Electrical Power and Energy Systems 43 (2012) 369–374

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Dynamical modeling investigation for economy of nuclear power plants (NPPs) in global nuclear energy market

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A R T I C L E   I N F O

Article history:
Received 16 January 2011
Received in revised form 30 May 2012
Accepted 1 June 2012
Available online 4 July 2012

Keywords:
Dynamical analysis
System dynamics
Feedback
Nuclear power plant
Simulation

A B S T R A C T

Non-linear dynamical analysis for the global nuclear energy market is investigated. Currently, the market means a different characteristics comparing to the past situation which had been done before two severe accidents as the Three Mile Island nuclear power plant (NPP) accident in the United States and the Chernobyl NPP disaster in the Soviet Union. For the nuclear related facility, the environmental and safety aspects are the important issues of the analysis. Fundamentally, the economic factor is still a critical matter for the commercial trade between two countries which depend on the energy demand and uranium price. The dynamics simulations show the trend of trade is affected by the several kinds of the aspects. Using system dynamics (SD) method, the event quantification is performed for the event flows, stocks, and feedback where the single and double arrow lines are incorporated.

1. Introduction

The worldwide energy demand can give a huge market in the nuclear industry. The feature of energy composition shows the steady portion of the nuclear energy. Therefore, the international trade market is affected by several factors which will be modeled in this paper. The main object of the paper is to find the quantified results for the global export and import in nuclear industry. It, however, is difficult for the simulation to express much tractably due to the linearity of the mathematical expression. So, the easy and non-linear method is needed to show the better explanations.

Recently, South Korean government took the trade order of the advanced power reactor (APR) 1400 to the United Arab Emirates (UAE), which is the new type of nuclear power plant (NPP) for 1400 MW(e) power [1]. There is some more export plan in Table 1 [2]. There is a merit that the nuclear power is a non-carbon production energy source which makes the international trade of NPP be active. So, it is necessary to investigate the systematic estimations. The export and import simulation could be done by the statistical calculations. Presently, nuclear power reactors in operation with a total net installed capacity of 370,187 GW(e) which is seen Fig. 1 [3]. Five nuclear power reactors are in long term shutdown. Fifty-six nuclear power reactors are under construction globally in Table 2 [4].

The system dynamics (SD) is used for the quantifications of the marketing in this nuclear industry. The SD was introduced by Dr. Jay Forrest in the Massachusetts Institute of Technology (MIT) for the non-linear characteristics of the social and economical system. This complex system for dynamical evaluation is tested by SD. The SD has been applied to the organizations by the transitions of the time [5,6]. Some other papers are also seen as the industrial markets [7–9]. In addition, there are some decision-making related papers [10–14]. The method section explains the method of the study. The calculation for the modeling is shown in the calculation section. The results section describes results of the study. There are some conclusions in the conclusions section.

There are several studies for the nuclear energy markets. Erdogdo worked that the aims at evaluating both the present status of nuclear power in general and its implications for Turkish energy market in particular [15]. After examining existing nuclear power technology and providing a brief overview of nuclear power economics; it focused on the repercussions of nuclear power for Turkish energy market. In addition, Miller et al. studied that the water electrolysis by nuclear energy was the only available technology today able to meet the first and second criteria [16]. The third criterion includes costs of electrolysis and electricity. The primary requirements for affordable electrolysis were low capital cost and high utilization. Consequently, the electricity supply must enable high utilization as well as being itself low-cost. Also, Dahl showed to determine the maximum effect on the gas market, it was assumed that all new planned nuclear facilities would be replaced by natural gas facilities [17]. Since the gas market was heavily dependent on the oil market and gas transport was expensive, this moratorium was simulated using a spatial model that included both gas and oil. Carlsson et al. worked the evaluation of

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0142-0615/$ - see front matter
http://dx.doi.org/10.1016/j.ijepes.2012.06.008

Table 1
Estimation of export in South Korea.

Year	Number of units (cumulative value)
2009	4
2012	10
2030	80
Total	94

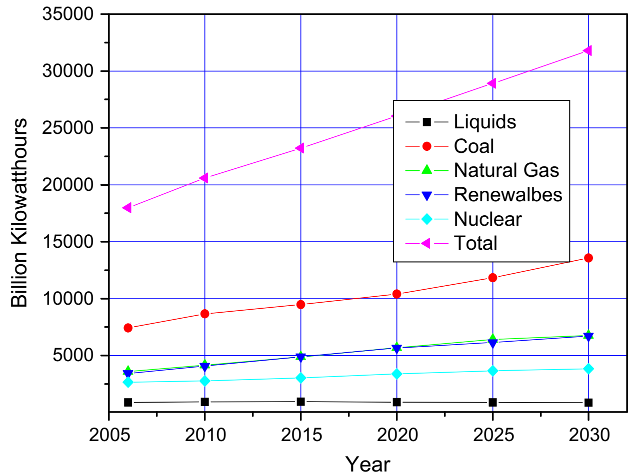

Fig. 1. International energy annual 2006.

Table 2
Under construction nuclear power plants (NPPs) by country.

Country	No. of units	Total MW(e)
Argentina	1	692
Bulgaria	2	1906
China	21	20920
Finland	1	1600
France	1	1600
India	5	2708
Iran, Islamic Republic of	1	915
Japan	1	1325
Korea, Republic of	6	6510
Pakistan	1	300
Russian Federation	9	6894
Slovak Republic	2	810
Taiwan, China	2	2600
Ukraine	2	1900
USA	1	1165
Total	56	51855

target market competition costs of fossil fueled cogeneration in 2030 which is allowable costs and cost breakdown for competitive nuclear cogeneration plant [18]. Nestle studied the effect of nuclear policy and the share of nuclear power was discussed and analyzed [19]. Grover showed the studies done by the Department of Atomic Energy indicated that even after exploiting full potential of every available source of energy including nuclear energy, India needed to continue to import energy resources [20]. Shropshire studied the future plans for energy production in the European Union as well as other locations called for a high penetration of renewable technologies (20% by 2020, and higher after 2020) [21].

Section 2 shows method for the modeling. The calculation for the modeling is given in Section 3. Section 4 is the results of the study. There are some conclusions in Section 5.

2. Method

For the simulations to the analytic estimation as well as the quantification, the SD method is applied. The particular problems of the technological implications are quantified by the SD for the variety of factors. In addition, the dynamical decision-making problem could be solved in the complex cases. Vensim package is used for the simulation, which was developed in the Ventana systems, Inc.

The SD was described by M. Radzicki, which is a powerful methodology and computer simulation modeling technique for understanding, framing, and discussing complex issues and problems [22]. It is helpful for managers to improve their understanding, which is practicable in all kinds of policy and design areas. The basic block could be expressed by the SD for how and why complex real-world systems behave the way they do during the specified time. The object is to support the understanding to implement much more effective policies. In SD molding, the most important thing is the dynamic behavior of system, where the operator tries to identify the patterns of behavior exhibited by interested system variables, and then builds a model with the characteristics of patterns. The single and double arrow lines are used for the purpose. Lines mean the event flows and time flows. The important thing is the dynamic behavior of a system, its key physical and information flows, stocks, and feedback structures for SD. There are several characteristics of the SD in the modeling. Firstly, there is a non-linearity of the algorithm. The large part of the SD modeling process involves the application of common sense to dynamic problems. Such behaviors usually indicate a nonlinearity of the events. This is seen as single and double arrow lines in the modeling, which will be explained in the below part. That is to say, the arrow line shows the event flow without any restriction. Secondly, the stock-flow is shown in the modeling. It is considered as the principle of accumulation to be raised by dynamic behavior. This means that all kinds of dynamic behaviors could be happened when flows accumulate in stocks. Both informational and non-informational object can move through flows and accumulate in stocks. Thirdly, the feedback is featured in the algorithm. The stocks and flows in real world systems are part of feedback loops. The feedback loops are often joined together by non-linear couplings where any object often causes counterintuitive behavior. Finally, the time paths are applied to the modeling. The most important thing of the SD modeling is the dynamic behavior of systems, in which the operator tries to identify the patterns of behavior exhibited by interested system variables, and then builds a model with the characteristics of patterns. In addition, for the SD modeling, there are special expressions for the above characteristics. Especially, in the Vensim code, the technical methods are done for connections between events by single and double arrow lines. The single arrow line is the flow of the event. The line means the sequence of the scenarios as well as the dynamical behavior. Therefore, the direction of line gives the event flow and event feedback. The double arrow line is also used. For the principle of accumulation, the dynamic behavior is raised in the SD modeling. All kinds of dynamic behaviors could be happened when flows accumulate in stocks, which are seen as EXAMPLE for accumulation and INPUT/OUTPUT for flows in Fig. 2. It is a case like a bathtub where a flow can be thought of a

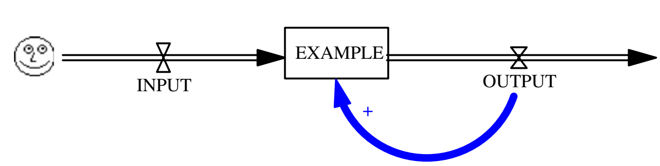

Fig. 2. Stock-flow and feedback.