July - August 2020
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Calculation Method of Locational Marginal Price Based on Petri Net Modeling

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Abstract

With the development of social economy, the demand for power system is increasing. However, most of the current electricity price calculation methods can not directly reflect the specific process of power distribution, and cannot be charged on demand based on the use of resources and services of power users, and has not yet established a mature and flexible pricing mechanism, which is not conducive to the further development of social economy. Based on this, this paper first analyses the role and characteristics of node marginal price, then studies the modeling technology based on Petri net, and finally gives the calculation method of node marginal price based on Petri net modeling.

Keywords: *Calculation Method,Petri Net Modeling, Locational marginal price;*

1. Introduction

With the rapid development of social economy, all walks of life in the society demand for electricity continues to increase, which requires the construction of a reasonable electricity price calculation system, so as to promote the normal development of the entire power industry and effectively support the healthy and stable operation of social economy. Due to the great differences in the economic development level of various regions in China, the spatial distribution of power production and consumption is also very uneven. For example, the demand for electric energy in the eastern region is far greater than that in the central and western regions, which requires further improvement of the utilization efficiency of power resources, so as to promote the harmonious development of the whole society and optimize the allocation of resources.

In addition, with the gradual liberalization of power market environment, the pricing of power grid system is faced with the influence and interference of many uncertain factors, such as the fluctuation of load, the change of power production cost, the randomness of power supply system and the sudden failure of power grid equipment. These uncertain factors that disturb the stable operation of power grid bring the risk of quantitative system of power transmission, and increase the difficulty of operability, and may cause great loss to the whole society. In this context, it is necessary to develop a set of scientific and reasonable electricity pricing mechanism, including several aspects of billing process as shown in Figure 1 below, so as to achieve a high degree of unity between the calculation of electricity pricing and customer demand and payment habits.

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July - August 2020
ISSN: 0193-4120 Page No. 5392 - 5399

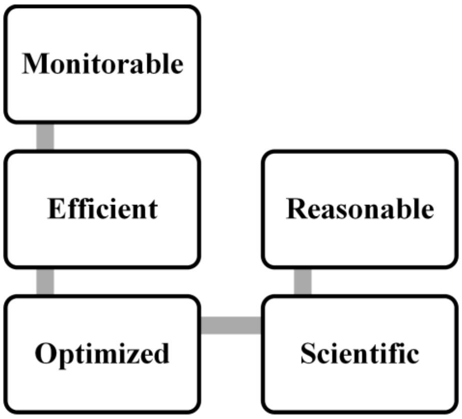


Figure 1. Elements of scientific and reasonable electricity pricing mechanism.

The calculation method of locational marginal price is based on the current operation state of the power grid system. Under the premise of ensuring the stable operation of the power grid system, the minimum unit power cost increased by the load of a single point is increased. It can be seen that the calculation of locational marginal price is directly related to the time and the state of power grid system. The regional power transmission based on the node marginal price principle is directly affected by the line capacity. Specifically reflected in the congestion area caused by insufficient line capacity, the power cost will rise linearly, while the non-congestion area with sufficient line capacity has rich low-cost power. This phenomenon will lead to significant differences in the price of electricity between congested and non-congested areas.

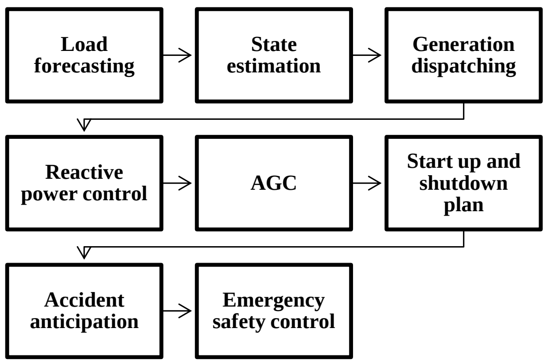
At present, there are many ways to calculate the electricity price, but most of them can't directly reflect the specific process of power distribution and can't be charged on demand based on the resources and services of power users. In addition, a mature and flexible pricing mechanism has not been established to realize the value-added of power users. As an important measure of service value of power providers, electricity pricing should have evaluation indicators such as billing stability and fair value, so as to achieve the growth of services.

The node marginal price calculation based on Petri net modeling can make full use of the advantages of discreteness, concurrency and distribution of Petri net to deal with the current electricity price calculation problem effectively, so as to realize the consistency of the node marginal price processing and parallel decision-making in the process of power transaction. Moreover, modeling the charging process based on Petri net under the current grid charging system is feasible in the calculation of node marginal price. It not only helps to realize the state-based resource utilization and billing process tracking, but also provides objective data support for the formulation of scientific and reasonable electricity pricing rules. Therefore, it has important practical value and role to study the calculation method of node marginal price based on Petri net modeling.

2. The locational marginal price

2.1. System marginal price

When there is no network constraint, ISO purchases electric energy from low to high according to the quotation of power suppliers. However, due to the scarcity of power grid resources, the limited transmission capacity of transmission lines naturally restricts the unlimited growth of power demand. With the current power grid gradually operating under the rules of the market economy system, the line power overrun involves the interests balance of all market participants[1]. At present, the power industry is based on the vertical management system of power generation, transmission and power supply integration, and under a more strict management system, the operation is smooth as shown in Figure 2 below.



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July - August 2020
ISSN: 0193-4120 Page No. 5392 - 5399

Figure 2. Management and operation system flow of electric power industry.

2.2. Congestion management

The operation of power grid will be restricted by line power. In case of emergency, it is necessary to adjust the power generation or reduce the power load, so as to reduce the line power[2]. These means can only be used as emergency treatment. From the perspective of long-term stable operation of the power grid, it is necessary to expand and reconstruct the power grid. Under the condition of market economy, the vertical integration of power generation, transmission and power supply is divided into independent business entities.

2.2.1. Congestion management problem

Under the market environment, if the independent operation entities, such as power generation, transmission and distribution, are still based on the traditional administrative intervention and branch line out of limit management methods, it is difficult to solve the problem of line power constraints, which will lead to the emergence of congestion management problems. The key to solve the problem of congestion management is to clarify the responsibilities of the relevant parties, so that both the buyer and the seller can freely access the market and meet the physical characteristics of the power network, so as to ensure the real-time transmission of information and promote the stability of the power system.

2.2.2. Congestion management definition

Congestion management includes carrying out corresponding management measures in two dimensions of technical level and economic level, so as to establish a scientific scheduling scheme at the technical level and promote stable and efficient operation within the scope of capacity limitation. In addition, on the economic level, congestion management is based on the allocation planning of transmission and distribution congestion costs, and reasonable economic incentives are given to stakeholders. In the economic and technical aspects of the two pronged approach, so as to maximize the elimination of power system congestion.

2.2.3. Characteristics of blocking management

The main purpose of congestion management is to maintain the safe and stable operation of the system, make rational use of transmission network resources, ensure the healthy development of the power industry and optimize the operation of the power system[3]. Under the background of simple market model, the congestion management method as shown in Figure 3 is usually adopted. With the deepening development of market model, simple congestion management model cannot meet the demand of power market for security and stability. In this context, it is necessary to carry out congestion management mode based on node marginal price.

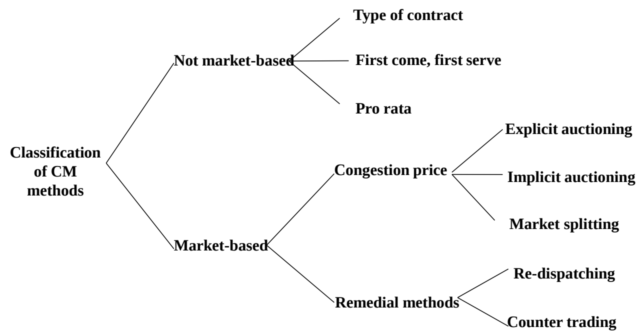

Figure 3. The congestion management method for simple market model.

2.3. locational marginal price

Locational marginal priceis the minimum purchase cost of increasing the unit active power of a node in the current operation state of power system, and it reflects the real-time supply cost and market supply-demand relationship in different positions of the power system, and is calculated based on the principle of ensuring the safe operation of power system. In addition, to ensure the safe operation of the power system is the constraint condition of the node marginal price.

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July - August 2020
ISSN: 0193-4120 Page No. 5392 - 5399

2.3.1. Calculation of locational marginal price

As a complex nonlinear system, Kirchhoff's law of power system transforms the constraints of safe operation of power system into that of active power. The objective function of locational marginal price calculation is as follows, so as to achieve the minimum electricity purchase cost, and its constraint condition is to maintain power balance.

$$\min \sum_{i \in I} f_i(p_i) \tag{1}$$

The constraints are as follows:

$$\sum_{i \in I} p_i - \sum_{j \in J} d_j = 0 \tag{2}$$

In which, p_i is the bid winning power of generation node *i*, and *I* is the set of nodes where generators are located. d_j is the demand of load node j, and *J* is the collection of load nodes[4]. The maximum transmission capacity of the line is as follows:

$$P_{line\_l}(p_i, d_j) \le p_{l\_TTC} \tag{3}$$

In which, the transmission power of $P_{line\_l}(p_i, d_j)$ branch *l* reflects the relationship between node injection and line power flow. p_{l_TTC} is the maximum transmission capacity of branch *l*.

Construction of extended Lagrange function:

$$F = \sum_{i \in I} f_i(p_i) - \lambda\left(\sum_{i \in I} p_i - \sum_{j \in J} d_j\right) - \sum_{l \in L} \mu_l \left(P_{line\_l}(p_i, d_j) - p_{l\_TTC}\right) \tag{4}$$

The extended Lagrange function is used to calculate the partial derivative of load nodes:

$$LMP_j = \frac{\partial F}{\partial d_j} = \lambda - \sum_{l \in L} \mu_l \frac{\partial P_{line\_l}(p_i, d_j)}{\partial d_j} \tag{5}$$

2.3.2. Node marginal price of complex network

For the complex network nodes as shown in Figure 4 below, it is more economical to reduce the output of G_1 unit first after grid congestion. Although G_1 unit price is lower than G_3 unit, G_1 unit reduces unit energy, corresponding to unit with more than half of *AC* load reduction, while G_3 unit reduces unit energy corresponding to unit with less than half of *AC* load reduction.

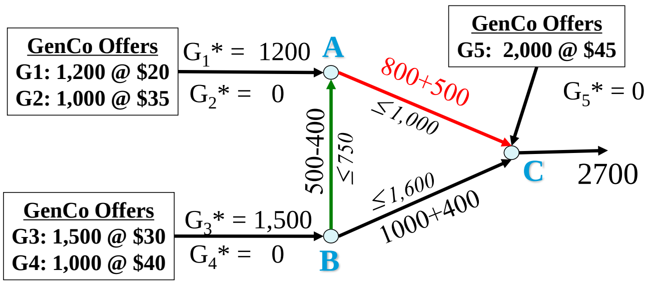

Figure 4. Nodes in complex networks.

The economic signal to guide resource allocation is that the generation resources of node *A* and *B* are redundant, and the generation resources of node C are deficient, so the capacity of line *AC* needs to be expanded.

2.4. Regional marginal price

1. The regional marginal price refers to the minimum purchase cost when the unit power demand is increased in a certain system operation condition[5]. It not only reflects the short-term marginal cost of different regions, but also varies with the time and location of power consumption.

In addition, transmission congestion exists between different regions without considering network loss. If there is no congestion, the marginal price of each region is the same, which is the system marginal price. The factors affecting regional marginal price mainly include quotation, demand, and congestion and so on.In general, the application framework of regional marginal price is shown in Figure 5 below.

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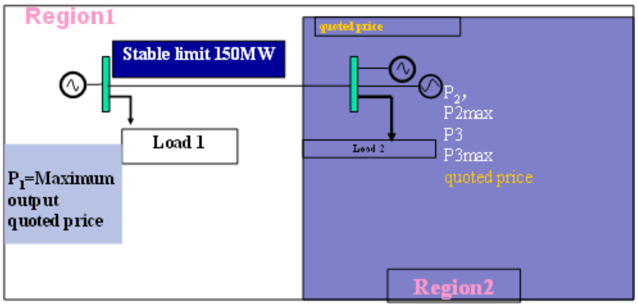

Figure 5. The application framework of regional marginal price.

3. Modeling technology based on Petri net

3.1. Basic concepts of Petri nets

As a dynamic tool for describing discrete-time systems, Petri net has the ability to describe asynchronous, synchronous and parallel logic[6]. At present, it has become an important analysis and control tool, and has been deeply applied in the engineering field. In power system, the application of Petri net is to model events and conditions, so as to describe the system state objectively. The former mainly refers to the action of time, while the latter refers to the event that occurs when the former condition is not established. Therefore, it can be seen that state and event transition are the most basic units.

3.2. Design of embedded system architecture

The simulation of power system based on the dimension of control and management can simplify the process and link of simulation. Secondly, Petri net can accurately describe the dependency relationship between events in power system, so as to build a more complete system structure and behavior, and is more suitable to describe the modeling of concurrency and blocking time. Based on the typical characteristics of the above aspects, Petri net is mainly used in power system performance analysis, system control, system simulation and digital analysis. The typical advantages and disadvantages of Petri net based modeling are shown in Table 1.

Table 1. The typical advantages and disadvantages of Petri netmodeling.

Aspects	Advantages	Disadvantages
Mathematical foundations	Accurately describe the dependency of events in the system	Too many elements make up the model
Semantic&graphic representation	Communication of different subsystems	Harder to understand than active networks
State modeling	More flexibility	Data flow cannot be reflected in the network

3.3. Typical construction of Petri nets

Petri net is a network composed of places and transitions. Its connection has direction and is between the library and the transformation[7]. Among them, token is a dynamic object, and its state is determined by the token distributed in the repository. The components of Petri net are shown in Figure 6 below, which mainly include place, which is represented by small circle *p*; transition is represented by small square *T*; connection is represented by *F* and *K* as the directed edge flow relationship between place and transition. In addition, as a dynamic object in place, token can be moved from one place to another, which is represented by.

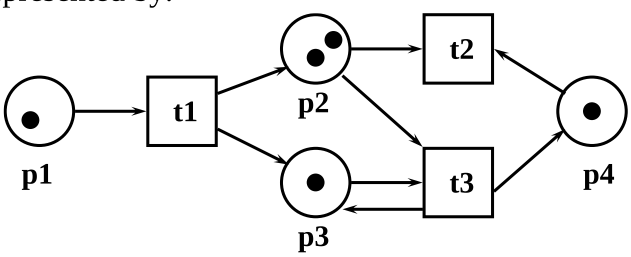

Figure 6. Structure and components of Petri net.

3.4. Rules of Petri nets

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ISSN: 0193-4120 Page No. 5392 - 5399

The rules of Petri net mainly include that the connection is directional, and the weight can be marked on it. There are no edges between two places or transitions, and there should be no isolated nodes, and place can have any number of tokens. The process includes sequence flow, cycle iteration process, selection process and concurrent process.

3.4.1. Input place/output place

As shown in Figure. 7, transition T1 has three input places (P1, P2 and P3) and two output places (P3 and P4). Among them, placep3 is both the input place and the output place of T1. Transition is the active element, while place and tocken are the passive elements. If the input place contains token, then the transition is activated. The active transition can be ignited, and the ignition will consume the token of input place and produce token for the output place.

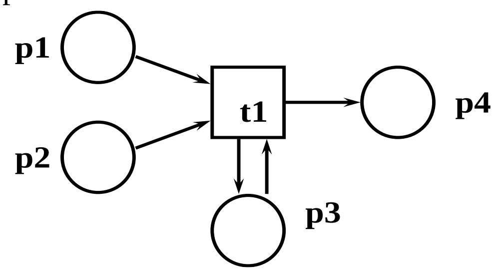

Figure 7. The input place/output place of Petri net.

3.4.2. Uncertainty

In Petri nets, when two transitions compete for the same token, there will be conflicts, and even if there are two tokens in Petri nets, there will still be conflicts, which will lead to its uncertainty.

3.5. Process modeling based on Petri net

In Petri net based process modeling, place stands for cache, channel, geographic location, condition or state. Transition stands for time, transmission or conversion. Token represents an object, information, or state of an object. The state of a process is represented by token in place, and the transition between States is represented by transition. Token represents the working object, and transition is the control point in the network. The algorithm extension of Petri net can make it have the ability to deal with the operation of model solving system.

3.6. High order Petri nets

In the methods of modeling based on Petri net and node edge and electricity price calculation, it is often applied to high-order Petri net, so as to avoid the scale and complexity of Petri net, reduce the modeling time and improve the efficiency of data processing. High order Petri nets mainly use color to represent attribute description, time is used to analyze performance, and hierarchy is used to decompose structure. In the extension level based on color, token has color to represent the specific properties of the object modeled by Token, so that each transition can have its own description. In addition, the contents of these descriptions include the number of tokens and the value of tokens, which makes the process description more compact and manageable.

In the time-based extension level, in order to effectively analyze the performance of the power grid system, it is necessary to model the time concepts of duration, delay, etc., which requires the corresponding tokens to have their corresponding timestamps, and the transition determines the delay of generating a token. At the level of hierarchy based extension, the structure information of more complex Petri nets is added. Its subnet is the extension of place, transition and subnet, as shown in Figure 8 below.

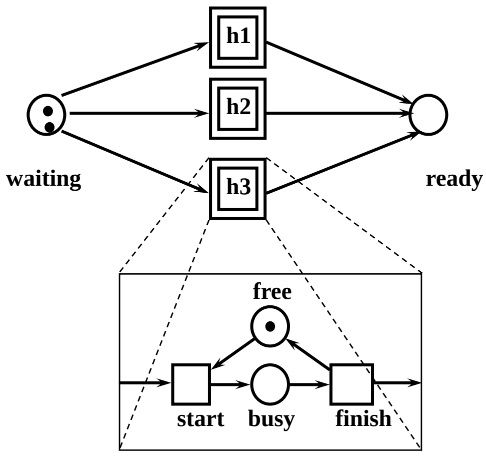

Figure 8. Extension of high order Petri net hierarchy.

4. Calculation of locational marginal price based on Petri net modeling

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4.1. Information layer of power system Petri net model

With the market environment of the power system gradually operating in the market economy environment, the power generation side, transmission side and power consumption side of the current power system have formed a mutual restriction and interdependence coexistence relationship. Under the condition of this relationship, the distribution of power resources in the system and the establishment of the node marginal price are affected by the final effect and influence of the lowest bidding price and the highest bidding price of the power consumers. In an ideal state, the lowest bidding power generation party generates power and supplies the power to the highest bidding power consumer. Based on this ideal state principle, the power supply quotation and the power load size will be sorted respectively, and then, the power supply will be transmitted to each use load based on the two sorting conditions.

In the process of transmitting power to each load, there will be an extreme case that the line capacity reaches the transmission limit. In this case, the power transmission needs to be redistributed. Generally speaking, the power supply will be based on the principle of selecting the electricity in the same area as the load point, and only when the power supply quotation is higher than the load quotation will the power distribution be carried out again. In addition, when the power system is congested, in order to reduce the operation cost of the system, it is necessary to quote the price based on the node margin, and take the minimum quotation of the node surplus power and load as its marginal quotation. The information layer of power system Petri net model can effectively collect and analyze the information of power supply and load in the case of power system congestion, so as to determine the reasonable node marginal price.

4.2. Signal temperature compensation of array belt weigher

The construction of power system Petri net model mainly includes four dimensions: power supply model, load model, line model and system model. Among them, in the power model level, the model mainly includes power capacity, command issuing node of information layer and power distribution module. At the level of load model, it mainly includes load node, connection between load and system and command issuing node. At the line model level, it includes the end of the line and the residual capacity of power transmission along the line. In addition, at the system model level, the power system model architecture includes several areas, as shown in Figure 9 below.

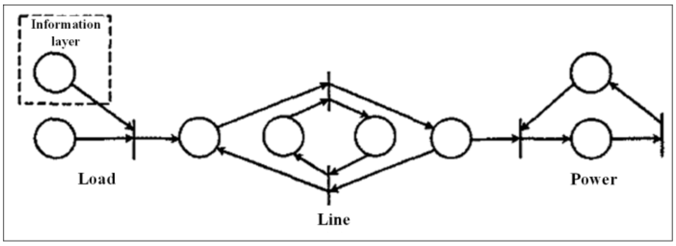

Figure 9. The Petri net model of power system.

Based on the theory of Petri net, the node marginal price is determined by sorting the bidding of power supply and load respectively, and the result of ranking is the basis of power supply and load distribution. In the case of power network congestion, according to the principle of node marginal price, the power suppliers with higher power quotation need to reduce the generation cost and improve their market competitiveness. For the low bidding power load side, it is necessary to increase the payment for electricity use. In a word, the calculation of node marginal price based on Petri net model can provide objective and scientific data support and information decision reference for power system planning and economic operation of power grid.

5. Conclusion

In summary, the calculation of locational marginal price is directly related to the time and the state of the power grid system. It is based on the current

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operation state of the power grid system. On the premise of ensuring the stable operation of the power grid system, the minimum unit power cost of the grid system is increased by increasing the load of a single point. The node marginal price calculation based on Petri net modeling can give full play to the advantages of discreteness, concurrency and distribution of Petri net, and effectively deal with the current electricity price calculation problem. It can guarantee the consistency of the node marginal price processing and parallel decision-making in the process of power transaction, and provide objective data support for the formulation of scientific and reasonable electricity pricing rules.

In this paper, the principle of marginal electricity price and its function on grid congestion are analyzed. Secondly, through the research of modeling technology based on Petri net, the typical structure, advantages and disadvantages of Petri net and its modeling process are analyzed. Finally, through the research on the calculation method of locational marginal price based on Petri net modeling, the construction of power system's Petri net model and the calculation of locational marginal price based on Petri net modeling are given, which provide objective and scientific data support for power system planning.

Acknowledgments

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