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A System Dynamics Approach for Cost-Benefit Analysis of Smart Grid Developments

YYichen Qiao[1],* and Yan Xu2

[1]*School of Electrical and Information Engineering, University of Sydney, Australia*

[2]*School of Electrical & Electronic Engineering, Nanyang Technological University, Singapore*

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***Corresponding author:** Yichen Qiao, School of Electrical and Information Engineering, University of Sydney, Australia, Email: corey.qiao@gmail.com

Abstract

This introductory paper aims to construct a framework using the System Dynamics theory to conduct a cost-benefit analysisof the development of any smart grid project. Since the current evaluation methods are static in nature and ignore the consideration of uncertainty in the process, a different method should be adopted. The theory of System Dynamics and its relevance has been explained and the smart grid scenario is given. The cost-benefit analysis model with System Dynamics could dynamically evaluate all the benefits by allowing any factors to be changed during the grid development process, this model aims to evaluate smart grid more comprehensively.

Keywords : System dynamics; Smart grid; Cost-benefit analysis; Uncertainty

Introduction

With the development of the modern society, humans have a much higher demand for energy, the efficiency and safety of such energy supply have brought much attention around the globe [1]. Meanwhile, the negative effects of climate change have forced humans to promote alternative clean energy and energy-savingapproaches [1-2]. Thus, some countries have introduced the concept of smart grid in the last decade, to satisfy the emerging demand and improve the overall supplying quality of electricity [3-7].

Developing a smart grid is a key component of many countries' strategy towards a better energy future [8]. However, the outcome of such enormous project is essential for every country, the question raised would be if the benefits of the developing a smart grid worth the investments? The Electric Power Research Institute (EPRI) and the IBM in the US, as well as the Joint Research Center (JRC) of the European Union, have provided similar guidelines and models on estimating the costs and benefits of smart grid, these models categorise all the relevant factors in different developing stages and aspects, then determine the benefits by matching factors and criteria [9-11]. These models evaluate smart grid in a more qualitative way, and such models are static in nature, thus, the System Dynamics model is introduced to evaluate the actual benefits of the smart grid development with the consideration of time effect and the dynamic nature of the developing process. The System Dynamics model aims to analyze the smart grid power system dynamically, to understand the influences brought by different factors to other components of the system, and to identify the pattern of change in evaluation result over time.

System Dynamics

System Dynamics is a computerized approach to system design and analysis, it may apply to any kind of system that has the characteristics of mutual interactions, interdependence, and circular causality, the power system is one of them. The approach is to understand the behavior of a complex system over time, it involves internal feedback loops and time delays that could affect the behavior of the entire system. In detail, based on a given objective, the system consists of a range of mutual interacted factors, these factors are interrelated, any minor change in one factor could impact other factors within the system, as the objective or the structure of the system may change over time, the entire system is dynamic in nature [12-15].

The basic structure of the System Dynamics is a feedback loop, initial cause ripples through a series of causation that eventually to re-affect it-self, at the same time other variables may also be affected. As the inflows and outflows are the rates of given quantity that is added or deducted from the stock variable, the stock variable if the integral of the net flow added to the initial values [16,17].

The interrelationship between diverse factors and benefits are analyzed, determine the way they interact with and influence each other, eventually examine the impacts on a range of benefits that are brought by energy policy, power system statue and consumer behavior.

Smart Grid Scenario

The transition to the smart grid from conventional power system would be a lengthy process, as most of the existing assets and equipment are still within the useful life, the replacement of such equipment would gradually take place along the constructing process. Furthermore, the smart grid is a vastly complicated system, with some sections that require continues capital input, while other sections need more human interaction and technology advancements [18].

Due to the lengthy and complex nature of the smart grid, all the components and factors within the system are closely correlated and interacted [19]. Considering the level of investments and inputs would vary in different phases of smart grid development, these inputs include but not limited to the capital, technology, and human resource, these influencing factors have the dynamic feature, which may change over time. To accurately estimate the benefit under dynamic environment, this paper proposed the System Dynamics approach to map out relationships between factors and to estimate the influences brought by any individual factor.

The Figure 1 shows a simplified small-scale smart grid system that equipped with smart meters, automation distribution system, renewable energy (RE) distributed generation system and electric vehicle (EV), this basic model aims to simulate the interactions between the smart devices and other factors such as energy policy and consumer behaviour, in order to analyse how the benefits are gained or lost due to such interactions or changes in variables.

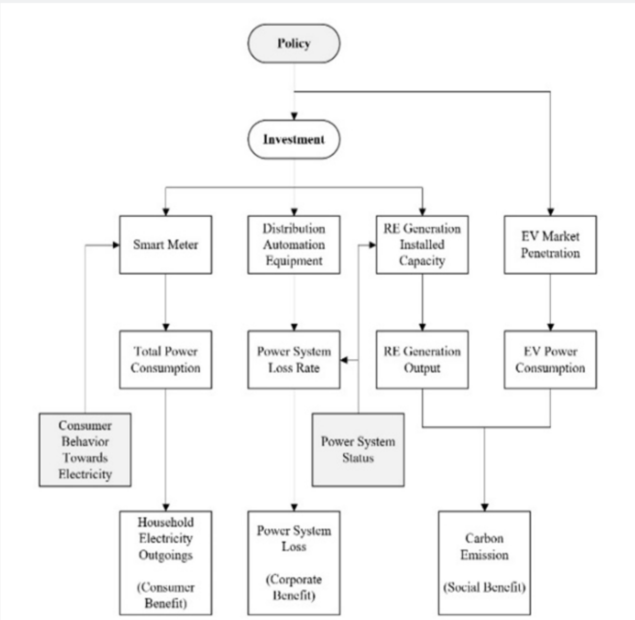

Figure 1: Various humanoid robot platform.

As the figure illustrates, a constructive energy policy would directly stimulate the investments on the smart grid, which leads to encouragement of installation and utilization of smart devices. Meanwhile, the policy could also raise the market penetration of electric vehicle. The status of the power system is crucial for the stability of RE generation capacity, as well as the overall system loss rate. The electricity consumer behavior would be closely related to daily power usage and the efficiency of smart-living devices. To further extend the framework, multiple factors are added into the System Dynamics model, as illustrated in Figure 2.

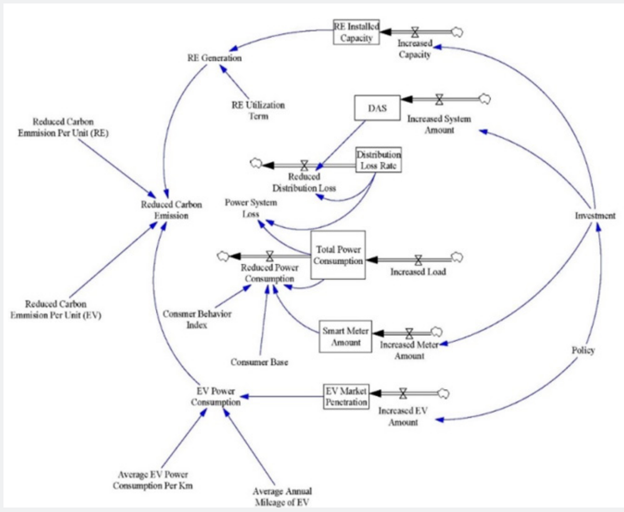

Figure 2: System Dynamics Modelling in smart grid.

Results and Preliminary Findings

The System Dynamics model could dynamically evaluate multiple benefits of the development process, the project is assumed to have a 20-yearcycle, any of the factors could be altered within the model, and the results would be varied accordingly. The initial investments are set to be 11 million dollars, the values of the factors are retrieved from multiple government reports and relevant sources [20-27]. With an encouraging energy policy and continuous increment of investment in the smart grid development, the overall power consumption and system loss are decreased, the clean energy installed capacity and electric vehicle market penetration increase.

The three major benefits gained from the smart grid would be power system loss improvements, reduced amount of power consumption and a reduced amount of carbon emission, all the benefits have been quantified and converted into financial figures, where the benefits are measurable and comparable. The Net Present Value (NPV) is calculated in this case to determine whether this project is profitable.

The cash flows of each year are calculated considering all benefits gained via the System Dynamics model, the detail shows in Table 1. The NPV of this project is $36,369,585 if

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the discount rate is assumed to be 3% [28]. As to examine the effectiveness of the model, assuming the policy has changed the investment proportion, the investment in smart meter installations, distribution automation system and renewable energy are 20%, 20%, and 60% respectively, where the original proportion was 30%, 30%, and 40%, the cashflows are altered accordingly as a result, the NPV has dropped to $35,691,365. Due to the alteration, all the factors within the model are affected by the change of policy, although the NPVs between two results have very little difference, the other factors such as the power consumption have dramatically changed.

Table 1: Cash flows and NPV 1.

Year	Cash flow	Year	Cash flow
0	($11,000,000.00)		
1	$107,078.86	11	$3,272,752.92
2	$252,117.77	12	$3,798,632.54
3	$435,191.75	13	$4,362,229.26
4	$656,363.70	14	$4,963,382.32
5	$915,681.68	15	$5,601,913.88
6	$1,213,175.44	16	$6,277,634.98
7	$1,548,854.16	17	$6,990,350.40
8	$1,922,703.40	18	$7,739,864.39
9	$2,334,684.25	19	$8,525,989.04
10	$2,784,731.18	20	$9,348,546.42
		NPV	$36,369,585.42

Conclusion

In this introductory paper, the concept of utilizing System Dynamics model as the evaluation framework for smart grid scenario is presented. The concept of System Dynamics approach is explained. Under the smart grid development scenario, the added consideration of time effect and uncertainty is demonstrated, meanwhile, the feasibility of the approach is briefly tested and the advantages of using such dynamic approach are justified. Furthermore, the two sets of preliminary results of the model are given which demonstrate the dynamic nature of this model where changes in one factor may bring enormous impact to the entire project.

References

1. Golombek R, Kittelsen S, Haddeland I (2011) Climate change: impacts on electricity markets in Western Europe. Climatic Change 113(2): 357-370.
2. Nejat P, Jomehzadeh F, Taheri M, Gohari M, Abd Majid M (2015) A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries). Renewable and Sustainable Energy Reviews 43: 843-862.
3. Colak I, Fulli G, Sagiroglu S, Yesilbudak M, Covrig C (2015) Smart grid projects in Europe: Current status, maturity and future scenarios. Applied Energy 152: 58-70.
4. Yu Y, Yang J, Chen B (2012) The Smart Grids in China-A Review, Energies 5(12): 1321-1338.
5. Simoes M, Roche R, Kyriakides E, Suryanarayanan S, Blunier B, et al. (2012) A Comparison of Smart Grid Technologies and Progresses in Europe and the US, IEEE Transactions on Industry Applications 48(4): 1154-1162.
6. Xu Y, Dong Z, Xu Z, Meng K, Wong K (2012) An Intelligent Dynamic Security Assessment Framework for Power Systems With Wind Power. IEEE Transactions on Industrial Informatics 8(4): 995-1003.
7. Xu Y, Zhang R, Zhao J, Dong Z, Wang D, et al. (2016) Assessing Short-Term Voltage Stability of Electric Power Systems by a Hierarchical Intelligent System, IEEE Transactions on Neural Networks and Learning Systems 27(8): 1686-1696.
8. Fan Z, Kulkarni P, Gormus S, Efthymiou C, Kalogridis G, et al. (2013) Smart Grid Communications: Overview of Research Challenges, Solutions, and Standardization Activities, IEEE Communications Surveys & Tutorials 15(1): 21-38.
9. Electric Power Research Institute (2011) Estimating the Costs and Benefits of the Smart Grid. Palo Alto.
10. IBM (2009) Smart Grid Maturity Model: Creating a Clear Path to the Smart Grid. Armonk.
11. Giordano V, Onyeji I, Fulli G, Jimenez M, Filiou C (2012) Guidelines for conducting a cost-benefit analysis of smart grid projects. Publication Office of the European Union, Luxembourg.
12. Schwaninger M, Grösser S (2008) System dynamics as model-based theory building, Systems Research and Behavioral Science 25(4): 447-465.
13. Roberts E (1984) Managerial applications of system dynamics. Cambridge, Mass [u.a.]: MIT Press.
14. Randers J (1990) Elements of the system dynamics method. Cambridge, Mass: Productivity Press.
15. Qiu J, Dong Z, Meng K, Xu Y, Zhao J, et al. (2015) Multi-objective transmission expansion planning in a smart grid using a decomposition-based evolutionary algorithm. IET Generation, Transmission & Distribution 10(16): 4024-4031.
16. Karnopp D, Margolis D, Rosenberg R (2012) System Dynamics. Hoboken (New Jersey): Wiley.
17. Huang J, Huang X, Shao L (2006) Peak and Valley time price model and simulation based on system dynamics. Automation of Electric Power Systems 30(11): 18-23.
18. Farhangi H (2014) A Road Map to Integration: Perspectives on Smart Grid Development. IEEE Power and Energy Magazine 12(3): 52-66.
19. Dong Z, Xu Z, Zhang P, Wong K (2011) Real-Time Stability Assessment of Electric Power System with Intelligent Systems. IEEE Intelligent Systems 99.
20. U S Department of energy (2016) Customer Acceptance, Retention, and Response to Time-Based Rates from the Consumer Behavior Studies.
21. U S Department of energy (2014) Evaluating Electric Vehicle Charging Impacts and Customer Charging Behaviors.
22. U S Department of energy (2012) Application of Automated Voltage and Reactive Power Management.
23. U S Department of energy, 2014.
24. U S Department of energy (2014) Factors Affecting PMU Installation Costs.
25. Internationl Trade Administration (2017) Smart Grid Top Markets Report.
26. Ausgrid (2014) Smart Grid, Smart City: Shaping Australia's Energy Future.

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27. Commonwealth Scientific and Industrial Research Organisation (2010) "Intelligent Grid- A value proposition for distributed energy in Australia".

28. Australian Rates & Bonds. (2017) Bloomberg.com.

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