Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

Laboratory of Electric Power Supply-Demand by Intelligent Engineering

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***Abstract*— Electricity demand is depend closely with national economic growth since the all most economical activities have to use electricity. So, it is necessary to study economic growth for forecasting electricity demand and balancing electric power supply-demand There are many semi-structured and unstructured problems in studying electric power supply-demand, which are very difficult to be solved by the traditional methods. In this paper, a laboratory of power supply-demand based on intelligent engineering is developed to do the national policy study and simulate economic operating for analyzing electricity supply-demand. It is in the closed-up model as "forecast - early warning - intelligent simulation experiment - expert discussion - forecast". The main functions of the laboratory and their features are suitable for policymakers to see what will be happed on economic operation and electricity demand with some national policies on promoting economic growth and energy efficiency An experiment about policy simulation is given to show how to use the laboratory. It has been used in 31 area and provincial electric power grids under State Grid Co. of China. The applications have showed that it is a useful tool to do policy analysis, national economic-energy simulation, and energy efficiency for both power supply and demand.**

***Keywords*—Intelligent engineering, Generalized model, Soft-science laboratory, Electricity demand, Economic simulation**

I. INTRODUCTION

It is clear that there is a closed relationship between electricity consumption and economic growth[1] since all most the economic activities have to use electricity It can see that electricity is the fundamental energy resource of GDP. On the other hand, the national policy on economy has great influence on electric power supply-demand. Since the growth of GDP is fast in China and so many uncertainties affect electricity demand, it is very difficult to forecast the electricity demand in high accuracy, and it is also difficult to do power planning. Then, it was in power surplus in some years and power shortage in other years in China in the last three decades. However, studying relationship between electricity demand and economic growth, forecasting economic growth and electricity demand, planning for generation and transmission network, and ensuring power development meet to economic development are very complex system issues, which includes not only some semi-structured problems but also some unstructured problems, such as simulating policy influence on electricity demand. Fortunately, Artificial Intelligence (AI), Neural Networks (NN), Fuzzy Systems (FS), and HWME (hall for workshop of meta-synthetic engineering) have been used to provide the way to model these complex systems. However, the techniques are performing with advantages and limitations, respectively. Intelligent Engineering(IE) [2] [3] combines all of the techniques together to share the advantages and avoids the limitations in modeling complex systems.

In this paper, the concept of IE will be briefly introduced in section 2 Based on theory of intelligent engineering, a laboratory of electric power supply-demand has been constructed with the "forecast - early warning - intelligent simulation experiment - expert discussion - forecast" closed-loop model in section 3. A case study has been shown the policy experiment in section 4

II. INTELLIGENT ENGINEERING

A. Intelligent Engineering

The fundamental of intelligent engineering theory has been studied in literature [2, 3] as follows.

Definition 1. Intelligent path P is a set of (fuzzy) relations, (fuzzy) mappings, transformations and all the ways between the start state set S_0 and destination state set S_n. It can be in the form as $P: S_0 \to S_n$ (1)

Definition 2. Let $d \in S_n$ and $s \in S_0$, P is a set of intelligent path between S_0 and S_n. Then, it is in the form as $d = IP(s)$ (2)

The formula (2) is called as intelligent equation.

Definition 3. Intelligent space is defined as $I = (P, S)$.

where S is the set of states, P is the set of intelligent path between S_0 and S_n, S_0 and S_n are subset of S.

Definition 4. A problem B is defined as

$$B = (S_0, S_n, PB) \quad (3)$$

where S_0 is a set of start states, S_n is a set of destination states, PB is a set of the intelligent path between S_0 and S_n and it is a subset of P in intelligent space I, i.e.,

$$PB \subset P \tag{4}$$

Definition 5. A α-smart solution for the problem B is defined as $SL(\alpha)$, if there is a fuzzy set fp in PB

$$fP : PB \to [0,1] \tag{5}$$

and $$SL(\alpha) = \{x \mid \mu_{fp}(x) \geq \alpha, x \in PB\} \tag{6}$$

where $\alpha \in [0,1]$.

Intelligent engineering is the extension and development of system engineering[4] It not only inherits analyzing and solving problem methods, but also introduces artificial intelligence, intelligent computing, uncertainty theory, multi-agent modeling and so on. Intelligent engineering provides a methodology to study the evolution of complex systems. To sum up, intelligent engineering is the combination of system engineering, computer science, artificial intelligence and other advanced subjects.

Methodology of intelligent engineering is shown in Figure 1, it expands mathematical model to generalized model, state space to intelligent space, and state-transition matrix to intelligent path. There are three illation modes in intelligent space:

- $B1$: from known initial state and known intelligent path to search target state $(S_0, PB) \to S_n$,
- $B2$: from known initial state and known target state to search intelligent path $(S_0, S_n) \to PB$,
- $B3$: from known target state and known intelligent path to verify initial state $(PB, S_n) \to S_0$.

By intelligent engineering, the forecasting, scenario analysis and planning can be modeled as problem $B1$, the strategy problem can be modeled as problem $B2$, and the reviewing history state can be modeled as problem $B3$.

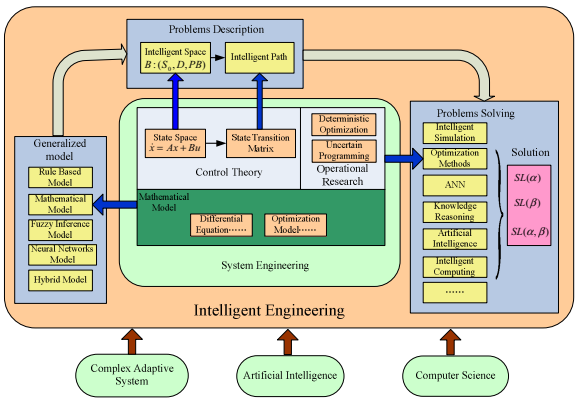

Figure 1. Methodology of intelligent engineering

B. Generalized Model

Complex system has characteristics of nonlinearity, high dimension, uncertainty, unascertained, and so on. It is not enough to descript and analyze all problems by using simple mathematical model, so, we proposed generalized model. There are five different kinds of the models in the IE as follows:

1) Mathematical Model

Mathematical model can be expressed by explicit formula (refer to the use of the expression of dominant function), it can quantitatively describe the static characteristics and dynamic process of things, and it can achieve the quantitative analysis and calculation. For example, differential equation, state equation, econometric model.

2) Rule Based Model

Rule based model can describe qualitative knowledge and experience knowledge in the form of rules. Using the model, we can carry out qualitative analysis and logical reasoning to solve the problem. Knowledge model includes fuzzy inference knowledge, knowledge of neural network training, and so on.

3) Fuzzy Inference Model

It is he model with fuzzy rules and fuzzy inference. It starts from fuzzy variables and get results by fuzzy inference. There are so many successful applications in complex problems with fuzzy factors.

4) Neural Networks Model

Neural networks have been used widely in solving the problem which is difficult to be modeled in mathematical form. It is a kind of model without mathematical formulations.

5) Hybrid Model

Hybrid model is the combination of the above-mentioned model, and the agent model is one of the hybrid models which will has a bright future in solving complex problems.

III. Laboratory of Electric Power Supply-Demand

A. Principles of the Laboratory

As a soft-science laboratory, theoretical basis of the laboratory includes the theories of macroeconomics, experimental economics, econometrics, theories of analysis and forecast of electric power supply and demand, and theory of early-warning. It synthetically applies information technologies, intelligent engineering and meta-synthesis, and is used to forecast the growth of economy, energy and electric power demand, analyze the relationships of electricity demand and economic growth, and warning unbalance of power supply-demand.

The principles of laboratory are shown as figure 2. Before the forecast, analysis of macro economy, electric power supply and electricity demand, and relationship of power and economy should be carried out. Based on that, power supply and demand can be forecasted according to the scenarios of economic growth. At the same time, the policy influences on economy and electricity demand can be simulated by using Computable General Equilibrium (CGE) and Multi-agent model. Then, forecasting results of power supply and demand are sent to HWME, early warning, and balance of power supply-demand

module. Finally, some policy advices are put forward according to results of early warning, balance of power supply-demand, and experts views. Some financial policies and monetary policies can be adjusted by using intelligent simulation experiment and CGE model. The forecast of electric power supply and demand can be adjusted in the loop "forecast - early warning - intelligent simulation experiment - expert discussion - forecast".

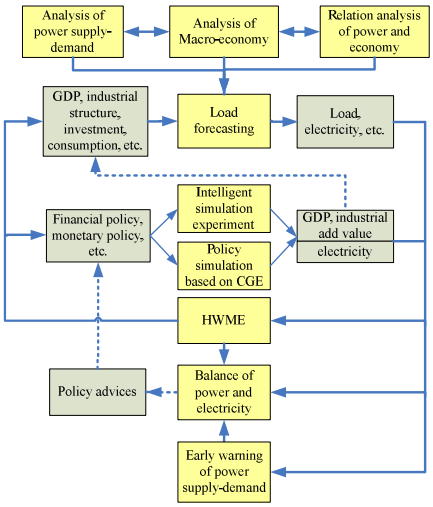

Figure 2. Principles of the Laboratory

B. Architecture of the Laboratory

The way of layered and module design has been used in the laboratory. It is consisted of fundamental hardware platform, data platform, supporting tools platform and application platform The structure of the laboratory is shown as Figure 3.

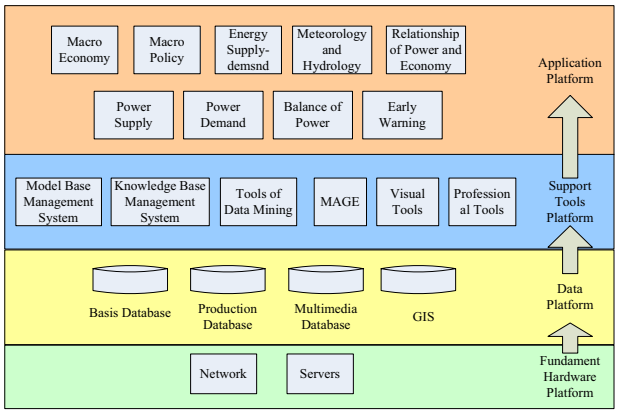

Figure 3. Structure of the laboratory

C. Functions of the Laboratory

There are nine study objects in the Laboratory, such as macro-economy and policies, energy demand, meteorology and hydrology, studying of the relationships between electricity and economy, power supply and demand, the balance of power supply and demand, and early-warning on unbalance of power supply and demand. It provides six kinds of analysis tools, such as analysis, forecast, early-warning, intelligent simulating experiment, deepening discussion and meta-synthesis, and geography information system.

1) Aanalysis of national economy

Main functions of macro economy operational analysis are to analyze the history, present and future development trend of macro-economy (such as GDP, Investment, Consumption, Export, Output and price of main products),which is the basis of the analysis and forecast of power supply and demand. In the module, monthly macroeconomic model and mid-to-long term macroeconomic model were developed. Using monthly macroeconomic model, we can not only dynamically analyze short-term economic development, but also carry out sensitivity analysis of economic variables. Using macroeconomic mid-long-term model, we can do scenario analysis of long-term economic development.

2) Policies browsing and querying

Policies browsing and querying would analyze varieties of economic policies, energy and power and relative laws and regulations published by the government, which mainly consist of macro policies, financial policies, monetary policies, industrial policies, energy policies, environmental protection policies, foreign trade policies, laws and regulations, etc. Using the module, we could be acquainted with the policies published, which is undoubted to support the policy simulation analysis.

3) Analysis on energy supply and demand

Functions of analysis energy supply and demand are to analyze the national and regional energy production and consumption. In the module, the relationship between energy consumption and power consumption can be analyzed.

4) Analysis on meteorology and hydrology

Meteorology and hydrology analysis is the foundation for analyzing the influence of meteorology and hydrology on power supply and demand. In this Module, we could analyze the factors of meteorology and hydrology which influence power supply and demand, such as temperatures in key cities, river and reservoir inflows, and so on.

5) Analysis on relationships between power and economy

The functions of the module are to analyze the relationships between power and economy which are consisting of power elasticity coefficient, and electricity intensity. It can analyze structural factors and technical factors which influence the electricity intensity based on structural decomposition model.

6) Analysis and forecst on power supply and demand

Analysis and forecast on power supply and demand is the significant function of the laboratory. It includes power supply and power demand. The functions of power supply analysis and forecast are to analyze national and regional power generation capacity, new installed and retired capacity, the change of generation unit utilization hours, and forecast total capacity based on the planning of the new installed and retired capacity. The functions of power demand analysis and forecast are to analyze and forecast national and regional power demand which include total social power consumption, industrial power consumption, residential power consumption, etc. In the module, many models of analysis and forecast are built, including short-term models and middle-long-term models.

7) Balance of power supply and demand

Balance of power supply and demand analysis is the key problem in the future development. Functions of the module are consisting of the analysis on power supply and demand balance situation in national, regional and provincial grid level. In the module, the actual reserve ratio, generation unit utilization hours, maximal power shortage or surplus can be calculated for each grid.

8) Early-warning on power supply and demand

Early-warning on power supply and demand is one of important functions in the laboratory. In the module, indexes of power supply and demand, power prosperity indexes are designed. Indexes of power supply and demand are separated into annual index and quarterly index. Annual power supply and demand index can be used in the early warning of the balance of national and regional power supply and demand in each year, while quarterly index can be used in each quarter.

9) Policies simulation experiments

Power demand has a close relationship with economic development, while economic growth rate, economic structure and macro policies could influence power demand. In this module, policies simulation experiments can be carried out by using computable general equilibrium (CGE) and multi-agent model. The influences of economic policies on economic development and power demand can be simulated. By using agent model, we can analyze the influences of residential consumption, government expenditure, import and export on power consumption. By using CGE model, we can analyze the influences of investment, consumption, imports and exports, exchange rate and tax policies on economy and power supply and demand.

10) Meta-Synthesis discussion

Power supply and demand belongs to typical complex systematic issues. It not only consists of generation, supply and demand of power, but also relates to various systems such as macro economy, energy production and transportation, meteorology and hydrology, and so on. There is large difficulty to model the complex system by traditional model. Therefore, it is essential to adopt scientific and effective methods. Qian Xuesen, one of Chinese scientists, proposed Meta-synthesis method. It can integrate and utilize the advantages of three systems including experts, computers, information and knowledge to solve the complex systematic issues [5]. In the module, many qualitative problems related with power supply and demand can be solved by using the Meta-synthesis method.

IV. EXPERIMENT CASE STUDIES

The laboratory of power supply-demand research is very complex computer system, and provides a great deal of data and simulation model. In 2008, with the development of the financial crisis, the export growth of China had dropped dramatically, which have significant influences on economic development and electricity demand, and the influences will continue in 2009 For defeating financial crisis, China implements some regulation policies to simulating domestic consumption, such as China's home appliance subsidy program. In intelligent space, the process of the analysis of export growth decline and regulation policies can be expressed as problem $B1$, namely, we know initial state and scenarios of possible (intelligent path PB), and simulate target state. As case, we designed the following experiments, and the experiment process includes scenario designing, parameter setting, running, and result showing.

A. Experiment 1: Impact of export growth decline in 2008

Question: the world financial crisis has affected growth of GDP and electricity demand by export growth decline. What they were in quantitative analysis?

Basic scenarios: It is assumed that the world financial crisis were no happen, China's export growth rate in 2008 maintains the level in 2007 as 25.7%.

Practical scenarios: Export growth rate is 17.2% in 2008.

Difference of the results between two scenarios is influence on economic growth and electricity demand because of world financial crisis. The simulation shows that GDP growth rate decreases 2.53% and total electricity consumption growth rate decreases 3.44%, value-added growth rate of primary industry decreases 1.47%, value-added growth rate of secondary industry decreases 3.46%, and value-added growth rate of tertiary industry is decreases 1.71%, electricity consumption growth rate of primary industry, secondary industry, tertiary industry decrease 1.55%, 3.91%, 2.13%, respectively(Fig.4) due to world financial crisis.

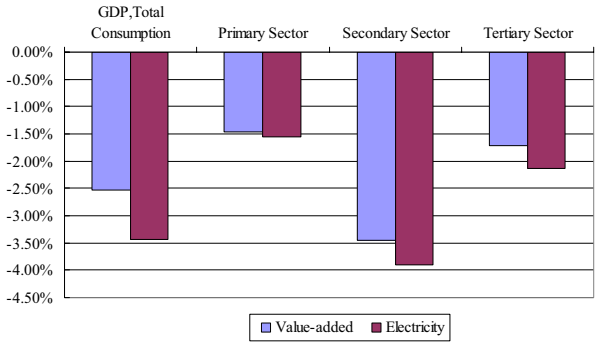

Figure 4. Impact on value-added and electricity of industries of decreased export in 2008

B. Experiment 2:Impact of China's home appliance subsidy program in 2009

Question: in Feb. 2009, Chinese government had decided to implements home appliance subsidy program to simulating domestic consumption. It is clear that the measure will pull the growth of GDP and electricity demand. What they will be in quantitative analysis?

Parameter setting: from February 2009, home appliance subsidy program for rural areas was implemented on a national scale. It is evaluated that 104 million yuan subsidy will drive 800 million yuan direct consumption of home appliance. From May 2009, home appliance old for new program for urban areas was implemented on Beijing, Shanghai, Tianjin, and so on. In 2009, about 20 million yuan subsidy will drive 200

million yuan direct consumption of home appliance. Considering two kinds subsidy, more than 1000 million yuan will be driveded to buy home appliance.

The results of the measures are shown in Fig.5 that GDP growth will increases 0.31% and total electricity consumption growth will increases 0.55%, value-added growth rate of primary industry will increases 0.08%, value-added growth rate of secondary industry will increases 0.52%, and value-added growth rate of tertiary industry will increases 0.21%, electricity consumption growth of primary industry, secondary industry, tertiary industry will increase 0.10%, 0.63%, 0.25%, respectively

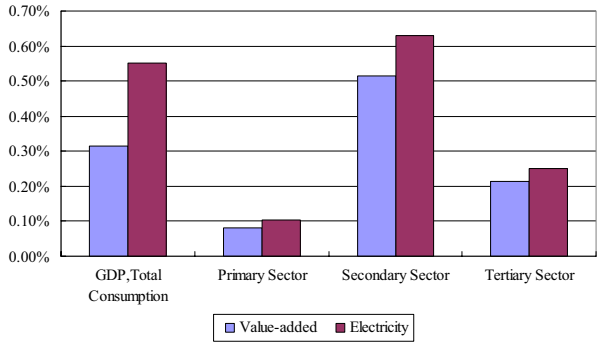

Figure 5. Impact on value-added and electricity of industries of China's home appliance subsidy program

V. CONCLUSIONS

Electric power supply and electricity demand are influenced by economic growth, national policy, energy and environment, meteorology and hydrology, etc. and then the power supply-demand researches are quite complex system issues, which include many semi-structured and unstructured problems. It is impossible to get very good results since there are lots factors and uncertainties. Intelligent engineering is a methodology for solving complex issues which difficult to be modeled in mathematics. In the paper, intelligent engineering is introduced, and it shares the theory and technique of artificial intelligent, soft computing, uncertain theory, and multi-agent system. Based on intelligent engineering, the laboratory of power supply-demand research is established and "forecast - early warning - intelligent simulation experiment - expert discussion - forecast" closed-loop research process is proposed. In the laboratory, there are a lot of generalized models for analysis and forecasting, users can focus on analysis of specific simulation task, and simply set up parameter for scenarios simulation. The laboratory can be the platform for policy studying, economic operating, electricity demand forecasting, and electric power supply-demand analyzing. A few experiments were designed for analyzing impact on economy and power demand of decreased export in 2008 and China's home appliance subsidy program in 2009 in China It has been used in 26 provincial grids and 5 area grids in State Grid Co. of China(SGCC). The electricity supply is around 2123TWh for more than 1 billion people by SGCC in 2008. The laboratory has been a useful tool in SGCC

ACKNOWLEDGMENT

The authors would like to extend our appreciation to SGCC to sponsor the project and all member of the project team for their hard work.

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