Maximizing Revenue Resource Allocation Algorithm for Power Communication Network Service Providers

Zhi Li 1,*, Fangjia Long 1, Hanlin Xia 1 and Jing Zhang 1

1 State Grid Chongqing Electric Power Company Electric Power Research Institute, Chongqing, China.

*Corresponding author e-mail: nanhuananmu@163.com

Abstract. In order to improve the revenue of power communication network service providers, this paper first constructs a power communication network resource allocation model composed of self-built service providers, third-party service providers and demanders, and models resource allocation problems in power communication networks. Secondly, the Jacobi iteration formula of service capability is derived, and the optimal resource allocation algorithm of service provider is proposed. In the simulation experiment, it is verified that in the competing environment including the self-built service provider and the third-party service provider, the resource allocation of the power communication network has achieved Nash equilibrium in terms of service capability, and when the third-party service provider is introduced, the capital investment of network resources is reduced and the benefits of service providers is increased.

1. Introduction

With the rapid development of smart grid services, the demand for smart grids for power grids is growing [1]. In order to meet the needs of the smart grid business, power companies generally adopt self-built power communication networks and lease third-party communication networks to solve this problem [2]. At present, most power companies adopt an internal performance system. Each power branch is responsible for self-building the power communication network in their respective regions, and then provides it to the power business department for use and performance evaluation. For the convenience of description, this paper refers to the self-built power communication network power branch as self-built power communication network service provider (SSP). A company that is a third-party communication network service provider is called third-party power communication network service provider (TSP).

In order to meet the needs of the power business, how to choose a self-built power communication network and rent a third-party communication network has become an urgent problem to be solved. Literature [3] analyzes the median characteristics of the shortest path of complex network topology, and evaluates the importance of nodes in complex networks, so as to better allocate important resources in the network to higher-priority business requirements. In [4], the problem of unbalanced distribution of power fiber network resources is proposed. The improved genetic algorithm is used to plan the optical transmission network, so as to realize the reliable construction of the power optical network with the least resources. In [5], the QoS priority of each smart grid service is realized, and an adaptive power communication network resource allocation mechanism is realized by dynamic programming method, thereby improving the satisfaction of power users and the resource revenue of
the power communication network. Literature [6] is based on multi-party game theory to meet the QoS requirements of all parties in power resource demand, and constructs a resource allocation mechanism that maximizes resource utility, and proves that the allocation mechanism can obtain Nash equilibrium and better solve QoS constraints. Power communication network resource allocation problem. Literature [7] models the network resource allocation problem as an auction problem in the economic field, constructs a resource allocation model composed of resource demand side, resource provider and resource allocation center, and builds a distributed network resource auction mechanism based on VCG mechanism. It better improves the utilization of network resources and the social benefits of all parties to the auction.

From the analysis of existing research results, most of the related research only considers the competition between SSPs or TSPs, but the related research is less involved in the competition between SSPs and TSPs. Therefore, it is especially important to establish a competitive game model to study the competitive relationship between SSPs and TSPs. In order to solve this problem, this paper firstly constructs the power communication network resource allocation model composed of SSPs, TSPs and Demand side of power communication network (DS). Secondly, the optimal resource allocation algorithm of service provider is proposed. In the simulation experiment, under the three environments of competition between SSPs, competition between TSPs, and competition between SSPs and TSPs, Nash Equilibrium has been achieved in the service allocation of power communication network resources, and when third-party service provision is introduced When business is available, the user's needs can be met through lower service capabilities, thereby reducing the capital investment of network resources and improving the revenue of network service providers under the premise of obtaining the same benefits.

2. Power communication network resource allocation system

The power communication network resource allocation model is shown in Figure 1. It includes three participants: SSPs, TSPs, and DS. Among them, SSPs and TSPs are responsible for providing power communication network resources, and DS proposes resource requests for power communication networks to SSPs and TSPs.

Figure 1. Power communication network resource allocation model

In order to realize power communication network resource allocation, DSs can make resource requests to multiple SSPs and TSPs. The SSPs and TSPs feed back the service quality and price to the DSs that submitted the resource request according to the resource request and the resource status of the DSs. DSs select one or more SSPs and TSPs to provide power communication network services based on service quality and price, and pay compensation to support the normal operation of SSPs and TSPs. Considering that SSPs and TSPs will compete for the benefit of their respective companies, this paper models the resource allocation problem of power communication network as a non-cooperative game model to analyze the competition between SSPs and TSPs.
3. Formal description of the problem

The total demand for the power communication network of the power communication network demand side $DSs$ is expressed by $M$. The demand for the $m$th $DSm$ power communication network is expressed by $\lambda_m$, so $\Lambda = \sum_{m=1}^{M} \lambda_m$ is used to indicate the sum of the market sizes of the power communication network requirements.

The connectivity rate of the service provider power communication network refers to the probability that the power service request is successfully received by the service provider, which is represented by $q$. In the $k$-th competition, the amount of information transmitted by $SSPi$ and $TSPj$ in unit time is expressed by $u_k^{i,j}$ and $u_k^{i,j}$, which is called service capability, and the constraint of obedience is $0 < u_k^{i,j} < 1, 0 < u_k^{i,j} < 1$. Because the service capability is directly related to the resource input of the service provider to build the power communication network, it is the key factor affecting the service quality and service price. This paper uses $u_k^{i,j}$ and $u_k^{i,j}$ to represent the optimal service capability of $SSPi$ and $TSPj$.

Based on the reception rate $q$ and the service capability $u_k^{i,j}$, $u_k^{i,j}$ of the service provider power communication network, the operating costs $c_k^{i,j}$, $c_k^{i,j}$, $k^i$ and $k^i$ of the $SSPi$ and $TSPj$ in the $k$-th competition are expressed by the formula (1) representing the service capability coefficient, $k^i$, $k^i$ indicates the network cost factor. Since the power communication network user rents the resources of $TSPj$, $TSPj$ also needs to rent the interface resources of the $SSPi$ to provide services for the power communication service, so, $k^i > k^i$.

$$
\begin{align*}
    c_k^{i,j} &= k^i u_k^{i,j} + k^i q \\
    c_k^{i,j} &= k^i u_k^{i,j} + k^i q
\end{align*}
$$

(1)

Based on the above analysis, the utility of $SSPi$ and $TSPj$ in the $k$-th competition is calculated using formula (2), $U_k^{i,j}$ and $U_k^{i,j}$ are used to represent the utility of $SSPi$ and $TSPj$, where $P'$ and $P'$ represent the service price of the power communication network provided by $SSPi$ and $TSPj$.

$$
\begin{align*}
    U_k^{i,j} &= P' - c_k^{i,j} \\
    U_k^{i,j} &= P' - c_k^{i,j}
\end{align*}
$$

(2)

Each service provider in the power communication network market tries to lower the price or improve the quality of service to attract more users of the power communication network, and to maximize the utility and profit. Therefore, this paper uses the non-cooperative game model under full information to analyze Resource allocation problem between $SSPi$ and $TSPj$. Suppose there are a total of $r$ service providers. When the total number of $SSPs$ is $m$, the total number $TSPs$ is $r - m$.

According to economic theory, under the conditions of a certain price, the better the service quality, the greater the market share. Use $f_k^{i,j}$ and $f_k^{i,j}$ to represent the market share of $SSPi$ and $TSPj$ in the $k$-th competition. Calculate using equation (3), $a_i$, $a_j$ represent the service coefficients of $SSPi$ and $TSPj$, $b_j$ and $b_j$ represent the alternative coefficients of $SSPi$ and $TSPj$. 

\[
\begin{align*}
\pi^{s,j}_k &= f^{s,j}_k \cdot U^{s,j}_k \\
\pi^{t,j}_k &= f^{t,j}_k \cdot U^{t,j}_k
\end{align*}
\] (4)

The benefits of the service providers \(SSPi\) and \(TSPj\) in the \(k\)-th competition are represented by \(\pi^{s,j}_k\) and \(\pi^{t,j}_k\), and are calculated using the formula (4) with the constraint \(f^{s,j}_k + f^{t,j}_k \leq \Lambda\).

In order to achieve the competitive game goal of maximizing \(SSPi\) and \(TSPj\) returns, under the Nash equilibrium problem, the objective function of the service provider's revenue maximization problem to be solved is shown in formula (5).

\[
\begin{align*}
\max \{ \pi^{s,j}_k(u^{s,j}_k, \ldots, u^{s,m}_k, u^{r-m}_k, \ldots, u^{r-m}_k) \}, i \in \{1, 2, \ldots, m\} \\
\max \{ \pi^{t,j}_k(u^{t,j}_k, \ldots, u^{t,m}_k, u^{r-m}_k, \ldots, u^{r-m}_k) \}, j \in \{1, 2, \ldots, r - m\}
\end{align*}
\] (5)

4. Service Capability Derivation and Resource Allocation Algorithm

From the response function of service capabilities \(u^{s,j}_k, u^{t,j}_k\) and profit \(\pi^{s,j}_k, \pi^{t,j}_k\) [8], the service provider's optimal service capabilities \((u^{s,j}_k)^*, (u^{t,j}_k)^*\) can be calculated using equation (6).

\[
\begin{align*}
(u^{s,j}_k)^* &= \arg \{ \max(\pi^{s,j}_k) = f^{s,j}_k \cdot U^{s,j}_k \}, i \in \{1, 2, \ldots, m\} \\
(u^{t,j}_k)^* &= \arg \{ \max(\pi^{t,j}_k) = f^{t,j}_k \cdot U^{t,j}_k \}, j \in \{1, 2, \ldots, r - m\}
\end{align*}
\] (6)

The Jacobian transformation is used to transform the response function of the service capability \(u^{s,j}_k, u^{t,j}_k\) to obtain the Jacobian iteration formula (7).

\[
\begin{align*}
u^{s,j}_k &= \left( \frac{P^s - k^s \cdot q}{2k^s} + \frac{\sum_{i=1,j \neq i}^m u^{s,j}_{k-1} + \sum_{j=1}^{r-m} b_j u^{t,j}_{k-1}}{2a_j} \right)
\end{align*}
\] (7)

Based on the above analysis, the resource allocation algorithms for maximizing revenue of power communication network service providers proposed in this paper mainly include: (1) Network environment initialization and service capability initialization; (2) Using Jacobian iterative formula to solve service capabilities; (3) Iterative execution until the service capability satisfies the convergence condition; (4) Resource allocation based on the service capability of the service provider. The details will be described below.

(1) Network environment initialization and service capability initialization. First, each parameter in the resource allocation model is assigned a value, and second, the service capability is initialized, that is, an initial value \(v^{s,j}_0, v^{t,j}_0, u^{s,j}_0 = v^{s,j}_0 \in (0,1), u^{t,j}_0 = v^{t,j}_0 \in (0,1)\) is assigned to the service capability of each service provider. Among them, \(i \in \{1, 2, \ldots, m\}, j \in \{1, 2, \ldots, r - m\}\).
(2) Using Jacobian iterative formula to solve service capabilities. The service provider's service capability is calculated using the Jacobi iteration formula (7), and its service capability is continuously updated. The $SSP_i$ and $TSP_j$ service capabilities calculated in the $k$th round are $u_{s,i}^k$ and $u_{t,j}^k$.

(3) Iterative execution until the service capability satisfies the convergence condition. When the decision is made, if the convergence condition is met
\[ |u_{s,i}^{k+1} - u_{s,i}^k| < \varepsilon \quad \text{or} \quad |u_{t,j}^k| \geq 1 \]
then the algorithm ends, at this time, $u_{s,i}^*$, $u_{t,j}$ are the optimal service capabilities, that is, $(u_{s,i}^*)^{*} = u_{s,i}^*$, $(u_{t,j}^*)^{*} = u_{t,j}$. Otherwise, the $k+1$th iteration is performed.

(4) Resource allocation based on the service capability of the service provider. Based on the service capabilities of the converged service provider, the market share of each service provider is calculated using equation (3) to achieve resource allocation.

5. Performance analysis

In order to verify the performance of the resource allocation algorithm proposed in this paper, the performance analysis part verifies the resource allocation under the three environments of competition between SSPs, competition between TSPs, and competition between SSPs and TSPs. The experiment was carried out using MATLAB, and the data in the experiment were all normalized. The parameters used in the experiment are as follows: $P^s = 1$, $k_s = 0.5$, $k_t = 0.7$, $P^t = 0.8$, $k_s = 0.4$, $k_t = 0.8$, $q = 0.8$, $u_{s,i}^1 = 0.12$, $u_{t,j}^2 = 0.22$, $u_{s,i}^1 = 0.32$, $u_{t,j}^2 = 0.4$. The competition between SSPs uses SSP1 and SSP2 simulations. The parameters of SSP1 and SSP2 are set to $a_1 = 2.5$ and $a_2 = 2.9$. The experimental results are shown in Fig. 2. The competition between TSPs uses TSP1 and TSP2 simulations, and the TSP1 and TSP2 parameters are set to $a_1^* = 2.5$, $a_2^* = 2.9$. The experimental results are shown in Figure 3. The SSP1 and TSPs compete for SSP1 and TSP1, and the SSP1 and TSP1 parameters are set to $a_i = 2.5$, $a_i^* = 2.5$, $b_{11} = 0.5$, $b_{11}^* = 0.6$. The experimental results are shown in Figure 4.

![Figure 2. Service capabilities in a competitive environment between SSPs](image-url)
The experimental results are analyzed from two aspects of Nash equilibrium and service capacity in three competitive environments. (1) In terms of Nash equilibrium in three competitive environments, from Figure 2 to Figure 4, the curve fluctuates before the service provider obtains a unique Nash equilibrium, indicating that the service provider is in a stable state before reaching a steady state. There is a fierce competition game, but as the number of iterations increases, the service provider's service capability gradually approaches a stable value, which proves the uniqueness of the Nash equilibrium. In terms of the comparison of the service capabilities in the three competitive environments, the service capability is lower when there is only a self-built service provider in Figure 2. In Figure 3, only third-party service providers have higher service capabilities. Explain that third-party service providers can provide better quality of service than self-built service providers. When self-built service providers and third-party service providers participate in competition at the same time, service capabilities will decline. It means that when a third party is introduced, the user's needs
can be met through a lower service capability, thereby reducing the capital investment of the network resources under the premise of obtaining the same income, thereby improving the revenue of the network service provider.

6. Conclusion

In order to meet the needs of the smart grid business, power companies generally adopt self-built power communication networks and lease third-party communication networks to solve this problem. In order to maximize the revenue of self-built power communication network service providers and leased third-party communication network service providers, this paper constructs a power communication network resource allocation model composed of demanders of power communication network service providers and power communication networks, and proposes services. Provider optimal resource allocation algorithm. In the simulation experiment, it is verified that the model can realize the Nash equilibrium of SSPs and TSPs and improve the revenue of network service providers. Although the algorithm herein achieves resource allocation that maximizes service provider revenue, it is assumed that competitors are aware of bidding strategies and service costs for other competitors. In order to make the model more universal and improve the application scenario of the model, in the next step, based on the research results of this paper, the resource allocation mechanism in the incomplete environment of competitive information will be analyzed. Thereby providing more research results for power companies to improve service quality and maximize resource revenue.

7. Acknowledgments

This work was supported by the State Grid Technology Project “Research on Application of interaction between shared mode electric vehicle and power grid”(5418-201971184A-0-0-00) from State Grid Corporation of China.

References
[1] ZHAO Ziyan, LIU Jianming. Reliability Evaluation Algorithm of Power Communication Network Based on Business Risk Balance. Power System Technology | Power Syst Technol, 2011, 35(10): 209-213.
[2] CAO Junwei, WAN Yuxin, TU Guoyu, et al. Research on the Architecture of Smart Grid Information System . Chinese Journal of Computers, 2013, 36(1): 143-167.
[3] CHEN Jing, SUN Linfu. Node importance assessment in complex networks. Journal of Southwest Jiaotong University | J Southwest Jiaotong University, 2009, 44(3): 426-429.
[4] SHI Yue, QIU Xuesong, GUO Shaoyong, et al. Power optical transmission network planning method based on improved genetic algorithm. Journal on Communications, 2016, 37(1): 116-122.
[5] YU Rong, ZHONG Weifeng, XIE Shengli, et al. QoS differential scheduling in cognitive-radio-based smart grid networks: An adaptive dynamic programming approach. IEEE Transactions on Neural Networks and Learning Systems, 2016, 27(2): 435-443.
[6] LI Min, XU Zhenfei, XU Chongzhi, et al. QoS-driven power communication network utility maximizes resource allocation mechanism. Computer Systemsand Applications, 2018, 27(7): 265-271.
[7] LIU Zhixin, SHEN Yanyan, GUAN Xinping. A Distributed Network Resource Allocation Mechanism Based on VCG Auction. Acta Electronica Sinica, 2010, 38(8):1929-1934.
[8] LI Jizhao, LIU Yishan. Discussion on Nash Equilibrium Application of Reaction Function Method. Journal of Henan Education Institute(Natural Science Edition), 2010, 19(3): 10-11.