. Hence, in a competitive market, supply shares of those companies are effectively curtailed [21] and thus reserve margin of the competitive market is higher (see Fig. 6). When new investments are made, the shares of the largest companies are expected to decline. Therefore, by applying these contracts, market structure can be altered and thus market power can be reduced.

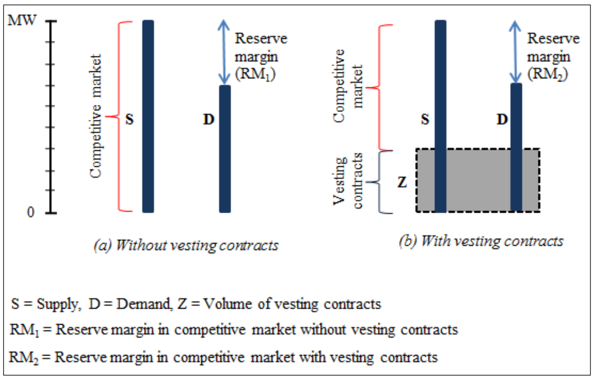

Figure 6. Effect of vesting contract on reserve margin

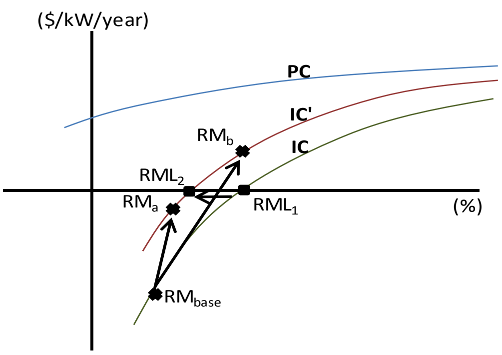

Figure 7. Effect of vesting contract on reserve margin limit

Effects of vesting contracts can also be depicted in reserve margin and premium required curves (see Fig. 7). Fig. 7 show that these contracts move the original curve to the left, indicating a decrease of market power. It also raises the reserve margin in the competitive market from point RM_{base} to point RM_a or RM_b.

where:

- PC is perfect competition;
- IC is imperfect competition before vesting contracts;
- IC' is imperfect competition after vesting contracts;
- RM_{base} is initial reserve margin;
- RM_a is reserve margin after vesting contracts;
- RM_b is reserve margin after vesting contracts;
- RML_1 is reserve margin limit before vesting contracts;
- RML_2 is reserve margin after vesting contracts.

VI. Conclusion

Creating competition for price efficiency while still encouraging new investment drives countries to restructure their electricity market systems. However, since the level of reserve margin raises issues with regards to both consumers' and investors' interests, this research adopts an approach that can capture the trade-off between price efficiency and attractive investments. Using the Java-Bali market, various simulations in a perfect and an imperfect competition conditions examined optimum reserve margin for the system. Reserve margin of -9.44 % and 67.44% are respectively yielded for perfect and imperfect competition condition of the system. The negative value from the perfect competition simulation indicates that a shortage condition is required for investors to recover their investment costs. Nevertheless, the shortage condition is not acceptable. Thus, perfect competition cannot create balanced advantageous conditions for investors and consumers. Higher than those reserve margin levels, the competition will be more intense, market prices will be more efficient and most of generators cannot recover their investment and will consider the market condition un-attractive to them.

Moreover, there are many factors that can affect the optimum reserve margins obtained, such as the type of generator operated, fuel used and market structure. The more efficient the generating unit considered, the lower the optimum reserve margin. Furthermore, reduction of market power, by separating some dominant companies or applying vesting contracts can alleviate the ability to control market prices and can lead to more efficient prices and lower reserve margin values. This condition implies that a high reserve margin conditions are not necessarily required for market price efficiency as long as some aspects are changed.

Considering the significance of this issue, it is suggested that governments could consider the competition issues as well as the technical/reliability issues when formulating reserve margin policy. A reserve margin condition in the system should encourage competition for price efficiency and investments besides meeting reliability requirements. Additionally, countries intending to or restructuring their electricity markets could assess the readiness of the systems, particularly the reserve margin, in order to obtain optimum benefits from competition. The proposed modeling framework in this research can be used as an important step towards analyzing and predicting an optimum reserve margin that can result in benefits from competition.

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