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The Distribution Service Pricing for Third-Party Access to Preserve the Responsibility of National Distribution Service Operator in Thailand: The Case of Industrial Estates

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Abstract

This study proposes the wheeling charge (WC) calculation for industrial estates of Thailand to prevent the increase of unfair competition of distribution system services between distribution authority and a small power producer (SPP), which operates both generation and distribution systems. The WC is calculated based on the postage stamp method with the consideration of actual technical and financial constraints. The energy market is analyzed to formulate the problem. The annual fixed charge rate and the grandfathered principle are adapted in the model, whereas the sensitivity analysis of possible schemes is conducted to depict the distribution network owner's wheeling revenue. The numerical example is solved by using distribution system data extracted from an industrial estate in the eastern part of Thailand. The results show that the WC can respond to principles of cost recovery, transparency, understandability, stability, predictability, and ease of implementation. Therefore, it can be used to prevent the exercising of SPP's market power, the partial competitive distribution services, and the redundant distribution investments. Moreover, the distribution authority's responsibility and SPP's income are still maintained.

Disciplinary: Energy Pricing Policy.

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1 Introduction

In several industrial estates of Thailand, there is a small power producer (SPP) generating and distributing energy to its customers using a private generator and distribution grid. Simultaneously, the national distribution Authority (NDA), i.e., the Provincial Electricity Authority (PEA) and Metropolitan Electricity Authority (MEA), supplies energy to its end users. Electricity pricing in Thailand is regulated by the government to a uniform tariff (UT) rate that includes energy, transmission, and distribution costs. Therefore, the NDA is imposed to charge their end users by using the UT rate. On the other hand, the SPP can offer its customers electricity prices lower than the UT rate in which the SPP seems to have more bargaining power than the NDA (EGAT, 2010; Levett, 1997; NEPO, 1997; PWC, 2005; PEA, 2006). From this situation, the facts can be ascertained:

1) From the structure of the national electricity tariff or UT rate, one key element is the national power demand charge (NPDC). The NPDC reflects the national distribution cost (NDC), which includes the subsidy cost for rural electrification. Conversely, when considering a confined area; such as an industrial estate, etc., the local power demand charge (LPDC) reflects the local distribution cost (LDC) which excludes the subsidy cost of rural electrification. This infers that, in the estate area, although the electricity service providers (NDA/SPP) bill the customers with the LPDC which is lower than the NPDC rate, both providers can still generate profit. Therefore, this results in unfair competition between NDA and SPP in that the SPP can freely exercise the price strategy using the LPDC to gain their new customers, whereas the NDA lacks the ability to compete with the SPP due to the regulatory constraint at the national level (Regulatory Commission Energy, 2007).

2) Although NDA and SPP can generate income using the same LPDC, the SPP has no transmission cost because it is closely located to the electricity users, whereas the NDA has to pay for transmission expenses to the Electricity Generating Authority of Thailand (EGAT) (Leeprechanon, *et al*, 2002).

For these reasons, it is not possible for NDA to compete with SPP without complying with its own distribution cost in the competitive area and unlock the regulatory constraint to use the price strategy to compete with the SPP, or enforcing the SPP to stop investing the distribution system by offering an acceptable wheeling charge (WC) rate for third-party access (TPA).

Therefore, these facts lead to the situation that most parts of the NDA's customers become the SPP's energy users causes the following disadvantages:

1) The capacity of the NDA's distribution grid, which is bulkily invested before the establishment of the SPP, cannot be used effectively, whereas the investment and maintenance costs still occur.

2) The NDA loses the opportunity to receive revenue from crucial end users, thus resulting in inappropriate income to compensate for the subsidization costs of the entire country. This causes a decrease in national benefits and an increase in the private sector's profit.

3) For the natural monopoly of the distribution system, the SPP redundantly installs new distribution lines for new customers, thus resulting in bulk investment, operation, and maintenance costs.

4) In the technical aspect, the distribution maintenance is managed with difficulty when the two distribution lines are closely and parallelly positioned (Allan, 2013).

If there is no procedure to prevent the increase in unfair competition, there is a high chance that the SPP will continue to negotiate with all of the NDA's customers. In addition to the mentioned disadvantages, other severe concerns are as follows:

1) The NDA will not receive any revenue in the industrial areas where there are SPPs located as competitors, thus losing the opportunity to generate income to cover the nationwide rural electrification subsidy.

2) The SPP will eventually become a complete monopoly, thus having full market power and excess income in crucial areas.

Hence, there are solutions to prevent the increase in the SPP's market power that should be chosen, announced, and regulated by the Energy Regulatory Commission of Thailand. The first solution is to relax the regulatory constraint for the NDA to compete with SPP by using the pricing strategy in the competitive industrial estate areas. This will lead to a more level playing field (Thuesen, *et al*, 1984). The second solution is that if the SPP has new customers who are connected to the NDA's network, the SPP has to connect its generator to the NDA's main grid and supply the energy as TPA. In this model, the SPP pays the wheeling expenses based on the WC method (Sood, *et al*, 2002). Unlike the first solution, the situation of the TPA is based on the regulatory strategy (Drahos, 2017) and can provide several benefits. Firstly, in the responsibility and financial aspects, without direct customers to buy electricity, the NDA can still provide the distribution system service and receive the appropriate revenue using WC rate to cover its financial budget. Secondly, to supply energy to new customers, the SPP does not have to pay for the bulk investment, operation, and maintenance costs of the new distribution lines. On the other hand, the SPP can gain profit based on the difference between the WC and NPDC. Thirdly, the revenue from the SPP's existing customers is not affected.

From the mentioned advantages, the situation of the TPA should immediately proceed. However, the problem is that there is no appropriate NDA data; such as the cost components, physical distribution system, energy market, data metering, etc, to input the WC model. As such, this can result in an ineffective and unstable rate for the NDA and cause disagreement with the SPP.

Therefore, to prevent the increase in the private sector's market power, the unfair competition in distribution services, and the difficulty of distribution maintenance, unlike previous studies, this paper proposes the WC model based on the main pricing principles; such as. cost recovery, transparency, stability, predictability, and ease of application by considering the NDA's real data and the components of the energy market. The hurdle rate (Thuesen, *et al*, 1984) is used for the financial values, whereas the grandfathered concept (Authority of Thailand Petroleum, 2017) is utilized for the network capacity allocation. Lastly, to analyze the financial effects of the NDA, the WC and wheeling revenue (WR) are calculated based on several possible schemes.

2 Developments of Network Topologies and Energy Markets in Industrial Estates of Thailand

To fulfill the description of the network topologies and the energy market mentioned in Section 1, the initial systems that have been developed until the present time and the upcoming systems that can severely affect the NDA are concisely explained (EGAT, 2010; Levett, 1997; NEPO, 1997; PWC, 2005; PEA, 2006).

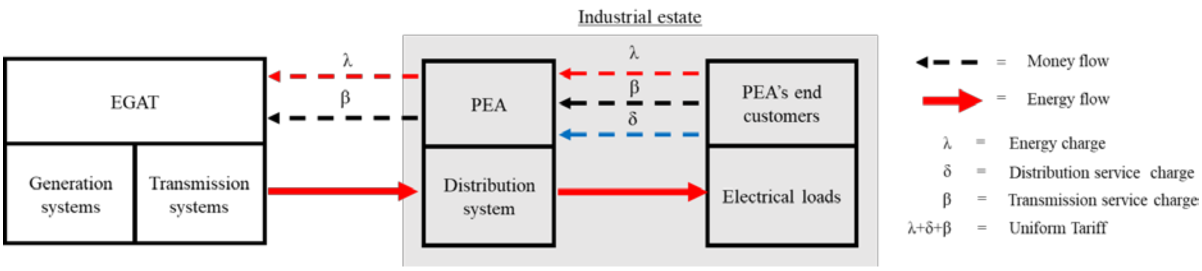

Figure 1: The conventional vertical ESI system.

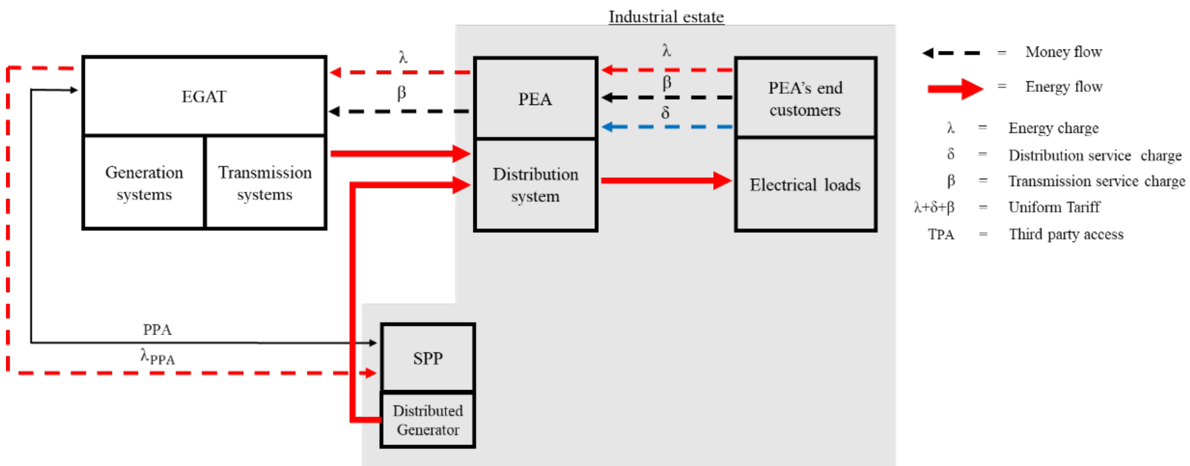

Figure 2: The ESI system with PPA contract.

Initially, as shown in Figure 1, the electricity supply industry (ESI) system was operated as a vertical market. The main system's components were EGAT, the NDA, and end-users. From the energy flow, the energy was consequently sent from EGAT to the NDA and from the NDA to the end-users. From the money flow, the end-users paid the revenue based on the UT rate to the NDA. Then, the NDA collected NPDC, whereas EGAT received the remainder. However, from the benefits of the distributed energy resources that could decrease the power loss in the transmission network and increase the system's reliability (Ackermann, *et al*, 2001; El-Khattam and Salama, 2004), as demonstrated in Figure 2, the SPP was allowed to firmly sell energy to EGAT according to a power purchase agreement (PPA). The energy is directly distributed to the NDA's main grid, whereas the revenue is directly sent to the SPP. To respond to the PPA, the SPP has to reserve its generation capacity, which results in investment and maintenance costs. Therefore, to cover this financial gap, the SPP has to find new customers for selling the surplus energy as a non-firm electricity contract. As such, when considering the national policy, there are the following criteria:

1) The SPP can make a contract with customers in the industrial area.

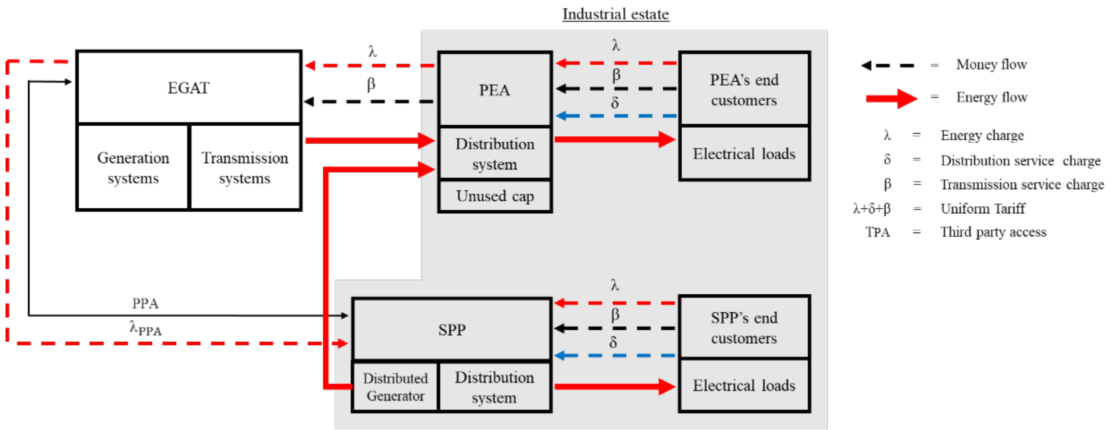

Figure 3: The ESI system operated as the unfair competition of the distribution services.

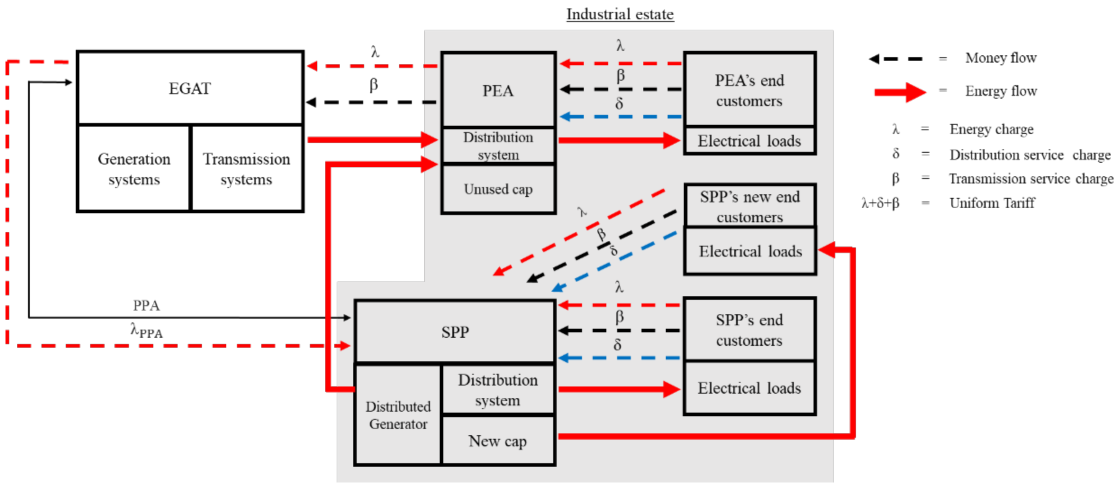

Figure 4: The ESI system leading to major disadvantages for the NDA.

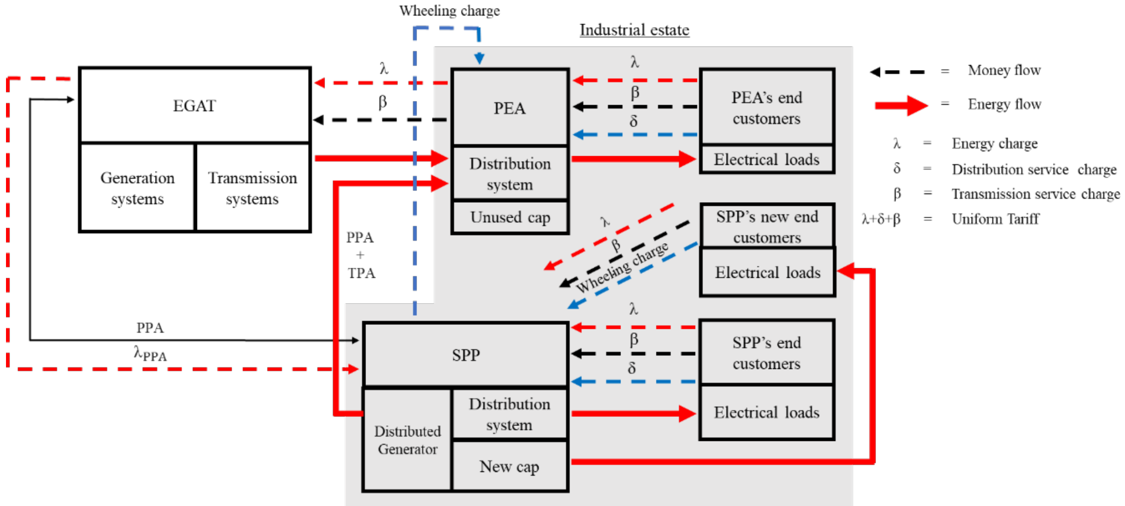

Figure 5: The ESI system for the TPA situation.

2) There is no regulatory announcement to use the WC for the TPA. Hence, the SPP could not supply the energy by using the NDA's network,

3) The SPP can build distribution lines in the private area.

Therefore, the SPP built the distribution lines to directly supply the energy to its customers. In this case, the SPP could receive a large profit based on the transmission and distribution charges as mentioned in Section 1. When the SPP received this benefit, it could use the price and reliability strategies for new customers. Hence, several consumers, which had been the NDA's former users, purchased energy from the SPP. This situation has been proceeded until the present time, thus resulting in the system depicted in Figure 3. Consequently, it can be seen that the NDA has more unused capacity, which cannot be effectively utilized but still used the maintenance budget. The distribution maintenance is also managed with difficulty when the two networks are simultaneously operated. Moreover, the SPP significantly has more market power than the NDA. If this situation to receive more money and market power is not prevented, there is a high chance that the SPP will build new distribution lines and persuade all of the NDA's customers to purchase its energy, while the NDA will not be able to fairly compete in the market. Thus, the topology will be formulated as shown in Figure 4. As a consequence, this will definitely lead to more disadvantages for the NDA, whereas the SPP will become a monopoly organization in the estate area, which includes crucial customers. Therefore, an appropriate electricity market should be formulated for the TPA as represented in Figure 5.

3 The Wheeling Charge Methodology for Distribution System in Industrial Estate of Thailand

3.1 General Wheeling Charge Methodologies

The WC and WR methodologies can mainly be categorized into six solutions, which are represented in Figure 6. The definition of each solution (Chen, *et al*, 2002; Economics, 2008; Regulatory Commission Energy, 2016; Happ, 1994; Lee, *et al*, 2001; Levett, 1997; PWC, 2005; Office of Utilities Regulation, 2012; Yu and David, 1997) can be briefly described as follows:

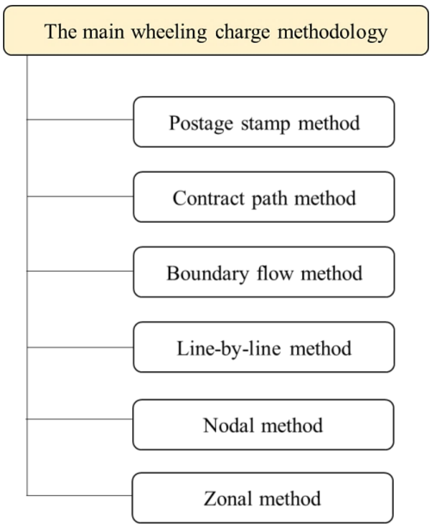

Figure 6: The wheeling methodologies.

1) The postage stamp method: The WC is based on the ratio of the total cost and total distribution capacity, while the WR is solved by the multiplication of the WC and the wheeling distribution capacity.

2) The contract path method: The WC is based on the ratio of cost and distribution capacity occurring only in the focused path. For the WR, it is calculated by the multiplication of the WC and wheeling capacity as the postage stamp approach.

3) The boundary flow method: The WC is calculated by using the postage stamp solution, whereas the WR is based on the power flow in the boundary buses occurring before and after the connection of third parties.

4) The line-by-line or MW-mile method: In this solution, for the financial values, the WC is based on the cost and length of the distribution lines. For the distribution capacity values, the WC and WR are solved by using the power flow on every distribution line occurring before and after the connection of third parties.

5) The nodal method: The WC and WR are separately calculated for each node or small group of nodes.

6) The zonal method: The WC and WR can be solved by using the definition of the postage stamp approach. However, they are calculated based on the specified data of each subarea.

Nevertheless, for the boundary flow, line-by-line, and nodal approaches, there are the considerations that if the situation of the TPA is included by several third parties, the power flow of each third party should be tracked by using the power tracing methods (Bialek, 1996; Bialek, 1997; Ng, 1981; Vidhya, *et al*, 2017) thus causing the complexation of the calculation procedures and data metering.

In addition to the main approaches, there are the combined solutions proposed in previous research. For a brief description, the amp-mile method is calculated by considering congestion and risk assessment (Jain, *et al*, 2019a) and the MVA utility factor and marginal participation (Jain, *et al*, 2019b). The exporter and importer zones are combined with the zonal method (Payakkamas, *et al*, 2017). The principle of proportional sharing is also modified to support the MW-mile method by considering the network losses (Li, *et al*, 2017). Furthermore, the power flow tracing method is used for calculating the WC with optimal placement IPFC controller's FACTS devices (Vidhya, *et al*, 2017). The wheeling charge is based on a power flow-based MW-mile method. The data on the NDA's sub-transmission system is used to calculate the results (Wongkom and Chaitusaney, 2019). Moreover, the MW-mile method with the differentiation of the line flow magnitude before and after the connection of the third party is proposed (Larbwisuthisaroj and Chaitusaney, 2018).

To choose the appropriate WC methodology for the distribution system in industrial estates in Thailand, the principles of the WC, the input data of the NDA, and the physical system in the area need to be taken into consideration

The main principles (Lee, *et al*, 2001; Office of Utilities Regulation, 2012) can be described as:

1) Economic efficiency: The rate should send the pricing signal to the system's users in order to adjust their behavior of the distribution capacity usage.

2) Cost recovery: The rate should reflect the operation and development costs of the network owner.

3) Transparency: The pricing mechanism should be conveniently inspected by the users.

4) Understandability: The pricing mechanism should be clearly and appropriately described to the correlating users.

5) Stability and predictability: the rates should be probable and unchanging. This can benefit both the network owner and the third party to effectively set the distribution price and manage the financial budget.

6) Non-discrimination: The electricity users should be equally and fairly treated by the price mechanism.

7) Ease of implementation: The price mechanism must not be difficult and complex to use. It should be conveniently applied by the network owner.

When considering the NDA's data, it is found that the information below cannot be easily extracted.

1) The costs of the overhead lines.

2) The distance between nodea to node.

3) The smart meter system.

4) The geographic database; such s, the sizes of the distribution lines positioned in the single root.

5) The distances of the multilayer distribution lines.

For the energy market in the industrial estates, this is as follows:

1) In the area, there is an SPP, which has the bulk generation capacity and firm distribution system.

2) The users that can be the SPP's new consumers are located in the entire area.

Therefore, the WC methodologies can be analyzed for the TPA situation as follows:

1) For the boundary flow, line-by-line, nodal, and combined methods: Tend to be very difficult and inappropriate to be used. This is because they need specific data of thonpower flow and equipment costs. Therefore, from the rack of the NDA's data structure and smart mete system, the methods cannot respond to the principles of transparency, ease of implementation, and understandability. From the variable rate that depends on the value of power flow, the stability and predictability properties are also not fulfilled.

2) For the contract path: The financial and physical data of the distribution lines based on each distribution path are needed. Therefore, this cannot compete with the principles of transparency and understandability. In addition, the WC is based on the distribution cost and capacity of the entire path. This causes the WC to be very high or low compared to the actual capacity used by the SPP, thus resulting in the rack of non-discrimination property. Furthermore, if the SPP proposes to use the network for several TPA contracts, the NDA will have several WC, thus

causing difficulty for the implementation and resulting in an unstable rate. Lastly, when the path is chosen, the power does not completely flow through the focused root following the electricity rules (Allan, 2013; Dorf, 2018; Grainger, 1999). The capacity allocation, hence, is complicatedly tracked. For these reasons, this method is suitable for the situation that the NDA separately builds new distribution lines only for the SPP, in which the data are conveniently corrected.

3) For the zonal rate: This method is similar to the postage stamp approach. However, this is appropriate for a large area that has multi boundary lines or subareas. When considering the industrial estates formulated in this paper, there is only one SPP that has a chance to persuade the customers in the whole area. Therefore, there is no need to divide the rate into several values. Moreover, the zonal WC is difficultly to calculate and adjusted when the NDA's data structure is formulated for the entire area.

4) For the postage stamp method: From the NDA's data structure and the energy market, this approach is simply used angivesve a single WC for the entire area. This results in benefits that the NDA and SPP can stably manage the financial values. The distribution capacity is also easily allocated although the power of third-party flowsthroughh several distribution lines. Therefore, this solution can respond to the principles of transparency, understandability, stability and predictability, and ease of implementation. Lastly, from the rate that is based on the cost of the entire system, it can complete the cost recovery factor.

$$\mathrm{WC} = \mathrm{AFCR} \times \sum \frac{\mathrm{NP}}{(\mathrm{PL}+\mathrm{WL})} \quad (1).$$

Hence, from the mentioned considerations, the WC in this paper is based on the postage stamp approach (Happ, 1994; Lee, *et al*, 2001), which its main definition can be expressed as (1).

3.2 The Adaptation of Annual Fixed Charge Rate (AFCR)

$$\mathrm{FCR} = \frac{\mathrm{Cost_{Expenses}}}{\mathrm{Cost_{NP}}} \quad (2).$$

$$\mathrm{Cost_{Expenses}} = \mathrm{Cost_{NP}^{t}} + (\mathrm{Cost_{OM}} \times \mathrm{F_{OM}}) + (\mathrm{Cost_{AD}} \times \mathrm{F_{AD}}) \quad (3).$$

$$\mathrm{AFCR} = \frac{\mathrm{Cost_{NP}^{t}}}{\mathrm{Cost_{NP}}} + \left(\frac{\mathrm{Cost_{OM}}}{\mathrm{Cost_{NP}}} \times \mathrm{F_{OM}}\right) + \left(\frac{\mathrm{Cost_{AD}}}{\mathrm{Cost_{NP}}} \times \mathrm{F_{AD}}\right) \quad (4).$$

$$\mathrm{Cost_{NP}^{t}} = \mathrm{Cost_{NP}} \times \frac{(1+r_h)^{t}.r_h}{(1+r_h)^{t}-1} \quad (5).$$

$$\mathrm{F_{OM}} = \frac{1}{r_h - r_{gm}} \cdot \left[1 - \left(\frac{1+r_{gm}}{1+r_h}\right)^{t_{om}}\right] \cdot \frac{(1+r_h)^{t_{om}}.r_h}{(1+r_h)^{t}-1} \quad (6).$$

$$\mathrm{F_{AD}} = \frac{1}{r_h - r_{ga}} \cdot \left[1 - \left(\frac{1+r_{ga}}{1+r_h}\right)^{t_{ad}}\right] \cdot \frac{(1+r_h)^{t_{ad}}.r_h}{(1+r_h)^{t}-1} \quad (7).$$

From previous studies, although the annual fixed charge rate (AFCR) has been partly mentioned, its detail is not economically demonstrated. Hence, the adaptation of the AFCR is considered in this section. In (2), the AFCR is based on the ratio of the expenses and net plant cost. In (3), the expenses can be divided into three factors, which are an investment, maintenance, and administration costs. The AFCR then can be formulated as (4). The principle of the lowest rate of return or hurdle rate RH) (Thuesen, *et al*, 1984) is adapted for $Cost^{t}_{NP}$, F_{OM}, F_{AD} as depicted as (5), (6), and (7), respectively.

$$r = WACC + RP \quad (8).$$

$$AFCR = \frac{(1+r_h)^t . r_h}{(1+r_h)^t - 1} + \frac{Cost_{OM}}{Cost_{NP}} + \frac{Cost_{AD}}{Cost_{NP}} \quad (9).$$

$$Cost_{OM} = PT_{OM} \times Cost_{NP} \quad (10).$$

$$Cost_{AD} = PT_{AD} \times Cost_{NP} \quad (11).$$

$$\text{Per Unit} = \frac{\text{Actual Value}}{\text{Base Value}} \quad (12).$$

$$\text{Actual Expenses} = \text{Per Unit x Base Value} \quad (13).$$

$$Cost_{Total} = \text{AFCR x } Cost_{NP} \quad (14).$$

$$Cost_{Total} = \left(\frac{(1+r_h)^t . r_h}{(1+r_h)^t - 1} + \frac{Cost_{OM}}{Cost_{NP}} + \frac{Cost_{AD}}{Cost_{NP}}\right) \times Cost_{NP} \quad (15).$$

The hurdle rate (r_h) is expressed as (8). For the risk premium rate (r_{RP}), it can be composed of asset insurance and risk management rates due to the regression of the load demand. For the gm and ga, if they are neglected (r_{gm} = 0%; r_{ga} = 0%), the F_{OM} and F_{AD} can be calculated as 1, thus resulting in the AFCR in (9). The $Cost_{OM}$ and $Cost_{AD}$ are depicted as (10) and (11), respectively. From the principle of per unit expressed as (12), the actual expenses are supposed to be an actual value and can be demonstrated in (13). When the per unit is adapted in the model by assuming that actual expense is the total cost, the total cost can be calculated as (14) and (15).

3.3 The Wheeling Charge Based on Grandfathered Principle for Third-Party Access

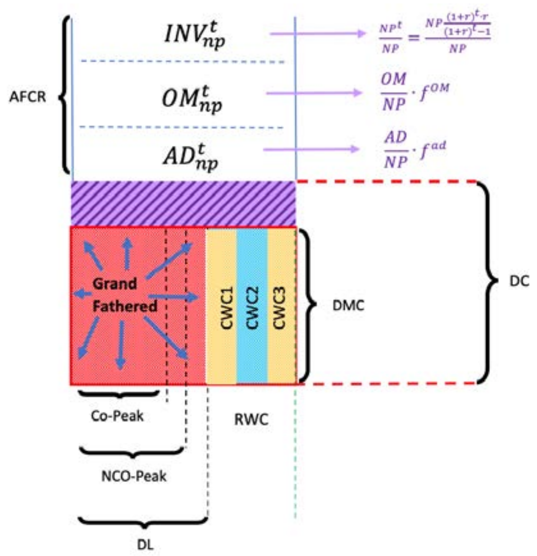

Figure 7: The schematic diagram of the distribution network allocation.

$$P_{DMC} = P_{DL} + P_{RWC} \quad (16).$$

$$WC = AFCR \frac{NP}{P_{DL}+P_{RWC}} \quad (17).$$

$$WC = AFCR \frac{NP}{P_{DMC}} \quad (18).$$

Subject to

$$\sum_{i=1}^{n} P_{Co-peak,i} \leq \sum_{i=1}^{n} P_{Nco-peak,i} \quad (19),$$

$$\sum_{i=1}^{n} P_{Nco-peak,i} \leq P_{DL} \quad (20),$$

$$\sum_{j=1}^{n} P_{CWC,j} \leq P_{RWC} \quad (21),$$

$$P_{DMC} < P_{DC} \quad (22).$$

To complete the system reliability, in the technical aspect, the distribution capacity constraint must be satisfied. Therefore, the grandfathered principle (Authority of Thailand Petroleum, 2016; 2017), is adapted to operate the situation of the TPA. Firstly, the NDA has to firmly allocate the distribution capacity for its customers and define the remainder for the SPP. Then, each SPP has to complete the form relating to the location and capacity required. Consequently, the NDA technically considers every requirement following the first come first served principle and NDA's grid code. If the constraints are satisfied, the TPA contract will be allowed. To mathematically formulate the mentioned steps, the allocation of the distribution capacity following the grandfathered method is depicted in Figure 7. The WC calculations are expressed as (16)-(18), whereas the distribution capacity constraints are depicted as (19)-(22).

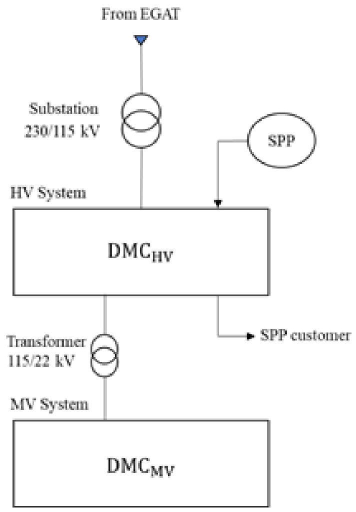

Figure 8: The possibility of the TPA situation (a case of an HV system).

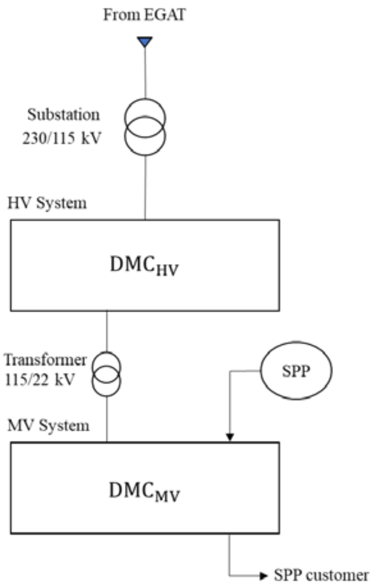

Figure 9: The possibility of the TPA situation (a case of an MV system).

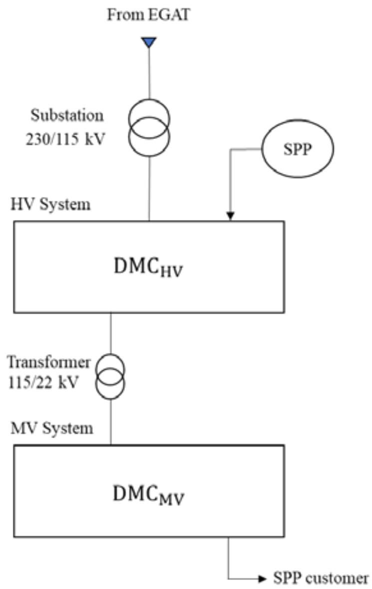

Figure 10: The possibility of the TPA situation (a case of HV and MV systems).

$$WC_{HV} = AFCR_{HV} \frac{Cost_{NP(HV)}}{P_{DMC(HV)}} \tag{23}$$

$$WC_{MV} = AFCR_{MV} \frac{Cost_{NP(MV)}}{P_{DMC(MV)}} \tag{24}$$

$$WC_{HV\ and\ MV} = WC_{HV} + WC_{MV} \tag{25}$$

$$WR_{HV} = \sum_{j=1}^{n} WC_{HV} \times P_{CWC(HV),j} \tag{26}$$

$$WR_{MV} = \sum_{j=1}^{n} WC_{MV} \times P_{CWC(MV),j} \tag{27}$$

$$WR_{HV\ and\ MV} = \sum_{j=1}^{n} WC_{HV\ and\ MV} \times P_{CWC(HV\ and\ MV),j} \tag{28}$$

When considering the situation of the TPA, there are three scenarios that the SPP can use with the NDA's network. As shown in Figure 8, the first scenario is that both the SPP's generator and SPP's customers are connected to the high voltage (HV) system. In the second one, in Figure 9, only the medium voltage (MV) network is used for the SPP's generator and SPP's customers. For the last one, the SPP proposes to use the HV network, whereas the SPP's customers are connected to the MV system. It is depicted in Figure 10. Therefore, the WC for these three cases can be expressed as (23)-(25), respectively. In addition, in (26)-(28), the wheeling revenue (WR) for all cases are formulated, respectively.

4 The Numerical Study

To solve the WC, the NDA's distribution system data from an industrial estate is extracted. The asset costs, load demand, and financial values are described. The distribution costs of HV and MV systems are corrected to be 499,109,386.14 THB and 2,795,089,312.80 THB, respectively. The capacities related to the WC are depicted in Table 1. The r_{WACC}, r_{RP}, r_h, t, PT_{OM}, and PT_{AD} are 6.04%/yr, 0%/yr, 6.04%/yr, 25 yr, 1.5% of $Cost_{NP}$/yr, and 1% of $Cost_{NP}$/yr, respectively. The r_{gm} and r_{ga} are assumed to be zero.

Table 1: The distribution capacities for the WC calculation.

Description	NCO-Peak (kW)	DL (kW)	RWC (kW)	DMC (kW)	DC (kW)
High voltage system	87,040	88,000	41,600	129,600	270,000
Medium voltage system	273,351	277,000	133,400	410,400	540,000

Table 2: The WC and distribution charge in uniform tariff.

Case	AFCR (p.u.)	The WCHV (THB/kW/ month)	The WCMV (THB/kW/ month)	The WCHV and WCMV (THB/kW/ month)	The DCUTHV (THB/kW/ month)	The DCUTMV (THB/kW/ month)
1	0.1035	7.97	58.76	66.73	71.14	132.93

Table 3: The scenarios of CWCs.

The jth CWC	The location connected by SPP	The location connected by customers of SPP
CWC1	HV system	HV system
CWC2	HV system	MV system
CWC3	MV system	MV system
CWC4	HV system	HV and MV systems

From the input data, the AFCR, WC_{HV}, and WC_{MV} can be solved and shown in Table 2. To calculate the difference between the WC and NPDC, the NPDC (PEA, 2015) is also demonstrated in Table 2. The possible situation that the SPP can supply electricity as a third party is formulated. The number of the TPA contracts is assumed to be four requirements, which are respectively defined as CWC1, CWC2, CWC3, and CWC4.

Table 4: The distribution capacity submitted and used by SPPs

The scenario	The submitted capacity of the HV system (kW)	The submitted capacity of the MV system (kW)	The CWCHV (kW)	The CWCMV (kW)	The remaining RWC for the HV system (kW)	The remaining RWC for the MV system (kW)
					41,600	133,400
CWC1	20,000	0	20,000	0	21,600	133,400
CWC2	0	40,000	0	40,000	21,600	93,400
CWC3	0	50,000	0	50,000	21,600	43,400
CWC4	10,000	43,000	10,000	43,000	11,600	0

Table 5: The results of WR.

The jth CWC	The WR based on the WC (MTHB/month)			
	The WRHV	The WRHV	The WRHV and MV	Total
CWC1	0.1595	0	0	0.1595
CWC2	0	2.6692	0	2.6692
CWC3	0	0	2.9378	2.9378
CWC4	0.0797	2.8961	0	2.9758

Table 6: The financial values for the cases of WC.

Case	RP (%/yr)	gm (%/yr)	gd (%/yr)	The cost factor of reliability improvement (pu)	Reliability premium charge (%/yr)	Target operating profit margin (%)	Variance of network peak demand (%)
1	0	0	0	1	0	0	0
2	2	2	2	1	0	0	0
3	2	2	2	1.5	10	0	0
4	2	2	2	1	5	0	-10
5	2	5	5	1	5	30	-10

Table 7: The WC and the WR in possible schemes.

Case	The WC_{HV} (THB/kW)	The WC_{MV} (THB/kW)	The $WC_{HV\ and\ MV}$ (THB/kW)
1	7.97	58.76	66.73
2	9.53	70.19	79.72
3	14.46	106.55	121.01
4	11.11	81.89	93.00
5	15.59	114.86	130.44

Table 8: The difference between WRs of possible schemes.

The difference between WRs of possible schemes (%)				
Case 1	Case 2	Case 3	Case 4	Case 5
-	19.46	81.35	39.37	95.48

The CWC's scenarios are shown in Table 3, whereas the distribution capacities allocated using the grandfathered principle are depicted in Table 4. Therefore, the WR based on the WC and NPDC are shown in Table 5.

To analyze the possible WC and WR that can occur for the NDA, the financial values are divided into five cases (Table 6). The results are illustrated in Tables 7 and 8.

From the results of Table 2, it can be seen that the $NPDC_{HV}$ and $NPDC_{MV}$ are almost higher than the WC_{HV} and WC_{MV} by ten and two times, respectively. This demonstrates that the rate the NDA has to charge users is very expensive compared to the local distribution cost. Moreover, when considering the SPP's distribution cost that only occurs in the industrial area, it should not be much higher than that of the NDA. Therefore, this clearly shows that the SPP can decrease the price by almost double to persuade the NDA's customers, while still generating a profit. If there is no regulatory policy to formulate the situation of the TPA, the SPP can become a monopoly in the system, whereas the NDA will have no chance to service customers. This will cause the NDA to lose an income of 8.7423 million THB/month. On the other hand, if the TPA can be processed, the NDA can at least charge the WR of 8.7423 million THB/month covering its financial budget and income, whereas the SPP can collect the benefit from the range between the WC and NPDC without the distribution of the investment, operation, and maintenance costs.

In addition, the rates that are fixed and calculated based on the uniform mathematical equations can be conveniently adjusted and tracked by the NDA and SPP, respectively. Therefore, they can respond to the principles of ease of the application, cost recovery, stability, predictability, and transparency. Simultaneously, they can be varied according to the factor of the AFCR, which depends on the NDA's policy; such as risk premium depending on the weather conditions. The $Cost_{OM}$ could also be resolved by using many factors; such as import tax, etc, whereas the $Cost_{AD}$ can be collected based on the changeable inflation. The adjustments of these two parts can be appropriately considered for the time periods; for example, a year or three years. In terms of the NP, it should be added when the distribution expansion is operated.

To analyze the adjustment of the WC in possible and reasonable schemes, from Tables 6-8, the results can be described as follows:

Case 1: For the financial parameters, these are the values that have already been used for Table 2. Therefore, the WC_{HV}, WC_{MV}, and $WC_{HV\ and\ MV}$ are 7.97 THB/kW, 58.76 THB/kW, and 66.73 THB/kW, respectively.

Case 2: The WC calculation is based on 2% of the r_{RP}, which comes from the unexpected failure of the distribution equipment based on natural events. The r_{gm} and r_{ga} are 2%/yr and 2%/yr, respectively. The WC_{HV}, WC_{MV}, and WC_{HV} are 9.53 THB/kW, 70.19 THB/kW, and 79.72 THB/kW, respectively. The WR is 19.46% higher than that of Case 1.

Case 3: The RP, gm, and ga have the same values as Case 2, whereas the cost factor of the reliability improvement is set to be 1.5 pu. This is invested to increase the NDA's network reliability in order to negotiate with the SPP. Moreover, the NDA adds the reliability premium charge of 10%. This is reserved to be the compensating cost when the network is out of the system. Then, the WC_{HV}, WC_{MV}, and WC_{HV} are 14.46 THB/kW, 106.55 THB/kW, and 121.01 THB/kW, respectively. The WR of this case is 81.35 % higher than that of Case 1. Therefore, from the results, it can be seen that the NDA's investment cost and reliability charge are increased by 50% and 10%, respectively. The WC_{MV}, which is in the main network and used by the SPP, is still lower than the NPDC (132.93 THB/kW). This clearly demonstrates that the NPDC is inappropriate for a competitive situation.

Case 4: In this case, the r_{RP} is set to be 2%/yr, while the reliability premium charge is 5%/yr. To allow the NDA to reserve the distribution capacity for supporting the fluctuations of the energy demand, the variance of P_{DMC} is -10%, meaning that the DMC is also decreased by 10%. The. WC_{HV}, WC_{MV}, and WC_{HV} are 11.11 THB/kW, 81.89 THB/kW, and 93.00 THB/kW, respectively. The WR is higher than that of Case 1 by 39.37%. Similar to the results of Case 3, the WC is still much lower than the NPDC.

Case 5: The r_{RP} is 2%/yr. The r_{gm} and r_{ga} are 1%/yr and 1%/yr, respectively. The variance of P_{DMC} is -10%, whereas the reliability premium charge is 5%/yr. Unlike previous cases, the NDA adds the expected profit of 30%. From all the factors, the WC_{HV}, WC_{MV}, and WC_{HV} are 15.59 THB/kW, 114.86 THB/kW, and 130.44 THB/kW, respectively. The WR is higher than that of Case 1 by 95.48%. In these results, it should be noted that although the NDA receives 30%/yr, 5%/yr, 2%/yr from the profit, reliability premium charge, and r_{RP}, respectively, the WC is still not higher than the NPDC. Hence, it can be concluded that although the NDA's expected profit and financial income are significantly added to the WC, the range between the WC and NPDC (132.93 THB/kW) is still very high.

From the results of these cases, they demonstrate that:

The NPDC is very expensive for competitive services. If the NDA cannot charge a lower rate to the users, it cannot definitely persuade the customers. On the other hand, the SPP can approximately drop its distribution prices by 30-35% and still generate a profit. Hence, it is impossible to fairly process the energy market for the NDA and SPP.

For the TPA situation, the NDA can charge a higher WC to the SPP. This results in the NDA's increasing revenue to compensate the subsidization costs outside the estate area, whereas the SPP can still receive new benefits without any incremental costs of the distribution system. This is based on the difference between the higher WC and NPDC that comes from SPP's new customers.

Therefore, it can be concluded that the situation of the TPA can prevent the increase of the SPP's redundant investment, unfair competition services, difficulty to maintain distribution lines, and the decrease of the NDA's main responsibility.

5 Conclusion

To prevent the increase of unfair competitive distribution services between the NDA and SPP in the industrial estates in Thailand, this paper, unlike previous studies, proposes the WC to support the situation of the TPA in the estate area. The hurdle rate is adapted in the financial values, whereas the grandfathered principle is used to allocate the distribution capacity for the third party. The input data are extracted from the real industrial area. The WC is calculated based on several possible schemes to analyze the income of the NDA. As a consequence, the results show that the WC can respond to the principles of cost recovery, transparency, understandability, stability, predictability, and ease of implementation. Also, the WC can be regularly announced as a tool to simultaneously maintain the main service of the NDA, allow the SPP to collect new revenue, and resist the increase of the SPP's market power. On the other hand, if the WC is not used, there will be a chance that the NDA loses its large income, while the SPP becomes a monopoly generation and distribution service provider in the special area, that includes industrial customers of the country. Therefore, this will result in the lower benefit of the national organization and the higher market power of the private generation and distribution sectors.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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