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Study on Smart Grid System Based on System Dynamics

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Abstract

Smart Grid is a large complex system, involving generation, transmission, distribution and delivery of four links. This paper analyzes the structure of the smart grid system in depth with a combination of qualitative and quantitative research approach. Then it explains state variables, rate variables and constants in the development of smart grid system under the Vensim software environment and analyzes subsystems causal feedback relationship in a macro point of view. Finally, this paper analyzes the simulation on the amount of funding and professionals in the smart grid system dynamics flow diagram after inputting DYNAMO language equations. The simulation analysis shows that the development of the smart grid should focus on training professionals. Professional talent is a source of strength in the smart grid development. At the same time, we should also pay attention to industrial policy related to the smart grid and seek break under the guidance of policy.

Keywords: s*ystem dynamics, smart grid system, feedback, countermeasures*

1. Introduction

Nowadays, the traditional State Grid transfers to the Intelligent Network and the coordination demand of electricity generation, transmission, distribution and use is very high under the background of complex power system and deepening power reform. Smart Grid is a new intelligent service network characterized with clean, efficient, safe and reliable operating system. It can be built by the latest information technology combined with various electrical infrastructures. It can improve energy efficiency, the safety and reliability of the power supply and reduce impacts of environment, power loss of the transmission. And the Real-time control technology can discover and eliminate hidden faults rapidly and improve the reliability of grid operation at the same time [2].There are multiple feedback loops in smart grid systems, complex interactions and dependencies among various elements of its subsystems. The behaviors of system are dynamic, complex and nonlinear. So it is really hard to conduct research on the Smart Grid system with human’s experience and judgment or traditional management science method.

This paper adopts system dynamics approach, using a combination method of qualitative and quantitative analysis to analyze structural features and operational mechanism of Smart Grid, describing the interaction and feedback between the various subsystems, thus providing a scientific basis for correct decision.

1.1. Structural features of Smart Grid

Smart Grid is a highly intelligent network based on physical grid. It integrates the generation, transmission, distribution and use into one internet by full use of advanced sensor measurement technology, communications technology, information technology, computer technology, control technology, new energy technologies. It can meet user demand for electricity and environmental constraints, optimize resource allocation, ensure safety, reliability and economy in the power supply, adapt to the market development of electric power for the purpose of reliable, economical, clean power supply and value-added services [3].

General speaking, Smart Grid’s constructions need a large-scale funding, technical team and effective demand for support. And the applications of Smart Grid system are constrained and influenced by many factors. For example, business-oriented applications

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determined by the industrial structure, industrial technology, the type of market, economy, business conditions etc. Services provided for community subject to market size and technical means [4-6] and so on.

Smart Grid system has five parts, including data collection, data transmission, information integration, analysis & optimization and information show [7].

2. Analysis on Development of Smart Grid by System Dynamics

2.1. System Dynamics Analysis

System Dynamic, SD for short, is a discipline analyzing feedback systems, created by MIT Professor Forrest in 1956 and applied mainly for the field of management science initially [13]. System Dynamics, a computer simulation method based on feedback theory, is used to analyze the problems of complex system, communicate the natural sciences and social sciences. It analyzes the system structure of information feedback, the dynamic relationship between function and behavior, causal relationship and structure model through the computer simulation techniques such as Vensim etc. And it's an extremely effective understanding and modeling tool, focusing on those dynamics problems stem from the feedback mechanism, to solve the higher order, nonlinear and time-varying multi-feedback system [13-15].

2.2. Causality Analysis

In Smart Grid systems, government action includes making policies, guiding and supporting grid companies, macro-control, formulating development strategy of Smart Grid and so on. The guidance and support of government will strengthen the development of Smart Grid Company, and in turn, government departments will fade out of this action with the increasing research capacity of Smart Grid Company. At the same time, the government shifted its focus to macro-control and strategic research.

There are clear positive correlations between network equipment resources subsystem, environment subsystem, power companies subsystem, the agency subsystem. Smart Grid will facilitate the above daily operating subsystems.

Causal relationships between the various subsystems are shown in Figure 1 [16, 17].

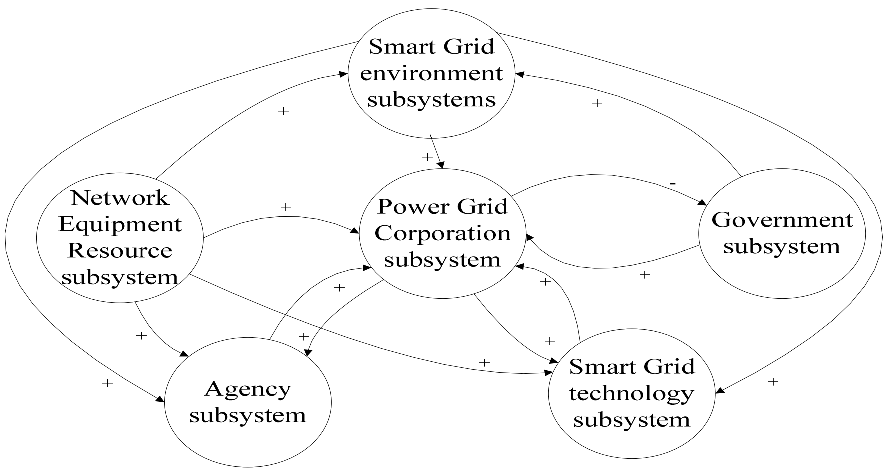

Figure 1. Smart grid system causality diagram

2.3. Feedback Loop Analysis

Feedback loop in the system dynamic model reveals the reason why the system state changes that the feedback structure. Seen from the above analysis, feedback loop in the Smart Grid system contains environment subsystem, network equipment resource subsystem, power corporate subsystem, government subsystem, agency subsystem, Smart Grid technology subsystem six [18]. Detailed analyses were as follows.

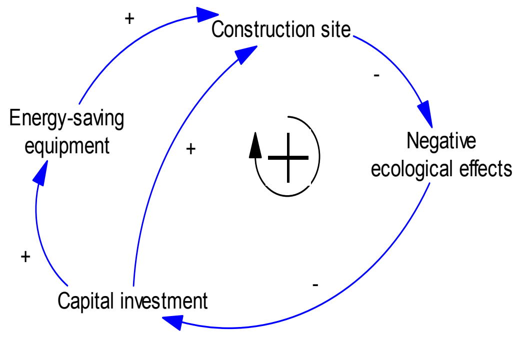

Figure 2. Environment subsystem feedback

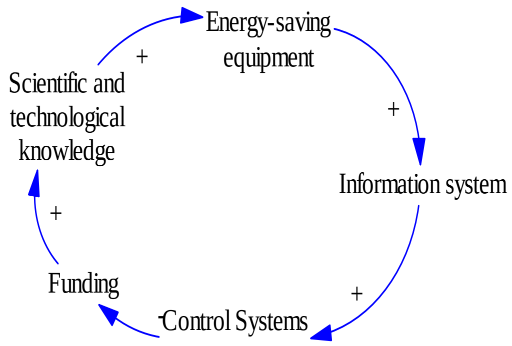

Figure 3. Technology subsystem feedback

Environment subsystem: Environment subsystem in Smart Grid is an important operation guarantee. Its ultimate aim is to reduce resource consumption, electricity production and transportation pollution and the land area occupied, improve the efficiency of grid operation and grid security by the technical improvements in the production, transport and client side [18], realize the coordinated development of Smart Grid and the environment.

Technology subsystem: Technology subsystem in Smart Grid is composed of energy-saving equipment, information system, control systems, etc. Power Grid Corporation can improve operational efficiency and stability of the grid by creating new energy-saving equipment. Update of energy-saving equipment will cause the transformation of information system. Portal system allows the Smart Grid to get data from multiple sources, making the processed information visually presented to the client. Information system transformation will also drive the development of control system, reducing the use of human resources in the production, operation and maintenance aspects. The management of Smart Grid can be improved by intelligent control system [19].

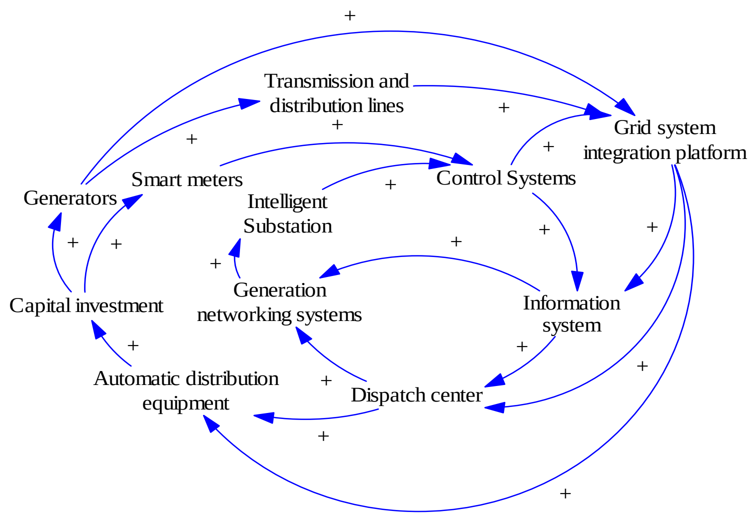

Figure 4. Equipment resource subsystem feedback

Equipment resource subsystem: Equipment resources subsystem is the core of Smart Grid, and the relationship between the elements is also the most complex. Generators, smart meters, smart substations, transmission and distribution lines, control systems and networked power generation systems are positive feedback to the integration platform of the grid system. Renovation and expansion of generators will inevitably lead to the transformation and upgrading of transmission and distribution lines. And the challenge, long-distance UHV transmission technology, has been compromised by our country [20]. Smart meters upgrading, smart substations upgrading, generators upgrading are often carried out simultaneously, and positive feedback to the control system and integration platform. Conversely, the development of integration platform requires information system, dispatch centers, networked power generation to coordinate with each other. The equipment resource subsystem formed a closed loop around the positive feedback.

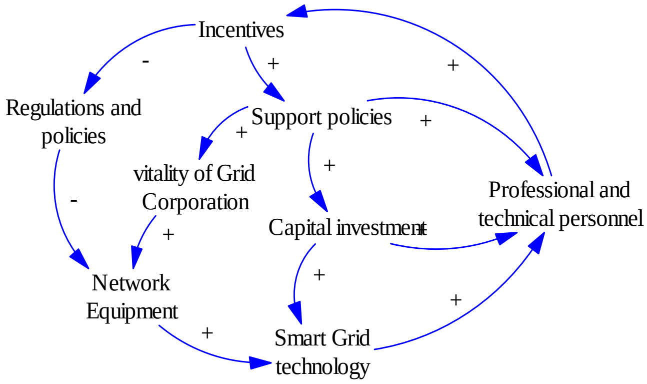

Figure 5. Government subsystem feedback

Government subsystem: Policies of government subsystem can determine the future direction of Smart Grid. Government's incentives can be taken to increase support efforts of the power industry and the amount of capital investment, to enhance the vitality of the grid company, to promote the rapid development of Smart Grid technology and equipment, and finally strengthening the professional personnel. Incentives, support policies, vitality of Power Grid Corporation, power equipment, capital investment, Smart Grid technology and professional and technical personnel form a positive feedback loop. On the other hand, the government's regulatory policy limits the development of the Smart Grid to some extent.

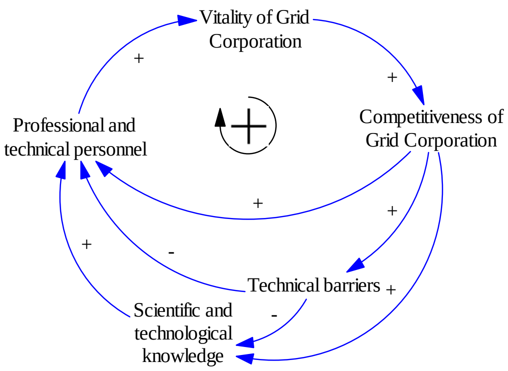

Figure 6. Power corporation subsystem feedback

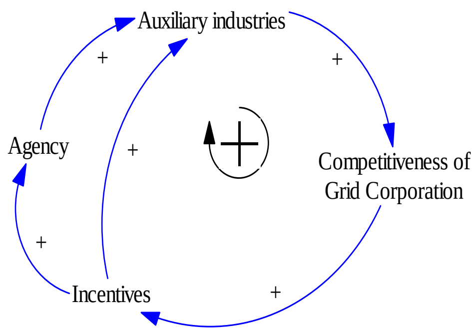

Figure 7. Agency subsystem feedback

Power Grid Corporation subsystem: Technical barriers form a negative feedback effect to scientific knowledge and professional personnel, and is not conducive to attract innovative technology, limiting the development of Smart Grid. And professional and technical personnel, vitality of Power Grid Corporation, competitiveness of Grid Company form a positive feedback loop, strengthening soft power of grid companies subsystem.

Agency subsystem: It contains intermediaries, supporting industries, competitive of power companies, incentive policies.

3. System Dynamics Flow Diagram of Smart Grid

We can qualitatively understand the driving forces and causal relationship of Smart Grid development by causality diagram as well as feedback mechanism diagram of the various subsystems above. In order to quantitatively express the development of Smart Grid, we intend to build Vensim model of the flow diagram [21].

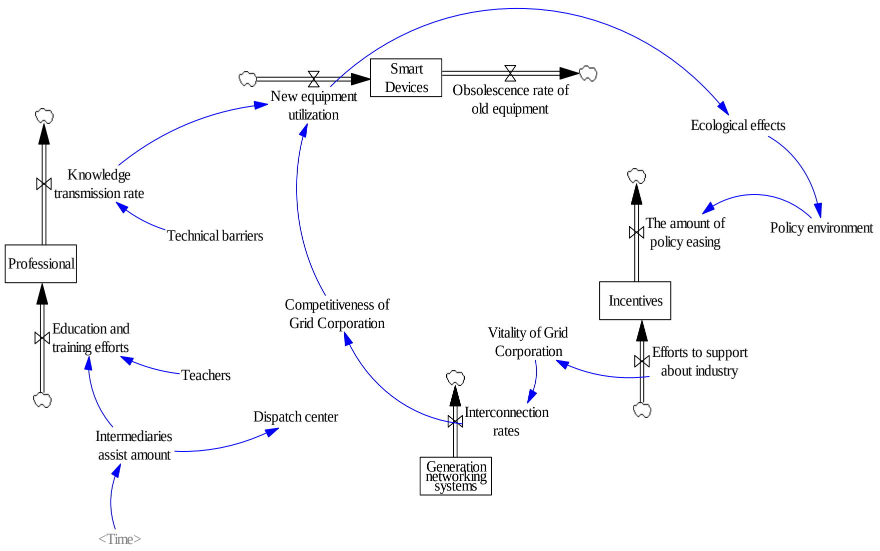

Figure 8. Smart grid system dynamics flow diagram

This paper selected 20 variables in System Dynamics flow diagram to describe the impact of Smart Grid system in Figure 8. To describe the development of the Smart Grid, this paper selected four level variables, smart devices, power generation networking systems, professionals, incentives as well as seven rate variables, knowledge transmission rate, education and training, new equipment utilization, obsolescence rate of old equipment, the amount of policy easing, efforts to support about industrial, interconnection rates as analysis variables [13, 22].

The article focused on professionals and funding of level variables, studying simulation results in Vensim software by changing the parameter values.

4. Vensim Simulation Analysis of Smart Grid System

Vensim simulation parameters set from 2005 to 2020, a time step of 1 year. We enter equations for each level and rate variables in the Smart Grid system flow chart.

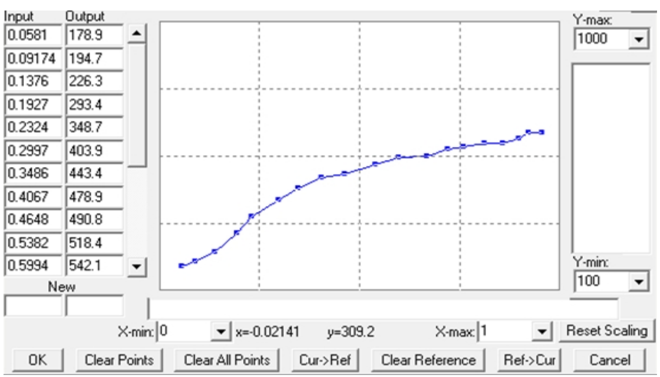

Figure 9. Smart grid system professional table function

There is an obvious correlation between the personnel training, education, teacher and other factors, but it's not easy to use mathematical or logical function to represent the relationships. So this paper intends to build a table function to describe the status of personnel training.

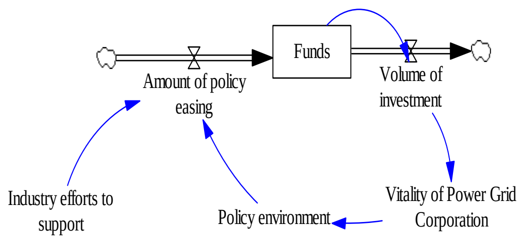

Figure 10. State of money flow diagram

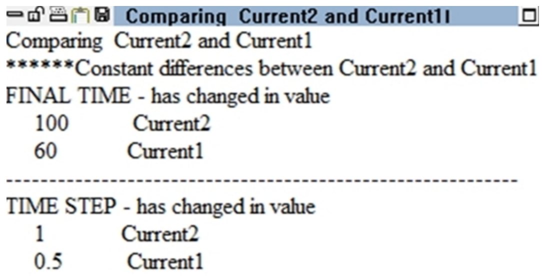

Figure 11. Comparison of different simulation parameters

DYNAMO language equation of Funds in Vensim Simulation System is written as follows.

a) Professional.K=Lookup[(0,100)-(1,1000)],(0.058104,178.947)…
b) Efforts to support industry.K=PULSE TRAIN(2,0.5,10,50)*30
c) Amount of policy easing.K= Efforts to support industry.L*Policy environment.L
d) Funds.K= Volume of investment.L+Policy environment.J*SQRT(Funds.J)
e) Volume of investment.K=PULSE TRAIN(Funds,0.5,2,25)
f) Vitality of Grid Corporation.K=INTEGER(Volume of investment.K)
g) Policy environment.K=ABS(Vitality of Grid Corporation.K)

K represents the present time, J is a moment before, L is the next point in time.

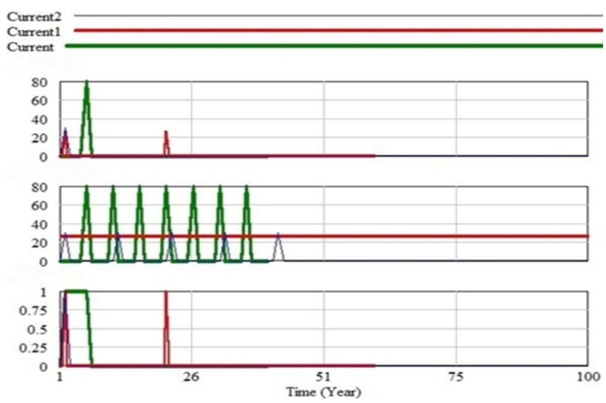

Figure 12. Simulation results related to smart grid policy easing variable amount

As support policies and funding of the government have obvious stages and cycles, so the amount of policy easing and industrial support may use PULSE TRAIN in the library of Vensim. Set its minimum value is 1 and the maximum is 80 [23,24]. Current time step of 1, the final value of 40; Current1 time step of 0.5, the final value of 60; Current2 time step is a final value of 100.

From the same period longitudinal comparison, the development of Smart Grid should be conducted when the amount of policy easing and policy environment are more lenient. From horizontal comparison, it can be found that the policy and support efforts have obvious peaks and troughs. Trough of the industry restructuring and rest stage, grid is in the suspension conditions, however personnel training and secondary industries is in the development stage.

Crest is the peak period of the development of the Smart Grid, and each grid equipment and control systems are in a phase of renovation [25].

5. Conclusion

5.1. Overall Planning

As can be seen from the above analysis, the construction of the Smart Grid is a huge project, involving a wide geographical range, long cycle time, a huge amount of money. Construction of Smart Grid should be unified planning, co-ordination, orderly building.

5.2. Carried Out Step by Step

Overall, the Smart Grid construction should be divided into three levels: Smart Meter:, Smart Grid and Smart City.

a) Smart Meter: Advantages of Smart Meter is to establish a two-way flow of information between the customer and the power companies to provide interactive services.

b) Smart Grid: Power companies need to continuously optimize the operation of systems, enhance vitality.

c) Smart City: Power transmission and consumption processes should be observed by power companies to improve the response speed of the demand-side, strengthening the capacity of the boot needs to improve the power efficiency.

5.3. Accelerate Talents

Technology, capital and policy environment are all factors, but professional and technical personnel is the key. Professional and technical personnel has become a source of strength for the national Smart Grid development.

5.4. Focus on Policies Related to Smart Grid

Part of the simulation analysis shows that companies should focus on policy environment and industrial policy that correspond to Smart Grid in the course of Smart Grid development, building a strong Smart Grid system.

Acknowledgements

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