This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2023.3283563

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2022.Doi Number

Premium power service for custom power devices based on trial-purchase model

LING PAN, BING SHEN, PENG ZHANG, XIAOFENG ZOU, QIAN FENG

Electric Power Research Institute of SG Shanghai Electric Power Company, Shanghai, 200437 China

Corresponding author: Bing Shen (e-mail: author@ boulder.nist.gov).

This work was supported by the State Grid Offshore Electric Power Company Science and Technology Project Funding under Grant 520940220007.

ABSTRACT Voltage sag is one of the reasons that hinders the high-quality and efficient development of high-tech manufacturing users. Custom power device (CPD) is one of the effective ways to solve voltage sag. The reason why most high-tech manufacturing users are hesitant to invest CPD is that the economic benefits of CPD are vague. To solve this problem, a new premium power service (PPS) for CPD based on trial-purchase model is proposed. By trialing CPD, users can choose to purchase or cancel the devices after trialing, so as to improve the enthusiasm of users to invest premium power and ensure the smooth progress of PPS. According to the operation process of the proposed service, an optimization model of service scheme is established with the goal of maximizing the interests of power utility and user, to optimize the return ratio of users' mitigation benefits and the length of trial service. The revenue distribution model based on Game theory (Nash negotiation) is established to obtain the revenue distribution strategies of power utility and devices company respectively. The feasibility of proposed service is verified by a semiconductor user in China. The trial-purchase premium power service could be replicable and applicable, which provides a new choice both for power utility and users.

INDEX TERMS Trial-purchase, custom power device, premium power service, multi-objective model, Game theory

NOMENCLATURE

A. Variables

P_u	Economic benefits of user
P_e	Economic benefits of power utility
C_u	Investment cost of user
C_e	Investment cost of power utility
T	Length of trial service
C_{ser}	Reduced voltage sag losses after providing PPS
n	Whole life cycle of the CPD
c_1	Whether to select scheme *a*
c_2	Whether to select scheme *b*
C_{loss}	Single economic loss of production interruption caused by voltage sag
N_{pre}	Average monthly interruptions before the user installs CPDs
N_{after}	Average monthly interruptions after the user installs CPDs.
α	Proportion of mitigation benefits returned to power utility form user
C_{dis}	Discount cost of CPD
C_{dem}	Dismantling cost of CPD
C_{dep_f}	Depreciation fee of CPD
C_{val}	Residual value after the trial service of CPD
C_l	Net residual value of CPD
C_{pur}	Purchase cost of the CPD below the market price
C_I	Installation cost of the CPD
C_L	Maintenance cost of CPD
C_m	Management cost of CPD
N	Depreciation period
Λ	Average value
d	Management rate of CPD
f_1	Maximum net revenue of user
f_2	Maximum net revenue of power utility
γ	Weight of the impact of time change on the price
P	Nash product
s^*_j	Most ideal distribution proportion of the *j*-th body

$s_j^{'}$	Least ideal distribution proportion of the j-th body
w_j	Distribution weight of the j-th body
V_j	Investment ratio
D_j	Risk coefficient
Q_j	Contribution degree
C_j	Investment cost of the j-th body

B. Acronyms

PPS	Premium power service
CPD	Custom power devices
T-P	Trial-purchase premium power service

I. INTRODUCTION

With the development of digital revolution, the industrial structures have been continuously optimized and upgraded [1-2], the forms and functions of the power grid has gradually changed [3-5], which make many new forms of power consumption have emerged [6-7]. As the high-tech manufacturing enterprises grows[8-9], a large number of loads which are sensitive to voltage sags have been connected to the power grid [10], bringing new opportunities and challenges to develop premium power. It has great theoretical and practical significance for studying the replicable and applicable PPS to meet the premium power demands of users.

One of the most common ways to achieve premium power is to install CPDs, such as energy storage [11], DVR [12], UPS [13], etc. As the investment costs of CPDs are huge, the production costs of sensitive users is greatly increased, which makes the investment attitude of sensitive users less. The premium power service comes to solve this problem. At present, PPS is still at the initial stage. The existing PPSs mainly aimed at the problems of large initial investment and later high risk of the CPDs [14-16]. Literature [14] proposes a service mode of leasing and property rights transfer of devices. Devices companies provide user with CPDs by leasing. However, devices companies have a long capital recovery cycle, which takes them under high capital pressure, and high business risk for a long time, resulting in negative participation attitude. Literature [15] proposes a service mode provided by power utility and multiple device manufacturers jointly based on trust leasing. However, there may be "bundling" of service providers, resulting in over-compensation problems, and user' participation attitude is relatively hesitant. Literature [16] proposes the retired devices leasing service, but the performance of the retired equipment can only meet the demands of some users. In other words, the serviced objects are limited. To sum up, the existing PPSs have their own characteristics and targeted objects, but the disadvantage of the existing PPSs is passive participation by service providers, which is not conducive to the long-term development and positive operation of the service mode, as shown in TABLE I.

In view of the problems in the above mode, this paper proposes a PPS for CPD based on trial-purchase model (T-P). In the trial period, users can fully perceive the mitigation effects of CPDs to dispel users' investment doubts; In the purchase period, it can reduce the business risk and enhance the participation enthusiasm of the service providers.

TABLE I
ADVANTAGES AND DISADVANTAGES OF DIFFERENT PPS

PPS	Advantages		Disadvantages	
	similarity	difference	similarity	difference
Leasing and property transfer[14]	(1) Initial investment costs of premium power for users are reduced. (2) Achievements of service providers are increased.	/	(1) Lease period is too long that users cannot exit midway, if they will be not satisfied with the effectiveness of custom power devices. (2) Custom power devices will be idled after leasing. (3) One of the service providers (device manufacturers) bear high operational risks, due to the long return term.	Device manufacturers will develop over-compensation plans to increase revenue.
Trust leasing[15]		Power utility acts as an intermediary guarantor to avoid over-compensation of custom power devices.		/
Second-hand devices leasing[16]	(1) Initial investment costs of premium power for users are reduced further. (2) Usage rate of Custom power device is increased, increasing the revenue of device manufacturers.		(1) Mitigation effects and usage time of second-hand devices are lower than the new ones. (2) Device manufacturers will develop over-compensation plans to increase revenue.	

There is a cooperative and restrictive relationship between user, power utility and device company, which is used to solve the phenomenon of binding and passive participation of service providers. Firstly, the operation process of T-P mode is discussed in detail, and the feasibility of T-P mode is analyzed. Secondly, the optimization model of service scheme with the goal of maximizing the net revenue of power utility and user is established. Based on the cooperative game theory, the revenue distribution model of power utility and device company is established. Finally, the feasibility and effectiveness of the proposed model are verified by a high-tech enterprise.

II. THE SERVICE MODE OF T-P

A. OPERATION OF PROCESS OF T-P MODE

T-P mode includes three bodies: user, power utility, and device company. The functional positioning of the three bodies is shown in FIGURE 1. According to the user's demand for premium power, the power utility customizes the CPDs from the device company. After installing CPDs on the user's

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and
content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2023.3283563

side, power utility will give the user a trial service for a certain period. During the trial period, user will not pay any additional fees other than commissioning, operation and maintenance.

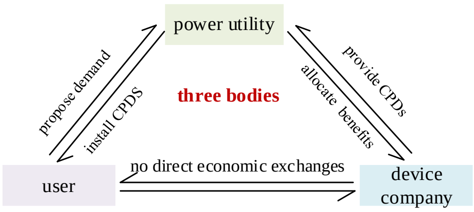

FIGURE 1. **Main bodies of the T-P Mode.**

According to the time node of the trial service, the T-P mode is divided into three stages: before trial, during trial and after trial. The specific operation process is shown in FIGURE 2.

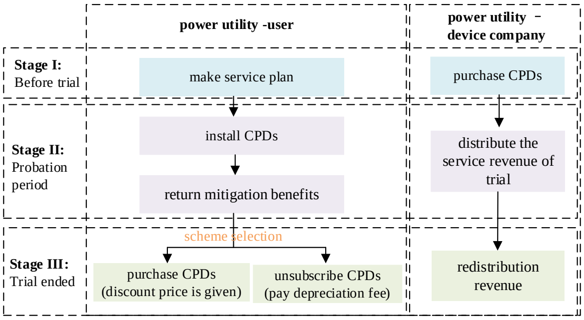

FIGURE 2. **Operation Process of the T-P Mode.**

Stage 1: before trial

(1) Make service plan. The power utility collects information about the types, capacities and voltage sag losses of the user's sensitive loads to define the types and capacities of CPDs, and clarifies the time node of trial service and the return ratio of mitigation benefits from voltage sags.

(2) Purchase CPDs. According to users' demand for premium power, power utility seek cooperation from device company, reach a willingness to purchase CPDs below the market price, and determine the distribution ratio of the benefits of trial service.

Stage II: trial period

(3) Install CPDs. The power utility arranges professional technical personnel to install the CPDs on the user side until the CPDs operate successfully and normally. The power utility bears the operation and maintenance costs during the trial period.

(4) Return mitigation benefits. The reduced voltage sag losses of users during the trial period are the mitigation benefits, and a part of them will be returned to the power utility according to the specific rules of the service plan, which is reflected in the profits of the trial service for the power utility.

(5) Distribute trial service revenue. The power utility and the device company shall distribute the revenue obtained during the trial period in proportion.

Stage III: Trial ended

(6) At the ending of the trial period, users have two choices.

Scheme *a*: User is satisfied with the effect of CPDs, that choose to purchase CPDs, and the power utility will distribute the trial service revenue;

Scheme *b*: User is not satisfied with the effect of CPDs, that choose to unsubscribe CPDs, and the power utility will return CPDs to device company. The user needs to pay the disassembly cost and depreciation fee of CPDs.

(7) Revenue redistribution. Power utility and device company redistribute the revenue which obtained in this period.

B. FEASIBILITY ANALYSIS OF T-P MODE

In the T-P mode, the power utility purchases the CPDs from the device company with a lower price, and provides CPDs to users by trial services. The device company has no direct economic contact with users.

(1) For sensitive users, they have strong demands for premium power without sufficient funds. Even more, they are skeptical of the expected mitigation effect of the premium power plan formulated by the device company. The T-P mode adopts the strategy of trial first. The user can choose whether to purchase CPDs at a discount price at the end of the trial service, which not only avoids the high investment problem of traditional modes, but also effectively avoids the problem of the existing mode, that users' passive participation in the service due to their skepticism about the expected effect of mitigation.

(2) For power utility, as an intermediary between user and device company, who has strong technical credibility and can formulate premium power plans for users. In the trust leasing mode, the power utility and the device company bind to become service providers, forming a community of interests. power utility provides the plan, the device company provides CPDs. There is a risk that service providers will design over-compensation plan to increase service fees. In order to restrict the moral hazard behavior, in the T-P mode, the power utility and the device company are connected to purchase CPDs at a price lower than the market price. Under this behavior, the power utility would reduce the capital pressure and avoid designing over-compensation schemes to reduce the initial investment cost. In addition, in the T-P mode, the profit sources of power utility are mainly divided into two parts. One part is the reduced voltage sag losses of users in the trial stage, which can not only guarantee the enthusiasm of power utility in the service process, but also restrict the power utility to design over-compensation scheme; The other part is that after the trial period, users purchase CPDs from power utility.

(3) For device company, provides CPDs. Under the T-P mode, the power utility purchases CPDs from the device company at a lower price. Although the device company cannot obtain complete revenue, it has been able to recover part of the funds. Subsequent benefits will continue to be reflected in the rebate of mitigation benefits in the trial stage. The phenomenon of passive participation of device company due to excessive financial pressure existing in the existing PPSs is avoided.

III. THE SERVICE OPTIMIZATION SCHEME OF T-P

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2023.3283563

In the T-P mode, the key point for the power utility and the user is to analyze the costs and benefits, which mainly includes the following two aspects: the return ratio of mitigation benefits and the duration of trial service.

A. COST-BENEFIT QUANTIFICATION

- Cost-benefit quantification of user

The economic benefits of user are reflected from the avoided voltage sag losses in the trail period and the purchase period.

The investment costs of user mainly include the mitigation benefits which returned to the power utility during the trial period, the equipment purchase cost of scheme *a* or the disassembly cost and depreciation fee of scheme *b* after the trial.

The economic benefits of the user P_u is:

$$P_{\mathrm{u}} = TC_{\mathrm{ser}} + c_1(12n - T)C_{\mathrm{ser}} \tag{1}$$

where T is the length of trial service, and generally takes "month" as the unit; C_{ser} is the reduced voltage sag losses after providing PPS; n is the whole life cycle of the CPD; c_1 is used to determine whether to select scheme *a* at the end of the trail period: user selects scheme *a*, c_1=1; user doesn't select scheme *a*, c_1=0.

$$C_{\mathrm{ser}} = C_{\mathrm{loss}}(N_{\mathrm{pre}} - N_{\mathrm{after}}) \tag{2}$$

where C_{loss} is the single economic loss of production interruption caused by voltage sag; N_{pre} and N_{after} are the average monthly interruptions before and after the user installs CPDs.

The investment cost of user C_{u}:

$$C_{\mathrm{u}} = \alpha P_{\mathrm{u}} + c_1 C_{\mathrm{dis}} + c_2(C_{\mathrm{dem}} + C_{\mathrm{dep\_f}}) \tag{3}$$

where α is the proportion of mitigation benefits returned to power utility form user, α<1； c_2 is used to determine whether to select scheme *b* at the end of the trail period: user selects scheme *b*, c_2=1, user doesn't select scheme *b*, c_2=0; C_{dis} is the discount cost of CPD; C_{dem} is the dismantling cost of CPD; $C_{\mathrm{dep\_f}}$ is the depreciation fee of CPD.

- Cost-benefit quantification of power utility

Since the power utility will distribute the revenue with the device company after charging from the user, the reduced benefit due to the revenue distribution will not be considered here. Therefore, the economic benefit of the power utility comes from the total investment expenditure of the user and the residual value of the equipment obtained by the user after selecting scheme *b*. The investment cost of power utility mainly includes the purchase cost of CPD before the trial period, the installation and maintenance of CPD during the trial period.

The economic benefits of the power utility P_e is:

$$P_{\mathrm{e}} = C_{\mathrm{u}} + c_2 C_{\mathrm{val}} \tag{4}$$

where C_{val} is the residual value after the trial service of CPD. The calculation formula of C_{val} is:

$$C_{\mathrm{val}} = C_{\mathrm{o}} - C_{\mathrm{dep\_c}} \tag{5}$$

where C_{o} is the original value of the CPD, $C_{\mathrm{dep\_c}}$ is the depreciation cost during the trial service period of CPD.

The annual depreciation value of CPD is calculated by the straight-line method [17], and the depreciation cost is obtained as follows:

$$C_{\mathrm{dep\_c}} = \frac{T(C_{\mathrm{o}} - C_l)}{12n} \tag{6}$$

where C_l is the net residual value of CPD.

The investment cost of the power utility C_{e} is:

$$C_{\mathrm{e}} = C_{\mathrm{pur}} + C_{\mathrm{I}} + C_{\mathrm{L}} + C_{\mathrm{m}} \tag{7}$$

where C_{pur} is the purchase cost of the CPD below the market price; C_{I} is the installation cost of the CPD; C_{L} is the maintenance cost of CPD; C_{m} is the management cost of CPD. In consideration of the degradation of CPD, in other words, the functions of CPD decline with the increase of operation time, and the maintenance costs of CPD will increases. C_{L} is:

$$C_{\mathrm{L}} = \lambda\left(\frac{N}{2} - \frac{T}{12}\right) \tag{8}$$

where N is the depreciation period; λ is the average value.

d is defined as the management rate of CPD, C_{m} is:

$$C_{\mathrm{m}} = dC_{\mathrm{o}} \tag{9}$$

B. COST-BENEFIT QUANTIFICATION

- Objective function

In the T-P mode, because the revenue of power utility and the device company come from user, the power utility expects to charge as much as possible from the user. Meanwhile, the user expects to get the maximum benefit with the least investment.

The objective functions are constructed from the maximum net revenue of user f_1 and power utility f_2. The optimization variable is the return ratio of mitigation benefits α, the duration of trial service T, the discount price of CPDs C_{dis}, the depreciation fee of CPDs $C_{\mathrm{dep\_f}}$。

Optimization objective 1 is to maximize the net revenue of user f_1:

$$\max\ f_1 = P_{\mathrm{u}} - C_{\mathrm{u}} \tag{10}$$

Optimization objective 2 is to maximize the net revenue of power utility f_2:

$$\max\ f_2 = P_{\mathrm{e}} - C_e \tag{11}$$

- Constraint condition

(1) Expected benefit constraints of power utility

The power utility expects that the user can finally choose scheme *a* to sell the CPD. Therefore, for the user, the net revenue of scheme *a* should be higher than that of scheme *b*, that is:

$$\alpha P_{\mathrm{u}} + C_{\mathrm{dis}} \geq \alpha P_{\mathrm{u}} + C_{\mathrm{dem}} + C_{\mathrm{dep\_f}} \tag{12}$$

(2) Restriction on the return ratio of mitigation benefits

The mitigation benefits returned by users to power utility change dynamically with the duration of trial service. With the decrease of marginal cost [18], the longer the trial service time, the smaller the growth and change of return benefits.

It can be concluded that:

$$\alpha P_{\mathrm{u}} = C_{\mathrm{I}} + \gamma(\ln T + 1) \tag{13}$$

where γ is the weight of the impact of time change on the price.

(3) Constraint of trial service duration

Considering the residual utilization rate of CPD and the recovery period of investment, the duration of trial service should not exceed half of the depreciation life (N/2) of CPD:

$$T \le \frac{N}{2} \tag{14}$$

(4) Scheme *a*: equipment discount price constraint

The discount price that users choose to purchase the CPD is based on the residual value with a certain discount coefficient, which is not less than 65%. At the same time, in order to ensure the subsequent revenue of user, the discount price should be lower than the expected voltage sag losses in the remaining service life.

$$0.65C_{\text{val}} \le C_{\text{dis}} < C_{\text{loss}}(N_{\text{pre}} - N_{\text{after}})(12n - T) \tag{15}$$

(5) Scheme *b*: equipment depreciation fee constraint

The depreciation fee paid by the user should between the depreciation cost and the original value of the CPD:

$$C_{\text{dep\_c}} \le C_{\text{dep\_f}} \le C_{\text{o}} \tag{16}$$

C. MODE SOULUTION

The service scheme of T-P is a multi-objective optimization. Furthermore, the two objective functions that formula (9) and formula (10) are contradict with each other. It means that if the value of one objective function is improved by changing a set of variables, it may cause the degradation of another objective function value. Due to the absence of a result that can meet all constraints while simultaneously maximizing the net profits of both users and power utilities. Pareto Optimal Front (POF) can solve the above problems, which is the compose of all Pareto optimal results. Non-dominated Sorting Genetic Algorithm-II (NSGA-II) [19-21] is an effective method for searching POF, which has some advantages, such as the lower computation complexity, the faster computation speed, the better astringency, etc. Therefore, NSGA-II is more suitable for obtaining T-P service scheme optimizations.

Power utility and user should choose the optimal result from the POF, which is the optimal scheme. In this paper, the partial large fuzzy membership function is used to represent the satisfaction of each objective function in each Pareto result. The optimal result is obtained by comparing satisfactions.

The flow of the proposed algorithm is shown in FIGURE 3.

IV. T-P REVENUE DISTRIBUTION STRATEGY

In the T-P mode, the key point for the power utility and device company is to put forward a reasonable and effective revenue distribution strategy to ensure that both bodies are profitable.

A. Revenue Distribution MODEL BASED ON COOPERATIVE GAME

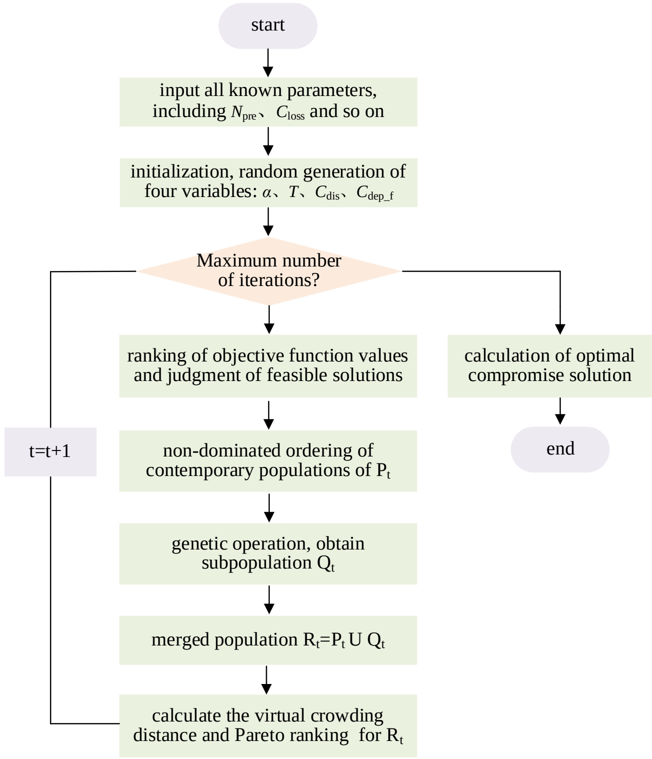

FIGURE 3. **Solution Flow of Model Algorithm.**

Power utility did not obtain the property right of CPD completely because of the price which is lower than the market. Therefore, the revenue obtained from user needs to be distributed with the device company. Considering that user may need multiple types of CPDs to work together, the providers have been extended into power company and multiple device companies. Nash negotiation [22] is the typical distribution model in Cooperative Game. This paper introduce it to obtain the revenue distribution strategy.

There are m bodies participating in revenue distribution, and the distribution strategy proposed by the j-th body is $\boldsymbol{S}_j=(s_{1j}, s_{2j},\cdots, s_{mj})$. Where s_{ij} is the distribution proportion of the i-th body proposed by the j-th body, $s_{ij}\in(0,1)$, and $s_{1j} + s_{2j} +\cdots+ s_{mj}=1$. Each body obtains a relatively satisfactory distribution result through game, and the final revenue distribution proportion of the j-th subject is s_j.

With the goal of maximizing the Nash product P of the distribution proportion of each body, a revenue distribution model based on Nash negotiation is established, as shown in formula (17).

$$\max P = \prod_{j=1}^{m} \left(\frac{s_j}{s'_j} - \frac{s_j^*}{s'_j}\right)^{w_j}$$
$$\text{s.t.} \begin{cases} s_j > s_j^* (j = 1, 2, \cdots, m) \\ \sum_{j=1}^{m} s_j = 1 \end{cases} \tag{17}$$

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2023.3283563

where s^{*}_{j} and s'_{j} are the most ideal and the least ideal distribution proportion of the j-th body respectively, as shown in formula (18); w_j is the distribution weight of the j-th body.

$$\begin{aligned} s_j^* &= \max\{s_{j1}, s_{j2}, \cdots, s_{jm}\} \\ s_j' &= \min\{s_{j1}, s_{j2}, \cdots, s_{jm}\} \end{aligned} \tag{18}$$

The Lagrange multiplier method is introduced to solve formula (19).

$$s_j = s_j' + (1 - \sum_{j=1}^{m} s_j') \frac{w_i \cdot s_j^*}{\sum_{i=1}^{m} w_i \cdot s_i^*} \tag{19}$$

B. Distribution WEIGHT

The distribution weight w_j of each body is determined by the investment ratio V_j, risk coefficient D_j and contribution degree Q_j. The calculation formula is:

$$w_j = \frac{V_j + D_j + Q_j}{\sum_{j=1}^{m} (V_j + D_j + Q_j)} \tag{20}$$

The investment proportion is the investment cost of each body in the total investment cost of T-P PPS, as shown in formula (21). The more investment, the more income in principle.

$$\boldsymbol{M}^w = \begin{bmatrix} m_{11}^w & m_{12}^w & \cdots & m_{1s}^w \\ m_{21}^w & m_{22}^w & \cdots & m_{2s}^w \\ \vdots & \vdots & m_{ab}^w & \vdots \\ m_{n1}^w & m_{n2}^w & \cdots & m_{ns}^w \end{bmatrix} \tag{21}$$

where C_j is the investment cost of the j-th body.

The risk coefficient is the risk degree that each body bears in the process of investment and operation, etc. There are M risks, the weight of the t-th risk is q_t, and the coefficient of the j-th body bearing the t-th risk is D_{jt}, then D_j is:

$$D_j = \sum_{t=1}^{M} (q_t D_{jt}) \tag{22}$$

The contribution degree is the fuzzy evaluation of the actual input of each body in T-P PPS, and the comprehensive score [23] is obtained to quantify the importance in T-P PPS to represent the negotiating position, $0 \leqslant Q_j \leqslant 1$, $Q_1+Q_2+\cdots+Q_m=1$.

V. CASE ANALYSIS

Take a typical semiconductor user in a high-tech industrial park in China as an example to provide T-P PPS, and analyze the cost and benefit of all bodies in T-P PPS.

A. Basic Data

The monthly average number of interruptions N_{pre} and economic losses of single production interruption C_{loss} can be obtained by field survey. N_{pre} is 0.75 times, C_{loss} is 1.4667 million CNY. According to the types, capacities, structure of production process and other information about the user's sensitive equipment obtained form the field survey, a PPS scheme is formulated.

Power utility seeks cooperation from a UPS manufacturer and a DVR manufacturer to purchase CPDs with standard capacity, that is, the total capacity can meet the requirements of PPS scheme. The detail information about PPS scheme is shown in TABLE II.

TABLE II
QUANTITY AND PRICE OF CPDS

	capacity (kVA)	quantity (amount)	market price (10 thousand CNY/per device)
UPS	200	2	22.456
	160	2	18.660
	100	1	12.388
DVR	150	1	37.500
	50	3	12.500
Total (10 thousand CNY)			289.536

It can be seen from TABLE II that the total market price of treatment equipment is 2.89536 million CNY. The device companies have reached a cooperation with the power utility, power utility could purchase CPDs at 65% of the market price, which is 1.88198 million CNY.

After installing CPDs, user can resist voltage sag events with magnitude higher than 0.6p.u. and duration shorter than 20ms. The average monthly interruptions will be 0.17 times.

B. SERVICE PLAN OPTIMIZATION

According to subsection A, the market price of CPD is 2.89536 million CNY, and the net residual value is about 0.8 million CNY; The life cycle of CPD is 15 years, and the annual average depreciation fee is 66.8 thousand CNY; The installation cost is about 25 thousand CNY, the dismantling cost C_{dem} is about 18 thousand CNY, the depreciation period N is 5 years, and the management rate d is 2%.

The populations of NSGA-II algorithm are 50, the iterations are 10000. The POF diagram of scheme a and scheme b are shown in FIGURE 4 and FIGURE 5. Take FIGURE 4 as an example, two adjacent points are randomly selected and highlighted in the figure, denoted as A and B respectively. By comparing the two points, it can be seen that the net revenue trend of user and power utility is opposite. This is because that the objective functions of users and power utilities are contradictory, the optimization of one will inevitably lead to the deterioration of the other. Next, compare FIGURE 4 with FIGURE 5, it can be seen that the net revenue of the power utility under scheme a is slightly higher than that of scheme b; Compare the abscissa of two figures, it can be seen that the net revenue of the user under scheme a is much higher than that of scheme b. Because the net revenue of scheme a takes into account the mitigation benefits of the user during the trial period and the expected benefits after purchasing CPDs.

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and
content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2023.3283563

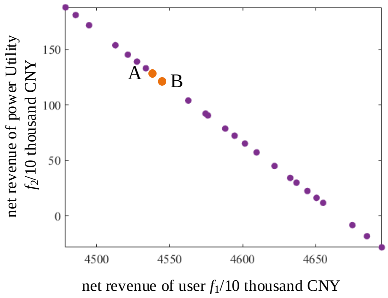

FIGURE 4. **POF Diagram for Scheme *a*.**

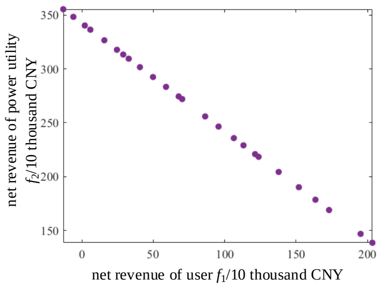

FIGURE 5. **POF Diagram for Scheme *b*.**

The optimization variables of scheme *a* and *b* are shown in FIGURE 6 and FIGURE 7. Scheme *a* corresponds to three optimization variables： α, T, and C_{dis}; Scheme *b* corresponds to three optimization variables: α, T, and C_{dep_f}.

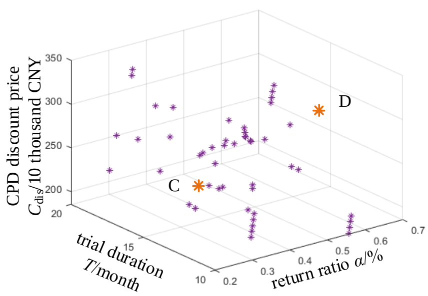

FIGURE 6. **Optimization Variables for Scheme *a*.**

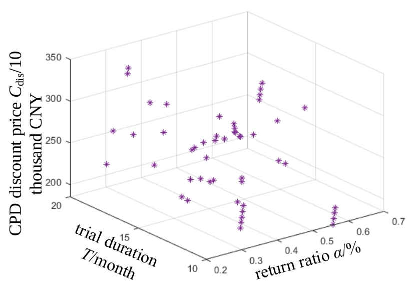

FIGURE 7. **Optimization Variables for Scheme *b*.**

Take FIGURE 6 as an example, two points are randomly selected and highlighted in the figure, denoted as C and D respectively. It shows that compared with point D, point C has a lower return ratio, a slightly longer trial duration and a lower discount price. However, the service schemes of points C and D both can be accepted by user and service providers. This is because the service scheme of point C has a longer trial period, but its return ratio is lower, which makes the lower difference between the cumulative return amount during the trial period and that of point D. Therefore, whether for users or service providers, the trial service schemes of points C and D are acceptable. In addition, the service scheme of point C has a longer trial period, which makes the residual life of the CPD lower than that of point D, so the purchase price will also be slightly lower. To sum up, if the service schemes come from the set of Pareto optimal solutions (FIFURE 6 shows all variable data that meet the constraint conditions), it will be accepted by both the users and service providers.

Next, compare FIGURE 6 with FIGURE 7. FIGURE 6 shows that in scheme *a*, $T\in$[10 months, 20 months], $\alpha\in$[20%, 70%], $C_{dis}\in$[200 thousand CNY, 350 thousand CNY]; As shown in FIGURE 7 , $T\in$[six months, fourteen months], $\alpha\in$ [40%, 100%] and $C_{dep\_f}\in$ [140 thousand CNY, 1,000 thousand CNY] in scheme *b*. It can be seen that although the discount price in scheme *a* is higher than the discount fee in scheme *b*, compared with scheme *b*, scheme *a* has a longer trial time and a lower return ratio, which enhances users' sense of experience to some extent and makes them more inclined to choose scheme *a*. At the same time, the discount price of CPDs is far lower than the mitigation revenue for user. From a long term perspective, after the trial is over, scheme *a* will get higher economic benefits than scheme *b*.

The optimal solution according to the descending order of satisfaction, as shown in TABLE III.

It can be seen from TABLE III that the two optimization schemes for T-P PPS are:

(1) The return rate of mitigation benefits is 43%, and the duration of trial service is 13.6 months. After the trial, user chooses scheme *a*, and purchases CPDs at a discount price of 2.216 million CNY.

(2) The return rate of mitigation benefits is 67%, and the duration of trial service is 6.5 months. After the trial, user chooses scheme *b*, and the depreciation fee needed users to pay is 467 thousand CNY.

TABLE III
OPTIMAL SCHEME *A* AND SCHEME *B* WITH DIFFERENT RETURN RATES

scheme *a*	α(%)	T(month)	C_{dis}(10 thousand CNY)
	0.43	13.6	221.6
scheme *b*	α(%)	T(month)	C_{dep_f} (10 thousand CNY)
	0.67	6.5	46.7

The objective function values of the optimal scheme *a* and *b* are shown in TABLE IV, that is, the net revenue of users is 2.551 million CNY and 236.231 thousand CNY respectively; the net revenue of power utility is 2.6467 million CNY and 2.0385 million CNY respectively.

TABLE IV
OPTIMAL SOLUTION FOR OBJECTIVE FUNCTION OF SCHEME *A* AND SCHEME *B*

objective function value	f_1(10 thousand CNY)	f_2(10 thousand CNY)
scheme *a*	2551.00	264.67
scheme *b*	23.6231	203.85

By comparing the two schemes, it can be seen that scheme *a* has a longer trial period, and the returned proportion of mitigation benefits during the trial period is lower. Although the final discount price of scheme *a* is higher than that of scheme *b*, user can enjoy premium power for a long time in scheme, the avoided voltage sag losses will be much higher than the purchase cost. Therefore, from the perspective of long-term development, scheme *a* is recommended to choose.

C. Revenue Distribution

It can be seen from TABLE IV that the net revenue of two schemes to be distributed by the power utility and device companies is 2.0385 million CNY and 2.6467 million CNY respectively.

The value of each factor can be calculated, and the distribution weight of each body can be gotten, which as shown in TABLE V.

TABLE V
INFLUENCE FACTORS OF REVENUE DISTRIBUTION AND DISTRIBUTION WEIGHTS

	investment proportion	risk coefficient	contribution degree	weight
power utility	V_1=0.62	D_1=0.42	Q_1=0.26	w_1=0.43
UPS manufacturer	V_2=0.28	D_2=0.22	Q_2=0.46	w_2=0.32
DVR manufacturer	V_3=0.10	D_3=0.37	Q_3=0.28	w_3=0.25

The optimal distribution proportion of each body is 1.5 times of its own investment proportion, then s^*_1=58%, s^*_2=45%, s^*_3=32%; The most unfavorable distribution proportion is 3/5 of the investment proportion, so s'_1=39%, s'_2=24%, s'_3=13%. Taking the relevant data into formula (21), the income distribution ratio of each body can be gotten: s_1=51.64%, s^*_2=31.30%, s^*_3=19.06%.

According to the income distribution ratio, calculate the net revenue of the three bodies under the two schemes, as shown in TABLE VI.

TABLE VI
NET REVENUE OF EACH BODY

net revenue (10 thousand CNY)	power utility	UPS manufacturer	DVR manufacturer
scheme *a*	136.6756	82.8417	50.4461
scheme *b*	105.2861	63.8051	38.8538

Comparing the two schemes, it can be seen that the net revenue from selling CPDs at the discount price is slightly higher than that from collecting the depreciation expenses of CPDs. Therefore, for power utility and device companies, scheme *a* is better than scheme *b*.

D. Comparison with leasing mode

Applying the leasing mode in reference [14] to the same user, signing CPDs leasing contracts with UPS manufacturer and DVR manufacturer respectively. If the lease term is 10 years, the annual rent and transfer fee will be calculated, as shown in TABLE VII.

The comparison of the net revenue in leasing service and trial-purchase service (Scheme a in TABLE III) for users, as shown in FIGURE 8.

TABLE VII
ANNUAL RENT AND TRANSFER FEE FOR THE LEASING SERVICE IN REFERENCE [14]

	annual rent (10 thousand CNY)	transfer fee (10 thousand CNY)
UPS manufacturer	78.25	20.15
DVR manufacturer	61.50	18.62

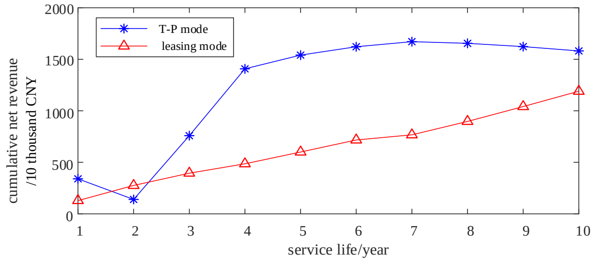

FIGURE 8. The cumulative net revenue of the two services.

The conclusions of FIFURE 8:

(1) The trial period for user is up to one year, that all economic benefits belong to the user without any cost. However, in leasing services, if the user will not be clear about the benefits of CPDs, they should pay rental fees to confirm. Therefore, for users, the service to confirm the benefits of CPD with free will be more attractive.

(2) In T-P service, users intuitively perceive the economic benefits during the trial period, and can take the choice of purchasing or unsubscribing after trialing. In leasing service, the lease term is longer that users cannot freely exit service or change the leasing plan during the lease period. Therefore, the flexibility and freedom of choice for users in T-P service is higher than in leasing service, that the participation enthusiasm of users in T-P service is higher.

(3) In the long term, for users, the cumulative net revenue in T-P service is further higher than leasing service.

To sum up, for the users with one of the following two characteristics, the T-P service will be more suitable. The two characteristics, one is that the user with enough capital is unclear about the benefits of the custom power device, the other is that the user may expand the scale of the industry or upgrade the production equipment.

VI. CONCLUSION

This paper proposes a premium power service for custom power devices based on trial-purchase model. For users, they can clarify the mitigation effectiveness of CPDs through trialing, thereby dispelling the doubts about investment failure on CPDs, and improving their mitigation willingness and power quality. For service providers, such as power utilities and equipment manufacturers, short-term trials can boost the numbers of users. Furthermore, the purchase model after trial can enable service providers to quickly return costs, reduce operating risks, obtain profits as soon as possible, that can stimulate service enthusiasm.

The main conclusions are as follows.

(1) By establishing a multi-objective optimization model, T-P PPS maximizes the benefits of power utility and device

companies while ensuring the benefits of users during the trial period;

(2) The T-P mode proposes a multi-body revenue distribution strategy by establishing the cooperative game mode, which ensures the cooperation willingness of each body to participate in PPS.

(3) Both scheme *a* and scheme *b* in T-P mode are feasible, but scheme a has higher investment efficiency and promotion value for each body.

REFERENCES

[1] Li C., Zhang Y., Saurabh P.,Zhou L., Liu B., and Zhou G. Regulation Effect of Smart Grid on Green Transformation of Electric Power Enterprises: Based on the Investigation of "Leader" Trap. *Frontiers in Energy Research*, 2023, vol 9, pp. 1-17.

[2] Zhao H., Wang Y., and Xiao X. Premium power supply scheme based on leasing mitigation equipment against voltage sag. *International Journal of Electrical Power & Energy System*, 2023, vol. 146, no. 108757.

[3] Khalil G., Shahram K., and Amjad A. M. Multi-objective Stochastic Planning of Electric Vehicle Charging Stations in Unbalanced Distribution Networks Supported by Smart Photovoltaic Inverters. *Sustainable Cities and Society*, 2022, vol. 84: 104029.

[4] Dong Y., Wang Z. and Ge L. Research on integration of power internet of things in demand side. *Institution of Engineering and Technology*, 2022, pp.191-197.

[5] Tan C., Tan Z., Yin Z, Wang Y., Geng S., Pu L. Study on grid price mechanism of new energy power stations considering market environment, *Renewable Energy*, 2023, vol. 203, pp. 177-193.

[6] Yang Z., Yang F., Min H., Tian H., Hu W., Liu J. Review on optimal planning of new power systems with distributed generations and electric vehicles. *Energy Reports*, 2023, vol. 9, pp. 501-509..

[7] Joan M. F. M., and Dorleta I. (2023). Technology-enabled circular business models for the hybridisation of wind farms: Integrated wind and solar energy, power-to-gas and power-to-liquid systems. *Sustainable Production and Consumption*, vol. 36, pp. 308-327.

[8] Xiao X., Chen Y., Wang Y., Ma Y. Multi-attribute analysis on voltage sag insurance mechanisms and their feasibility for sensitive customers. *IET Generation, Transmission & Distribution*, 2018, vol. 12, pp. 3892-3899.

[9] He H., Zhang W., Wang Y., Xiao X. A sensitive industrial process model for financial losses assessment due to voltage sag and short interruptions. *IEEE Transactions on Power Delivery*, 2021, vol. 36, pp. 1293-1301.

[10] Xiao X., Zhao H., Li C. Optimal cooperative governance scheme of park-level and equipment-level voltage sag and its investment and financing strategy. *Electric Power Automation Equipment*, 2020, vol. 40, pp. 157-165.

[11] Celik, D., Ahmed, H. Enhanced control of superconducting magnetic energy storage integrated UPQC for power quality improvement in EV charging station. *Journal of Energy Storage*, 2023, vol. 62: 106843.

[12] Babu V., Ahmed KS., Shuaib YM., Manikandan M. Power Quality Enhancement Using Dynamic Voltage Restorer (DVR)-Based Predictive Space Vector Transformation (PSVT) With Proportional Resonant (PR)-Controller. *IEEE Access*, 2021, vol. 9, pp. 155380-155392.

[13] Dong YF., Zhang GY., He GF., Si WJ. A Novel Control Strategy for Uninterruptible Power Supply Based on Backstepping and Fuzzy Neural Network. *IEEE Access*, 2023, vol. 11, pp. 5306-5313.

[14] Chen W., Yao Z., Guo M., Jin Q., Ruan S. Service pattern for premium power supply based on a combination of leasing and property transfer. *Power System Protection and Control*, 2021, vol. 49, pp. 145-152.

[15] Zhang H., Wang Q,. Liu Y. Service pattern for premium power supply based on trust lease. *Institute of Electrical and Electronics Engineers Inc*, 2022, pp. 463-469.

[16] Li P., Yu Y., Ma Z., Cai C. High quality power supply service mode considering the service life of mitigation equipment against voltage sag. *Electric Power*, 2022, vol. 55, pp. 147-159.

[17] Xiao X., Ma Y., Zhang Y., Liu Y. and Wang Y. Premium Power Valuation Method Based on Customer Perception of Utility for High Technology Manufacturing Customers. *IEEE Transactions on Power Delivery*, 2016, vol. 31, pp. 1655-1662.

[18] Yang M., Liu Y., Sun L., Wang D., Liang X. Research on Government-Enterprise Regulation of Online Car-Hailing Based on Differential Game. *Froniers in Psychology*, 2022, vol. 13.

[19] Anabel M. V., Josué D. G., Ángel G. A., Roberto S., and Oscar M. R. Application of NSGA-II algorithm to the spectrum assignment problem in spectrum sharing networks. Applied Soft Computing, 2016, 39, pp. 188-198.

[20] Wang Y., Luo H., and Xiao X. Joint optimal planning of distributed generations and sensitive user considering voltage sag. IEEE Transactions on Power Delivery, 2021, vol. 37, pp. 93-104.

[21] Sabir O., Achour B., Sabrina A., and Abdelkrim M. Fuzzy-predictive direct power control implementation of a grid connected photovoltaic system, associated with an active power filter. Energy Conversion and Management, 2016, vol. 122, pp. 515-525.

[22] Quentin Hoarau, Yannick Perez. Interactions between electric mobility and photovoltaic generation: A review. *Renewable and Sustainable Energy Reviews*, 2018, vol. 94, pp. 510-522..

[23] Kazi N. H., Robin P., and Jovica V. M. Application of game theoretic approaches for identification of critical parameters affecting power system small-disturbance stability. *International Journal of Electrical Power & Energy Systems*, 2018, vol. 97, pp. 344-352.

Ling Pan is an Engineer at the Electric Power Science Research Institute of SG Shanghai Electric Power Company. Her research interests include power quality analysis and control.

Peng Zhang is an Engineer at the Electric Power Science Research Institute of SG Shanghai Electric Power Company. His research interests include power quality analysis and control.

Bing Shen is a Senior Engineer at the Electric Power Science Research Institute of SG Shanghai Electric Power Company. His research interests include analysis and control of power quality in distribution networks.

Xiaofeng Zou is a Senior Engineer at the Electric Power Science Research Institute of SG Shanghai Electric Power Company. His research interests include analysis and control of power quality in distribution networks.

This article has been accepted for publication in IEEE Access. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2023.3283563

Qian Feng is an Engineer at the Electric Power Science Research Institute of SG Shanghai Electric Power Company. Her research interests include power quality analysis and control.