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Establishment on Evaluation Indicator System for Power System Simulation Software

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Abstract: Computer simulation has become an important means of data processing, calculation analysis, online debugging, closed loop control, fault diagnosis, condition forecasting in power system. In order to solve the problem that there is a lot of power simulation software and users of the software have difficulty in choosing the evaluation index system, this paper studies evaluation indicator system of simulation software based on analytic hierarchy process and provides support for software selection. Firstly, analyzed and summarized the structure of evaluation index system model which consists of 8 indexes, and the indexes were described; Then, create a mathematical model to calculate the weights, including judgment matrix, hierarchical ordering, consistency inspection process; Finally, calculate the evaluation index weigh according to the steps in mathematical model. The results show that posterior simulation function, software maintainability, eigenvalue analysis function, power flow calculation accuracy, these indicators have bigger impact on the power system simulation software, when selecting software these indicators should be considered. The content of this paper is the foundation of system evaluation , and it plays an important role in promoting the informatization level of power system.

Keywords: Analytic hierarchy process, comprehensive evaluation, computer simulation, indicator system, power system, simulation software.

1. INTRODUCTION

Simulation is a method which use physical or mathematical model to analog, imitate the real system and then seek the process regularity. The basic idea of simulation is to create a test simulation model that includes the main features of the system which is under study. By running on the experimental model, obtain the necessary information. Modern mathematical simulations are carried out on a computer and that is computer simulation. Computer simulation refer to use computer technology to make a dynamic lifelike imitation of the system structure, function and behavior as well as those involved in the system control initiative - human thought processes and behavior. It is a comprehensive technology based on the mathematical theory, with computer and various physical facilities for equipment tools, system model is used to analyze the actual or vision system experimental simulation [1, 2].

Using virtual reality technology, power system simulation makes industrial plant and equipment of the real world in computer virtualization and using database technology, supervisory control and data acquisition technology, operating parameters of production equipment are sent back to the virtual power system, in 3D virtual scene can be realized query management of equipment. Due to human's increasing demand for power, the modern power system, presents a large capacity units, ultrahigh pressure heavy load transmission and the trend of large area power grid interconnection. Due to the demand of safety, it cannot understand the dynamic characteristics by applying various disturbance test, so the understanding method for power system dynamic performance is the most effective through dynamic simulation. The computer simulation has become an important means for power system to improve the data processing, calculation and analysis, online debugging, working condition of closed loop control, fault diagnosis, forecast and dynamic equivalence, etc [3, 4].

With the development of computer simulation technology, aspects of power system simulation for the calculation of power system planning, scheduling, running safety and reliability and so provides strong technical support, power system simulation software has become a powerful tool to fo researching, computing of power systems. The representative domestic and international power system simulation software today [5]: BPA software and EMTP (Electromagnetic Transients Program) software that developed by BPA (Bonneville Power Administration) company; EUROSTAG software developed by EFD (Electricite de France) company and Tractebel company of Belgium; PSCAD/EM TDC (Power System Computer Aided Design/Electromagnetic Transients Program including Direct Current) software developed by Manitoba HVDC Research Center; NETOMAC (Network Torsion Machine Control) developed by Germany's Siemens; PSASP (Power System Analysis Software Package) developed by China Electric Power Research Institute; Power World developed by Power World; PSS/E (Power System Simulator / Engineering) developed by PTI (Power Technologies Inc). When power system simulation, there are

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multiple simulation software to choose from, simulation software selection is based on the content and features of the power system simulation desire, considering the characteristics and simulation software integrated indicators, and use scientific methods for proper evaluation and judgment select the most suitable process simulation software. Only with the right simulation software can we obtain accurate simulation results. Therefore, the simulation software selection and evaluation is an important task of policy makers, and is an important part of the early simulation work . In this paper, comprehensive evaluation of power system simulation software is made, and it provides support and reference for simulation software selection.

2. ESTABLISHMENT OF EVALUATION INDICATOR SYSTEM

Developing scientific, systematic and comprehensive evaluation system is the basic work of a systematic review. Using a single indicator or index has one-sidedness and subjectivity on the comprehensive evaluation of power system simulation software, is usually built index system. The whole system refers to a certain range or similar things according to certain order and internal contact together, only the scientific and reasonable evaluation index system, it may draw the science fair appraisal conclusion. In the process of building index system, the general principles should be followed to construct the index system, scientific principle, systematic principle, practical principle, comprehensive principle, the principle of unity, the principle of comparability, the evaluation method of the consistency principle; Also pay attention to the necessity of the index system of elements, in the case yet comprehensive, to minimize the number of system indicators, greater emphasis on evaluation index system function, promoting function and decision-making functions.

2.1. Indicator System Structure Model

Because the decision-making complex issues involved many indicators, and there are complex relationships between indicators, the indicators related to the principled, hierarchy, construct a hierarchical structure model index system is an effective way to solve complex problems. The usual practice is to make index into a number of levels, the upper index lower index of the dominant role played, this top-down hierarchical structure called hierarchical structure. Hierarchical structure can generally be divided into the highest level, the middle layer and the bottom. In this paper, in order to simplify the calculation, to build a two-tier hierarchical structure, the top layer is the target layer, the system's overall goal; underlying is an index layer, said a variety of measures to achieve goals, decision-making, programs and so on. Based on the analysis in the full survey, combined with results of previous studies, the index system constructed hierarchical structure model shown in Fig. (**1**).

2.2. Indicator System Description

Eight indicators in Fig. (**1**) are made a detailed description as follows:

(1) Power flow calculation accuracy. Power flow calculation is based on the operating conditions given grid structure, parameters and generators, load and other elements, etc., to determine the steady-state calculation of the various parts of the power system operating state parameters. Typically the given operating conditions the power pivot point voltage, the voltage and phase angle of the balance point of the power system and the load point. Required operating state parameter include a voltage magnitude of the power and phase of bus nodes, and each branch of the power distribution network of the power loss.

(2) Frequency-domain analysis method. With Fourier series, the non-sinusoidal periodic voltage (current) is made into a series of sinusoidal quantity of different frequencies, in accordance with the calculation method for sinusoidal AC circuit sine amount of different frequencies are solved, then the linear superposition theorem circuit overlay solution is ask, which is the basic method of non-sinusoidal periodic circuit analysis.

(3) Eigenvalue analysis function. Whether series compensated transmission system sub synchronous resonance of a kind of important method, is under the condition of small disturbance to linear system model, by solving the system coefficient matrix eigenvalues of a method to judge the stability of the system, has been widely used in the analysis of linear systems. Advantage theory is strict, accurate analysis and provide accurate vibration frequency and attenuation factor and eigenvalue sensitivity, etc. A lot of useful information.

(4) Time-domain analysis method. Refers to the control system in a certain input, output based on the time domain expression, analyze system stability, transient and steady-state performance. Because of the time-domain analysis is performed directly on the system time domain analysis method, so intuitive and time-domain analysis accurate. System time domain representation of the output of differential equations can be obtained, the transfer function can also be obtained. When the initial value is zero, are generally studied using transfer function, using an indirect transfer performance index function evaluation systems. Specific performance is delivered to the poles and zeros of the function analysis system based on the closed-loop system.

(5) Posterior simulation function. Only to ensure the validity of all the models and parameters, in order to ensure the credibility of a prior simulation results. And after only rely on experience to determine what caused the error simulation models and parameter errors and fix these models and parameters, in order to improve the effectiveness of the model and its parameters. The main purpose of the simulation is a posterior according to the error between measured data and simulation results, the reasonable judgment of error sources and related model parameters to correct and improve the effectiveness of the model and its parameters, namely, to improve the accuracy of the simulation experiment. Only through constant posterior validate simulation models and parameters in order to achieve the purpose of improving the effectiveness of the model and parameters.

(6) Software generality. Simulation software has diversity, have their own characteristics and simulation software

Table 1. Relative importance value table of scale method.

Scale Value	Meaning
1	x_i and x_j are equally important
3	x_i is slightly more important than x_j
5	x_i is significantly more important than x_j
7	x_i is strongly more important than x_j
9	x_i is extremely more important than x_j
2,4,6,8	values between the two cases
Countdown	shows the opposite case and the importance of the ratio of $a_{ij} = 1/a_{ji}$

range, a variety of simulation software focus is not the same, the results are not the same output. But in order to expand the scope of the need to consider its versatility when companies buy emulation software. The main simulation software versatility from a stable part of the data format of the physical model, language, interfaces, functions, etc. to achieve versatility by writing program, using a computer to automatically convert the data to meet the needs of a specified format emulation.

(7) Software portability. Refers to the ability of the software to other computers on a computer. In a narrow sense, refers to the portable software should be independent of the computer's hardware environment; Broadly speaking, portable software should be independent of the computer software, namely advanced standardized software, system architecture and machine-independent functions, can span machine boundaries. To consider when selecting simulation software portability index, after expanding the use of the software.

(8) Software maintainability. Refers to the maintenance personnel to maintain the degree of difficulty of the software, specifically including understanding, correct, change and improve the degree of difficulty of the software. As software applications, exposing the growing problem of software maintenance is becoming increasingly important, software maintenance is a time-consuming, consumption of energy work. By modifying the software defects and improve software performance or other attributes that make software products to adapt to the new environment, to extend the software life cycle.

3. MATHEMATICAL MODEL TO CALCULATE WEIGHTS

When use a comprehensive evaluation index system, the relative importance of the different between each indicator, the relative importance of this level of size between index called weights or weight coefficients. Different weights will come to different evaluation results, determining a reasonable weight is an important issue to build the index system. There are many ways to determine the weight, the more common are: direct judgment method, Delphi method (Delphi), set the value of statistical iterative method, adjacent index comparison, the analytic hierarchy process (AHP), multiple correlation coefficient method, principal component analysis (PCA), KLEE method, the variation coefficient method (CVM), the other statistical methods. Of these methods, and some are too subjective, some are too complex, and some less practical, combining the characteristics of the power evaluation simulation software, the choice of AHP.

AHP is the complex decision-making system hierarchical layers and the associated comparative importance of the various factors to create the model for analysis and decision-making to provide quantitative basis. AHP is particularly suitable for hard quantitative analysis of complex problems entirely, so in the area of resource allocation, optimal selection sort, policy analysis, forecasting and other conflict solving and decision-making has been widely used.

3.1. Constructing Judgment Matrix

Hierarchical analysis is the main information for each level of judging the relative importance of each index, quantified by introducing an appropriate scale, form a judgment matrix, the relative said on a level of a certain indicators, the comparison of the relative importance between the level indicators. Because it is difficult to directly determine the index of relative importance between, so in two more ways to establish judgment matrix [6, 7].

n factor associated with the upper set of indicators $x_1, x_2, \cdots, x_n$, use a_{ij} to present x_i and x_j the ratio of the impact of the indicators on the upper, $i, j = 1,2,\cdots,n$,indicators on the upper index n pairwise comparison matrix to determine:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

For ease of operation, Satty recommended value of 1-9 and a total of 17 number as the reciprocal of the scale to determine a_{ij} , Customarily referred to 9 scale method. As the relative importance of the values shown in Table **1**.

For any judgment matrix *A*, has the following properties:

$$\begin{cases} a_{ij} > 0 \\ a_{ji} = 1/a_{ij} & i, j = 1,2,\cdots,n \\ a_{ii} = 1 \end{cases} \quad (2)$$

3.2. Hierarchical Ordering

Hierarchy, refers to the biggest feature matrix is calculated by using linear algebra knowledge value and corresponding eigenvector, normalized weight vectors, the influence degree of each evaluation index of the level of a hierarchy of goals. Usually have a square root method and sum product method, then using the sum product method.

The basic process and product method is first to each column vector normalization judgment matrix, and then for each row vector of the new matrix of the arithmetic average, get the weight vector. Mathematical derivation follows the process model [8-10]:

Matrix *A* is consistency matrix, thereby gaining the right to:

$$a_{ij} = w_i / w_j \quad (3)$$

That is:

$$w_i = a_{ij} w_j \quad (4)$$

Both sides make summation of *j*:

$$nw_i = \sum_{j=1}^{n} \left(a_{ij} w_j \right) \quad (5)$$

That is:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \left(a_{ij} w_j \right) \quad (6)$$

For formula (4) on both sides make summation of *i*:

$$\sum_{i=1}^{n} w_i = w_j \sum_{i=1}^{n} a_{ij} \quad (7)$$

Because $\sum_{i=1}^{n} w_i = 1$, then:

$$w_j = 1 \Big/ \sum_{i=1}^{n} a_{ij} \quad (8)$$

Bring equation (8) into equation (6): get:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \left(a_{ij} \Big/ \sum_{i=1}^{n} a_{ij} \right) \quad (9)$$

Set:

$$b_{ij} = a_{ij} \Big/ \sum_{i=1}^{n} a_{ij} \quad (10)$$

Equation (9) can be simplified to:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} b_{ij} \quad (11)$$

3.3. Consistency Check

In constructing judgment matrix process, does not require judgment matrix with consistency, this is the understanding of the affairs of the objective complexity and diversity of the decision, scaling also determines the judgment matrix is hard to satisfy the consistency. But when solving practical problems, must ask judgment matrix with consistency. Appear, for example, a is more important than b, b is more important than c, and is more important than b, c is perverse, weight is calculated by using this kind of judgment matrix deviation consistency, reliability degree is low, may be wrong evaluation results are obtained. Therefore, must be consistency of judgment matrix. Consistency retrieval [11-13] according to the following steps..

Step 1, calculate judgment matrix, the largest eigenvalue of A

Calculated as follows:

$$\lambda_{\max} = \frac{1}{n} \sum_{i-1}^{n} \frac{(AW)_i}{w_i} \quad (12)$$

$(AW)_i$ is the *first i* component of AW.

Step 2, calculate CI (Consistency Index).

In deciding judgment matrix coefficients, requiring expert pairwise contrasts exist between consistency score is calculated as:

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (13)$$

Step 3, calculate *RI* (Random Index).

R.I. is consistency metrics, algorithms are described as follows [14]:

(1) In 17 the number of $1,2,\cdots,9$ and $1/2,1/3,\cdots,1/9$, according to average probability $1/17$, evenly extract n^2, making K-order pairwise comparison matrix form B;

(2) Calculate the consistency index matrix B CI;

(3) Repeat run multiple times to generate multiple random k-order judgment matrix B_k, calculated for each of the consistency index, an average, namely:

$$RI = \frac{1}{n} \sum_{k=1}^{m} CI_k \quad (14)$$

According to the literature [15], *RI* is calculated result shown in Table **2**.

Step 4, calculate CR (Consistency Index).

For comparison matrix than average random consistency index of consistency it is called the index of the same order as their consistency ratio. The formula is:

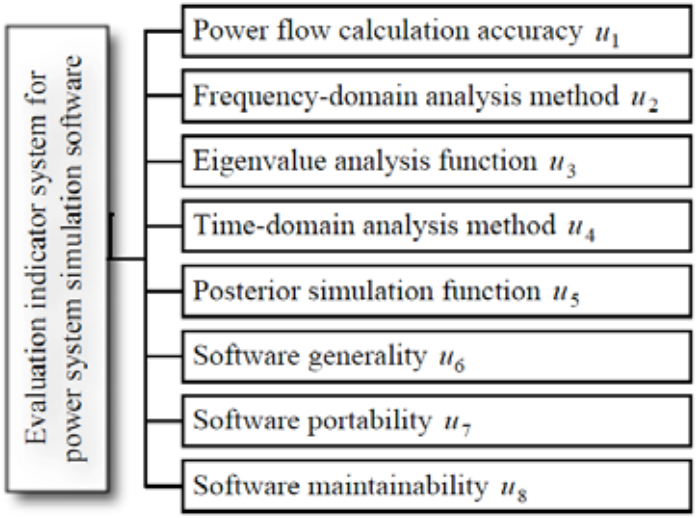

Fig. (1). Hierarchical structure model of evaluation indicator system.

$$CR = \frac{CI}{RI} \tag{15}$$

when $CR \le 0.1$, Considered inconsistent with the degree of judgment matrix A is within the allowable range, with a consistency that can be used as a feature vector whose weight vector. Otherwise, it does not have the consistency, the need for re-judgment matrix A paired comparison, re-construction of judgment matrix.

4. PROCESS AND RESULT OF CALCULATE WEIGHTS

According to the mathematical model to calculate the weight calculation evaluation index weights.

4.1. Constructing Judgment Matrix

According to the formula (1) and Equation (2), in Fig. (**1**), make the pairwise comparison of each indicator of the result of the judgment matrix constructed as follows:

$$A = \begin{bmatrix} 1 & 5 & 1/2 & 3 & 1/4 & 2 & 4 & 1/3 \\ 1/5 & 1 & 1/6 & 1/3 & 1/8 & 1/4 & 1/2 & 1/7 \\ 2 & 6 & 1 & 4 & 1/3 & 3 & 5 & 1/2 \\ 1/3 & 3 & 1/4 & 1 & 1/6 & 1/2 & 2 & 1/5 \\ 4 & 8 & 3 & 6 & 1 & 5 & 7 & 2 \\ 1/2 & 4 & 1/3 & 2 & 1/5 & 1 & 3 & 1/4 \\ 1/4 & 2 & 1/5 & 1/2 & 1/7 & 1/3 & 1 & 1/6 \\ 3 & 7 & 2 & 5 & 1/2 & 4 & 6 & 1 \end{bmatrix}$$

4.2. Hierarchical Ordering

For comparison matrix *A*, using the formula (10) for each column of data normalization get matrix *B*:

$$B = \begin{bmatrix} 0.089 & 0.139 & 0.067 & 0.137 & 0.092 & 0.124 & 0.140 & 0.073 \\ 0.018 & 0.028 & 0.022 & 0.015 & 0.046 & 0.016 & 0.088 & 0.031 \\ 0.177 & 0.167 & 0.134 & 0.183 & 0.122 & 0.187 & 0.175 & 0.109 \\ 0.030 & 0.083 & 0.034 & 0.046 & 0.061 & 0.031 & 0.070 & 0.044 \\ 0.355 & 0.222 & 0.403 & 0.275 & 0.367 & 0.311 & 0.246 & 0.435 \\ 0.044 & 0.111 & 0.045 & 0.092 & 0.073 & 0.062 & 0.105 & 0.054 \\ 0.022 & 0.055 & 0.027 & 0.023 & 0.052 & 0.021 & 0.035 & 0.036 \\ 0.266 & 0.194 & 0.268 & 0.229 & 0.184 & 0.249 & 0.211 & 0.218 \end{bmatrix}$$

For the matrix B, using equation (11) can be calculated:

$$w_1 = \begin{pmatrix} 0.089 + 0.139 + 0.067 + 0.137 \\ +0.092 + 0.124 + 0.140 + 0.073 \end{pmatrix} \Big/ 8 = 0.108$$

so, "Power flow calculation accuracy u_1" the weight of index for $w_1 = 0.108$。

Similarly, the results of its indicators are as follows:

"Frequency-domain analysis method u_2" the weight of index for $w_2 = 0.033$.

"Eigenvalue analysis function u_3" the weight of index for $w_3 = 0.152$.

"Time-domain analysis method u_4" the weight of index for $w_4 = 0.050$.

"Posterior simulation function u_5" the weight of index for $w_5 = 0.324$.

"Software generality u_6" the weight of index for $w_6 = 0.073$.

"Software portability u_7" the weight of index for $w_7 = 0.034$.

"Software maintainability u_8" the weight of index for $w_8 = 0.226$.

Index weight composed of eight evaluation weight vectors is as follows:

Table 2. Mean random consistency index.

Order	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.45
Order	10	11	12	13	14	15	16	17	18
RI	1.49	1.51	1.54	1.56	1.57	1.58	1.59	1.60	1.61
Order	19	20	21	22	23	24	25	26	27
RI	1.62	1.63	1.64	1.64	1.65	1.65	1.66	1.66	1.67

$$W = (w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8,)^T$$
$$= (0.108, 0.033, 0.152, 0.050, 0.324, 0.073, 0.034, 0.226)^T$$

4.3. Consistency Check

Step 1, calculate judgment matrix, the largest eigenvalue of A

$$AW = \begin{bmatrix} 1 & 5 & 1/2 & 3 & 1/4 & 2 & 4 & 1/3 \\ 1/5 & 1 & 1/6 & 1/3 & 1/8 & 1/4 & 1/2 & 1/7 \\ 2 & 6 & 1 & 4 & 1/3 & 3 & 5 & 1/2 \\ 1/3 & 3 & 1/4 & 1 & 1/6 & 1/2 & 2 & 1/5 \\ 4 & 8 & 3 & 6 & 1 & 5 & 7 & 2 \\ 1/2 & 4 & 1/3 & 2 & 1/5 & 1 & 3 & 1/4 \\ 1/4 & 2 & 1/5 & 1/2 & 1/7 & 1/3 & 1 & 1/6 \\ 3 & 7 & 2 & 5 & 1/2 & 4 & 6 & 1 \end{bmatrix} \begin{bmatrix} 0.108 \\ 0.033 \\ 0.152 \\ 0.050 \\ 0.324 \\ 0.073 \\ 0.034 \\ 0.226 \end{bmatrix}$$

$$= \begin{bmatrix} 0.937 & 0.205 & 1.376 & 0.427 & 2.831 & 0.633 & 0.291 & 1.993 \end{bmatrix}^T$$

According to equation (12) calculated as follows:

$$\lambda_{\max} = \frac{1}{8}\left(\frac{0.937}{0.108} + \frac{0.205}{0.033} + \frac{1.376}{0.152} + \frac{0.427}{0.050} + \frac{2.831}{0.324} + \frac{0.633}{0.073} + \frac{0.291}{0.034} + \frac{1.993}{0.226} \right) = 8.408$$

Step 2, calculate the consistency index CI

In this example $n = 8$, according to the formula (13), calculated as follows:

$$CI = \frac{8.408 - 8}{8 - 1} = 0.0583$$

Step 3, to determine the average random consistency index RI

When $n = 8$, look-up Table **2** and then get $RI = 1.41$

Step 4, calculate the consistency ratio CR

According to equation (15), calculated as follows:

$$CR = \frac{0.0583}{1.41} = 0.0413$$

When $CR = 0.0413 \le 0.1$, determine the extent of the inconsistency matrix A within the allowable range, to meet compliance requirements.

CONCLUSION

Computer simulation has repeat-ability, effectiveness, economy, security, reliability, flexibility, practicality and other characteristics, and it has become a means for many complex systems analysis, design, testing, evaluation work essential. Current power system simulation software has been widely used in power system design, operation and other departments. Analytic Hierarchy Process is a practical and multi-criteria decision making method, the scheduling problem under single criterion is the basis of the analytic hierarchy process, and the key to solving this problem is by pairwise comparison judgment matrix elements to get a set of weights. Sum and product method as a kind of effective sorting method, has the advantages of sequence, compatibility, symmetry, translation in-variance, etc. the evaluation index system and weight which is based on the analytic hierarchy process , is not only the foundation of system evaluation, but also a reference standard when select simulation software .

Eight indicators in Fig. (**1**), according to the importance of the program as follows: Posterior simulation function (u_5, 32.4%), Software maintainability (u_8, 22.6%), Eigenvalue analysis function (u_3, 15.2%), Power flow calculation accuracy (u_1, 10.8%), Software generality (u_6, 7.3%), Time-domain analysis method (u_4, 5%), Software portability (u_7, 3.4%), Frequency-domain analysis method (u_2, 3.3%). 4 indicators are relatively important considering the selection of the power system simulation software (u_5, u_8, u_3, u_1), because the degree of importance of these four indicators accounted for 81%.

Using AHP to calculate the weight, the advantage is affecting the degree of quantitative, the result is very clear, clear. Defect is it needs consistency check [16]. Practical application to construct judgment matrix objectively, in order to make weight value is closer to the actual. In this paper, the research content as evaluation index of empowerment provides a new way, convenience of application, scientific and reasonable, has a broad application prospect.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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