Modeling Power IoT Terminal Entity Based on OOPN

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Abstract: With the continuous development and ceaselessly construction of power IoT system, a huge number of power terminal entities are connected to the power IoT system, which largely affect the performance of power IoT system. The lifecycle process analysis of power IoT terminal entity becomes more and more important. However, the traditional analysis methods often have some shortcomings such as complex process and huge workload. Therefore, it is urgently needed to find out some more effective method to analyze the state and behaviour of power IoT terminal entity. To overcome the shortcomings of traditional analysis methods, an OOPN-based power IoT terminal entity model is proposed by combining object-oriented idea with Petri net technology. The proposed model has the advantages of modularity design, object-oriented, simplified calculation and great flexibility, which is verified with a case study by selecting a transformer as an example of power IoT terminal entity and comparing the data.

1. Introduction
With the deep integration of IoT technology and smart grid, the access of massive terminal entities and the explosive growth of data put forward higher requirements for the data processing and diversified business service capabilities of power IoT terminal entities. How to model the states and activities of these terminal entities becomes an urgent need. The traditional terminal entity modelling methods often have the shortcomings of complicated modelling process, complex mathematical calculation, high modelling cost, insufficient flexibility and low precision, which are not conducive to the practical application and seriously affect the efficiency improvement of the power IoT system. In order to overcome the shortcomings of the traditional power IoT terminal entity modeling method, this paper proposes an OOPN-based power IoT terminal entity model that has the advantages of modularity design, object-oriented, simplified calculation and sufficient flexibility. To verify the effectiveness of the proposed model, this paper conducts a case study with a power IoT terminal entity-transformer and find out that it is easy to operate and widely use when modeling many common power IoT terminal entities.

The rest of this paper is organized as follows. This paper begins with the related works in Section 2 and introduces the OOPN-based power IoT terminal entity model in Section 3. In Section 4, we conduct a case study to analyze the effect of the proposed model. Finally, the conclusion is drawn with discussion in Section 5.
2. Related Works
To solve the modeling problem of entity activities in numerous fields, Zheng et al. have established a process model with good flexibility for hybrid process enterprises by using the Petri net model[1]. Shu et al. established a general model for the actual FMS by combining object-oriented technology with Petri net theory, which can reflect the dynamic characteristic of many application scenarios[2]. Cao et al. used the Petri net to model and analyze the complete process of a production line[3]. Johtela et al. simulated the production process by establishing a production planning system, and set the input batch of the system, the position, sequence and processing cycle of each machine, so as to obtain the time of production cycle and the workload of each machine[4]. Zhang et al. proposed an object-oriented and integrated test-bed simulation method that can continuously test the effectiveness and practicability of new plans[5]. In addition, some research works used MES and Citect monitoring software to simulate the continuous process and constructed several models of continuous casting process simulation system with continuous casting sub equipment as the main object and aggregation relationship and active object as the main structure[6-8]. Based on these models, the differences between continuous casting production equipment and process are solved through equipment configuration, and the universality, maintainability and scalability of continuous casting production process simulation system are realized.

3. The OOPN-based Power IoT terminal Entity Model
The Petri net model can not only use graphics to structurally describe the complex event logic and sequential relationship in the production process of power IoT terminal, but also quantitatively analyse the production process of power IoT terminal based on mathematical methods. Therefore, it is widely used in the modeling, analysing and controlling of power IoT terminal production process. However, with the complexity increase of power IoT terminal production process, the establishment and analysis of the Petri net model becomes very cumbersome, and the Petri net model lacks modularization and reusability, which increases the time to reconstruct the Petri net model of power IoT terminal production process. In order to overcome these shortcomings, the object-oriented idea is introduced into the modeling of power IoT terminal production process, and a power IoT terminal production process model based on OOPN is proposed. The OOPN model regards the power IoT terminal production process as a series of entities and their information transmission, and uses the places and transitions and directed arcs in the Petri net model to describe the entities and the information transmission between entities.

3.1. The Relevant Definitions of OOPN
Definition 1: The classical Petri net is a simple process model, which is composed of several elements such as Place, Transition, Directed Arc and Token. The triple \( N=(P,T,F) \) is a Petri net if and only if:
\[
\begin{align*}
P \cap T &= \emptyset \\
P \cup T &\neq \emptyset
\end{align*}
\tag{1}
\]
\( P \) is the finite place set of \( N \), \( P=\{p_1,p_2,\ldots,p_m\}(m>0) \); \( T \) is the finite transition set of \( N \), \( T=\{t_1,t_2,\ldots,t_n\}(n>0) \). \( F \) is the flow relation of \( N \) and its elements are called directed arcs, \( F \) should meet the following conditions:
\[
\begin{align*}
F &\subseteq (P \times T) \cup (T \times P) \\
\text{dom}(F) &\cup \text{cod}(F) = P \cup T
\end{align*}
\tag{2}
\]
Here, \( \text{dom}(F) \) and \( \text{cod}(F) \) represent respectively the definition domain and value domain of \( F \), that is:
\[
\begin{align*}
\text{dom}(F) &= \{x|\exists y:(x,y) \in F\} \\
\text{cod}(F) &= \{x|\exists y:(y,x) \in F\}
\end{align*}
\tag{3}
\]
A token is a dynamic object of \( P \) and can be moved from one place to another place.

Definition 2: The color Petri nets is a nine tuple, i.e. \( CPN=(\Sigma;P,T;A,N,C,G,E,I) \). Here, \( \Sigma \) is a finite nonempty set of a type and the type is called a color set. \( P \) is a finite place set of CPN. \( T \) is a finite transition set of CPN. \( A \) is a finite arc set of CPN and meet the condition: \( P \cap T=P \cap A=\emptyset \). \( N \) is the
The node function of CPN and is defined as \( N:A \rightarrow (P \times T) \cup (T \times P) \). \( C \) is a color function and is defined as \( C:P \rightarrow \Sigma \). \( G \) is a guard function \( G(t) \) from \( T \) to an expression. If \( B \) is a boolean type element, the expression should satisfy: \( \forall t \in T:(\text{Type}(G(t))=B \land \text{Type}(\text{Var}(G(t)))) \subseteq \Sigma \). \( E \) is an arc function \( E(a) \) from \( A \) to an expression and meet: \( \forall a \in A:(\text{Type}(E(a))=\text{C}(p)_{\text{MS}} \land \text{Type}(\text{Var}(E(a))) \subseteq \Sigma) \). \( p \) is a place in \( N \), \( C(p)_{\text{MS}} \) is the type of a multiset that returns back to \( p \). \( I \) is an initialization function \( I(p) \) that is defined from \( P \) to a closed expression, which refers to an expression without any variables. \( I(p) \) must meet: \( \forall p \in P:(\text{Type}(I(p))=\text{C}(p)_{\text{MS}}) \). When \( I(p) \) initializes the place \( p \), the result type of its closed expression must be consistent with the type of the multiset on \( p \).

**Definition 3:** The seven-tuple representation of power IoT terminal entity model is as follows:

\[
OOPN=\{P,T;I,O,fi,fo,C\}
\]

(4)

\( P \) represents a finite place set of power IoT terminal entities such as terminal parts, status information, personnel information, occurrence events and their corresponding attribute sets. \( T \) represents a finite transition set of power IoT terminal entity activity in its lifecycle. \( I, O \) represents a finite input information set and a finite output information set of OOPN. \( fi \) and \( fo \) represents an input mapping function and an output mapping function from \( P \) to \( T \). \( C \) represents a color set, which is called an incidence matrix of OOPN. \( P, I, O \) and \( C \) describe the static entity objects and their attribute information, and \( T, fi \) and \( fo \) describe the dynamic entity activities and their change conditions. Using the Petri net theory, the above tuple can be calculated to provide the information for decision-making and process control.

### 3.2. The Modelling Procedure with OOPN

OOPN is a dynamic modeling method and the procedure of OOPN modeling power IoT terminal entity is as follows:

1. Analyze the operation process of a power IoT terminal entity.
2. Analyze the state and activity of the power IoT terminal entity.
3. Establish the OOPN model of the power IoT terminal entity operation process.
4. Construct the incidence matrix of the OOPN model.
5. Establish the objective function of the OOPN model.
6. Analyze the real effect of the OOPN model.

### 3.3. The Model Analysis of OOPN

#### 3.3.1 The Deadlock Analysis

The occurrence of deadlock in the OOPN model will lead to the suspension of service process, which will seriously affect the efficiency of power IoT terminal entity. If all active transitions and gates of each sub module in the OOPN model can be triggered under the initial identification through appropriate transitions and gates, it indicates that there is no deadlock in the sub module. Similarly, if all sub modules can be triggered, there is no deadlock in the OOPN model.

#### 3.3.2 The Conflict Analysis

The purpose of conflict analysis in the OOPN model is to find out all possible conflict events and provide the most appropriate resolution. In the OOPN model, conflicts are generally divided into two categories: input conflicts and output conflicts. When there are conflict events, the following methods can be used to solve them.

- Each conflict defines a control/decision rule so that this rule can be used as the condition for control triggering. The rules that can be adopted include: the shortest processing time, the maximum number of renewal operations, and the fewest number of renewal operations.
- Which transition to trigger or which place to use can be determined by the token color.
- Decide at random.
3.3.3 The Conservation Analysis

Conservation is another important feature of the OOPN model. If the OOPN model is not conserved, the entity state may overflow because the entity resources are limited. If the OOPN model is conserved, the entity state is safe. When there is an invariant \( p \), it is an \( n \times 1 \) nonnegative integer vector \( x \), so that \( x^T C = 0 \) (\( C \) is the incidence matrix), then the Petri net is strictly constrained. When analyzing the actual situation of a power IoT terminal entity, as long as the actual data meets the above constraint, the OOPN model is conserved and bounded.

4. The Case Study

4.1. Modeling a Power Transformer Production Process

We take the 240MVA/220kV transformer as an example of the power IoT terminal entity to analyze its production process. The production process of the transformer can be abstracted into 11 sub modules: raw material warehousing, coil winding, high-frequency welding, coil press fitting, coil drying, coil suiting, iron core manufacturing, body assembly, gas-phase drying, transformer assembly and test. The production process model of the transformer is established as shown in Figure 1.

Figure 1. The power transformer production process model based on OOPN

The detailed description of each place and transition corresponding to Figure 1 is shown in Table 1.

| Unit       | Unit Meaning                  | Place     | Place Meaning                  | Transition | Transition Meaning                      |
|------------|-------------------------------|-----------|--------------------------------|------------|-----------------------------------------|
| \( U_1 \)  | raw material warehousing      | \( P_1 \) | raw material preparation       | \( T_1 \)  | raw materials are ready                 |
| \( U_2 \)  | coil winding                  | \( P_2 \) | coil vertical winding and      | \( T_2 \)  | coil winding is completed                |
|            |                               |           | horizontal winding            |            |                                         |
| \( U_3 \)  | high frequency welding        | \( P_3 \) | high frequency welding of high | \( T_3 \)  | high frequency welding of high voltage   |
|            |                               |           | voltage coil                  |            | coil is ended                            |
| \( U_4 \)  | coil press fitting            | \( P_4 \) | coil press fit size adjustment| \( T_4 \)  | coil press fitting is completed and      |
|            |                               |           |                                |            | ready to enter the oven for drying      |
| \( U_5 \)  | coil drying                   | \( P_5 \) | the oven drying for the coil   | \( T_5 \)  | the coil is discharged and ready for    |
|            |                               |           |                                |            | phase sleeve work                       |
| \( U_6 \)  | coil suiting                  | \( P_6 \) | coil phase suiting            | \( T_6 \)  | after the coil is sleeved, it can be     |
|            |                               |           |                                |            | directly entered into the body assembly  |
|            |                               |           |                                |            | or entered into the body assembly by     |
|            |                               |           |                                |            | buffer                                   |
| \( U_7 \)  | iron core manufacturing       | \( P_7 \) | iron core preparation         | \( T_7 \)  | iron core is ready                      |
| \( U_8 \)  | body assembly                 | \( P_8 \) | body assembly                  | \( T_8 \)  | body out of furnace ready for general    |
|            |                               |           |                                |            | assembly                                |
| \( U_9 \)  | gas-phase drying              | \( P_9 \) | VPD body drying               | \( T_9 \)  | VPD body drying is finished              |
| \( U_{10} \)| transformer assembly          | \( P_{10} \)| transformer assembly         | \( T_{10} \)| the final assembly is completed and     |
|            |                               |           |                                |            | ready to enter the test hall             |
| \( U_{11} \)| testing transformer           | \( P_{11} \)| transformer testing          | \( T_{11} \)| transformer testing is completed        |
|            |                               |           |                                |            | distribute or return the winding unit for |
|            |                               |           |                                |            | rewinding                               |
| \( Buf \)  | phase set buffer unit         | \( P_{12} \)| phase set buffer             | \( T_{12} \)|                                            |
The incidence matrix corresponding to Figure 1 is shown in Table 2.

| C | T₁ | T₂ | T₃ | T₄ | T₅ | T₆ | T₇ | T₈ | T₉ | T₁₀ | U₀ |
|---|----|----|----|----|----|----|----|----|----|-----|----|
| P₁ | -1 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 1  |
| P₂ | 1  | -1 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0  |
| P₃ | 0  | 1  | -1 | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0  |
| P₄ | 0  | 0  | 1  | -1 | 0  | 0  | 0  | 0  | 0  | 0   | 0  |
| P₅ | 0  | 0  | 0  | 1  | -1 | 0  | 0  | 0  | 0  | 0   | 0  |
| P₆ | 0  | 0  | 0  | 0  | 1  | -1 | 0  | 0  | 0  | 0   | 0  |
| P₇ | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0  |
| P₈ | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1   | -1 |
| P₉ | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0  |
| P₁₀| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0  |
| Buf| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0  |

4.2. The Objective Function of the OOPN Model

According to the actual production situation of power transformer, the objective function model of power transformer capacity is established as follows:

\[
\text{Target} = \sum_{i=1}^{n} t_f \theta_i + \sum_{i=1}^{n} t_f \theta_i + \sum_{i=1}^{n} t_f \theta_i + \sum_{i=1}^{n} t_f \theta_i \times \phi(\delta)
\]

\[
f(x) = C_n^p x^{n-x}, x \in \{0, 1, \ldots, n\}
\]

\[
f(y) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(y-u)^2}{2\sigma^2}}, -\infty < y < +\infty
\]

\[
f(z) = \beta - \alpha z^{\alpha-1} e^{-z/\beta}, Z > 0
\]

\[
f(q) = a, 0 \leq q < 1
\]

\[
\phi(\delta) = 8\delta \times (1-\lambda), \delta \in \{2\}
\]

\[
k, i, o > 0, 0 < \theta, \lambda < 1
\]

Where \( S_k \) represents the number of equipment included in the production unit, \( f(x), f(y) \) and \( f(z) \) represents the distribution function of production preparation time, equipment downtime and daily maintenance time, \( \phi(\delta) \) represents the daily effective working time function of the processing station, \( \lambda \) is the leniency rate (including the leniency time for going to the bathroom, workshop exercise, drinking water, etc.), \( \delta \) is the number of shifts per day, it represents the number of hours of equipment required for the \( i \)th product, \( \theta \) Represents the proportion of the output of the \( i \)th product in the total planned output, \( \omega \) Indicates the number of product varieties.

4.3. The Production Capacity Efficiency Comparison

After improving the production process of power transformer with the OOPN model, we compared two indices before using OOPN with after using OOPN, and the improvement effects are shown in Table 3. Taking the index of annual capacity as an example, the improvement efficiency was \((93.6 - 79.5) / 79.5 = 17.74\%\).

Table 3. The effectiveness statistics of the OOPN model

| Index                 | Before using OOPN | After using OOPN | Efficiency |
|-----------------------|-------------------|------------------|------------|
| production cycle(hour)| 653.8             | 571.7            | 82.1       |
| annual capacity       | 79.5              | 93.6             | 14.1       |
5. Conclusion and Future Work
The OOPN model provides a theoretical basis and an operable method for power IoT terminal entities. This paper describes the basic definition and modeling process of OOPN and gives tentative research on OOPN-based power IoT terminal entity modeling. Many specific works need to be further studied, such as how to calculate the sub modules of the OOPN model, whether human factors need to be considered in the application of the OOPN model, and how to embed the OOPN model into an existing enterprise ERP system, etc. These problems should be deeply explored according to the actual situation so as the OOPN model can obtain widely application in the power IoT terminal entity modeling. In the future, we will improve the proposed model by introducing more modeling methods.

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