Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (18): 3847-3851, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.3847.3851

Study of Economical Operation of Power Grid Considering the Integration of Large-scale Renewable Energy

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Abstract: With the technical progress of Renewable Energy Resources (RERs) generation and the support from domestic incentive policies, the installation proportion of renewable energy resources has been increased steadily. The integration of renewable energy resources not only shows significant environmental effect, social effect and economic effect, but also brings many challenges to grid planning and economic operation of power grid. Based on system dynamics, from the perspective of changes of cost and benefit of grid enterprises caused by the integration of RERs, the effect of the integration of RERs on economical operation of power grid is studied. Finally, a simulation of effect trend based on empirical data of one province demonstrates the validity of the model proposed in this study.

Key words: Integration of renewable energy resources, system dynamics, economical operation of electric power network

INTRODUCTION

For guaranteeing the safe operation of power grid, ensuring the level of quality of power supply and meeting the demand of power supply, grid runs on condition that the costrate of electricity supply, the consumption rate of the energy generation and network loss rate was the lowest, namely the economic operation of power grid. As practical energy-saving technologies, under the safety of technology and reasonable economic situation, the economic operation of power grid should make full use of existing equipments and components and select the best operation mode by relevant technical verification to reduce system loss, which could improve operation performance for grid companies (Wang and Huang, 2008).

In recent years, with the technical progress of Renewable Energy Eesources (RERs) generation and the support of domestic incentive policies, the development and application of renewable energy resources have been greatly promoted. However, wind power, photovoltaic and other renewable energy technologies has brought greatchallenges for the economic operation of power grids (Wang *et al*., 2011). Researching the effects of the integration of RERs on economical operation for power grid, especially on power consumption and economic dispatch is greatly significant for scientific, reasonable choice of power system economic operation and the improvement of the operating efficiency for grid companies (Wang and Lu, 2012).

So, far some literatures have studied the impact of the integration of renewable energy resources on economical operation of power grid. Literature (Geng *et al*., 2012) analyses and summarizes the basic characteristics of wind power and some particularities of wind power in China such as centralizing the development, long-distance transmission and direct access to the main network. For power system energy-saving optimal scheduling problem in wind farm, it is considered the dual goals of energy conservation and emission reduction of power generation in the generation scheduling, and the possible risks brought by wind power in the objective function of optimal scheduling, meanwhile put forward orthogonal genetic simulated annealing algorithm for solving the optimization scheduling problem (Luan *et al*., 2010).

The above researches study the impact of integration of RERs on certain aspects of the power system in different points, but not provide a comprehensive analysis about the impact of RERs on the economical operation of grid and of the overall operation of power grid enterprises from generation, transmission, sale of electricity and other aspects. Therefore based on system dynamics, from the perspective of changes of cost and benefit of grid enterprises caused by the integration of RERs, the effect of the integration of RERs on economical operation of power grid was studied. Finally, a simulation of effect trend based on the empi rical data of one province in the next decade is studied.

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IMPACT OF THE INTEGRATION OF RENEWABLE ENERGY ON ECONOMICAL OPERATION OF POWER GRID

Renewable energy power generation technology has achieved rapid development in recent years, the cost has reducing recently. However, with renewable energy into grid will have a huge impact on distribution system structure and economical operation of power grid. It mainly manifests in following two aspects:

- **Impact on the grid loss:** Renewable energy generation system access to the distribution network, then load distribution of the entire distribution network will change, which may result in the increase of grid loss. This depends on the location of renewable energy access, size of access capacity, network topology and other factors
- **Impact on the trend of the line:** Some impacts of the integration of RERs on economical dispatching operation have been exerted, mainly including difficult power prediction, poor power generation plan and the challenge brought to the grid arrangement and real-time monitoring

The integration of RERs has some of the following impacts on operating costs of grid enterprises.

Generation side: The integration can share partial load of traditional thermal power and hydropower units, greatly reducing the consumption of fossil fuels and the operating cost of generation side

Grid side: Due to the intermittency, uncertainties and other characteristics, the integration of RERs will have an effect on the stability, reliability system and power quality, increasing frequency control, reserve capacity, reactive power, voltage regulation and other ancillary service cost of grid

Electricity side: In the acceptance of the renewable energy generating capacity by grid enterprises at the same time, some subsidies was given to sale price, which reduces the cost of power grid enterprises to some extent

MODEL DESCRIPTION

Based on the above analysis fot the impact of the integration of RERs on the economical operation of grid, this section adopts the proposed dynamics and establishes system dynamics model of the integration of RERs on economical operation of grid. System dynamics is a method of combing qualitative analysis and quantitative analysis, qualitative analysis-oriented, quantitative analysis in support and both supplement each other (Wang, 2009).

The model established in this study consists of three main parts: First, renewable energy generating capacity; then the operation costs of grid enterprises, finally, the income of grid enterprises.

Renewable energy generation capacity: Based on the supporting role in technological progress as well as government policies, analyze the total renewable electricity generation in a region.

Operating costs of power grid enterprises: Based on guaranteeing the safe operation of power grid, ensuring the level of quality of power supply and meeting the demand of power supply, consider the line losses cost and ancillary service cost committed by grid enterprises of the integration of RERs generation.

Revenue of power grid enterprises: Study revenue from electricity sales in power grid of the integration of RERs. Renewable energy power tariff subsidies are considered in the power tariff of renewable energy (Zeng *et al*., 2012).

Based on the above analysis, we select operating efficiency of grid enterprises, renewable energy generating capacity and other core indicators as well as related indicators that affect the core indicators. By using system dynamics vensim, we combine qualitative relationship between various indicators and then constructed system flow chart of economical operation of power grid, as is shown in Fig. 1.

We make an explanation on the meaning of related factors in figure one for comprehensibility.

In the build of system flow chart, analyze the relationship between indicators quantificational, and give the following system dynamics equations.

State equation:

$$Q_{renew}(t) = Q_{renew}(0) + \int_0^t q_{renew}(t)dt \tag{1}$$

where, Q_{renew} (t) is the generating capacity of RERs in kWh; Q_{renew} (0) is the initial generation of RERs in k Wh; q_{renew} (t) is the change value of RERs in kWh every year.

Rate equation:

$$q_{renew}(t) = \frac{TECH(t)*TECHW(t)+POLICY(t)*POLICYW(t)}{TECHW(t)+POLICYW(t)} *Q_{renew}(t-1) \tag{2}$$

where, TECH (t) is technological progress factor; TECHW (t) is the weight of technological progress;

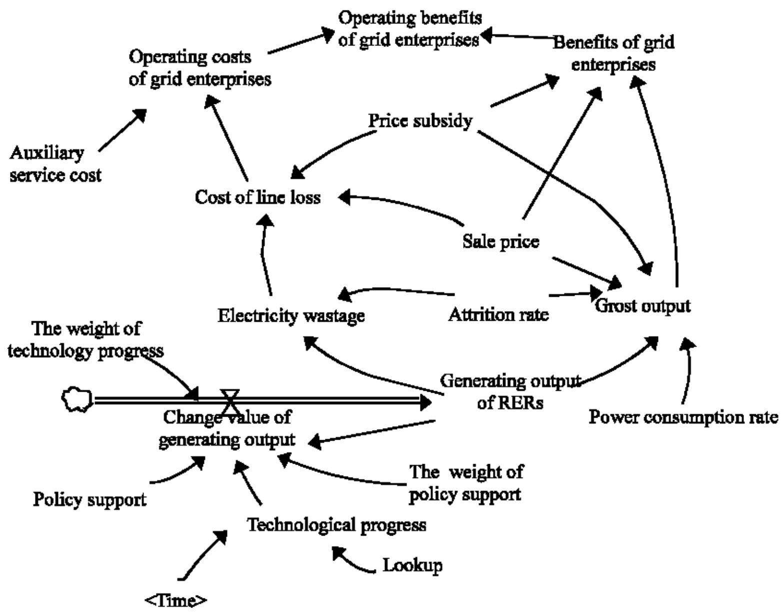

Fig. 1: System flow chart of economical operation of power grid

Table 1: Related factors of economical operation of power grid and their meanings

Influencing factor	Meaning of influencing factor
Gross output	The generating output of RERs provided by grid enterprises to end users
Sales price	The generating price of RERs sold by grid enterprises to end users
	The price is different due to the various generating technologies of RERs, including wind power price, price of solar power and biomass power and so on
Price subsidy	The subsidies for grid enterprises during the development and promotion provided by country for encouraging the integration power of RERs
	Price subsidies are different with various generating technologies
Costs of line loss	The cost of loss in the transmission of power generated by RERs
Auxiliary service cost	Including peaking,frequency modulation and spinning reserve costs caused by the Volatility and instability due to the generating output of RERs
Amount of electricity wastage	The loss power during the transmission of power generated by RERs
Attrition rate	The proportion of loss power which account for the overall transmission power in the transmission of power

POLICY (t) is the factor of policy support; POLICYW(t) is the weight of policy support.

Auxiliary equation

Operating cost of power grid enterprises

$$C_{grid}(t) = C_{auxi}(t)+C_{loss}(t) \quad (3)$$

$$C_{loss}(t) = Q_{loss}(t)*P_{grid}(t) \quad (4)$$

$$Q_{loss}(t) = Q_{renew}(t)*\vartheta \quad (5)$$

where, C_{grid} (t) is the operating cost of power grid enterprises, C_{loss} (t) is the cost of line loss in dollar, Q_{loss} (t) is the amount of power loss in kW h, θ is attrition rate, p_{grid} (t) is electricity tariff in dollar every kW h.

Revenue of power grid enterprise:

$$B_{grid}(t) = Q_{grid}(t)*(p_{grid}(t)+p_{subs}(t)) \quad (6)$$

$$Q_{grid}(t)=Q_{renew}(t)*(1-\vartheta-\zeta)*\left(\frac{\alpha * p_{subs}(t)}{\beta * p_{grid}(t)}\right) \quad (7)$$

where, B_{grid} (t) is the revenue of grid enterprises, Q_{grid} (t) is electricity sales amount in dollar, p_{subs} (t) is power price subsidies in dollar every kW h, α is influence coefficient of price subsidies, which means the impact of the unit price subsidy on electricity sales amount and is proportional to the electricity sales amount, β is influence coefficient of power price, which means the impact of the unit price on the amount of inverse relationship.

Operational benefits of the power grid enterprises:

$$E_{grid}(t) = B_{grid}(t)-C_{grid}(t) \quad (8)$$

where, E_{grid} (t) is the operational benefit of grid enterprises in dollar.

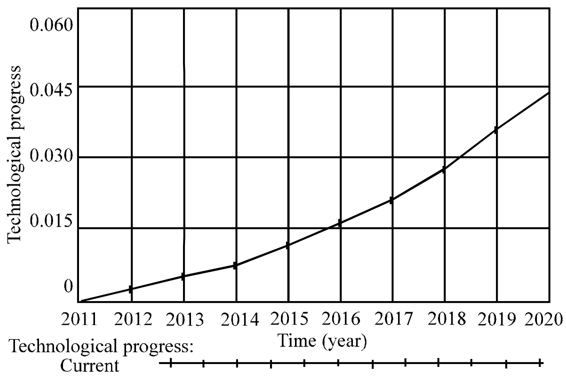

Fig. 2: Graph of technical progress function

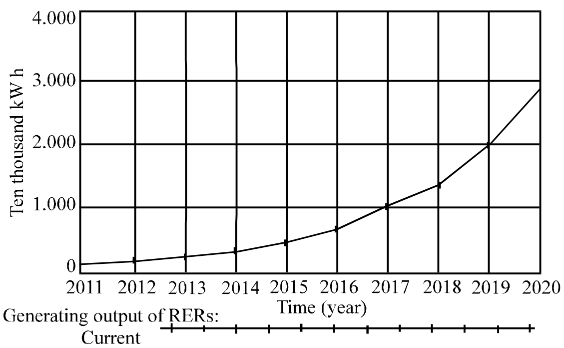

Fig. 3: Simulation graph of gross output of RERs

ILLUSTRATIVE EXAMPLE

Taking the integration of RERs in one province for example in this section, run a simulation for ten years in one year interval. Simulate and analyze the impact of the integration of RERs on the economical operation of grid from the year of 2011-2020:

- Value the constant in the model, as is shown in Table 2
- Considering the technological progress of renewable energy generation, the integration of grid, scheduling, etc., set "technological progress" as variable function in this section. The image of function is shown in Fig. 2
- With the technological progress of renewable energy generation, simulate the model by Vensim software, then the graph of gross output of RERs (Fig. 3) and operation benefit of the integration on the grid are achieved (Fig. 4)

Seeing the above figure, with the development of technology in the next ten years, gross output of RERs

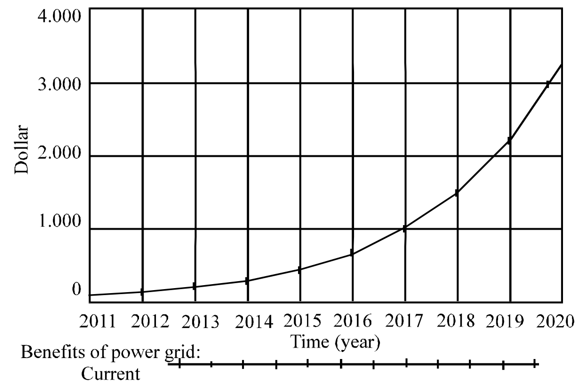

Fig. 4: Simulation graph of pperation benefit of grid enterprises

Table 2: Values of parameters in SD model

Variable	Evaluation	Unit
Operating maintaining expenses of unit length	0.05	Ten million km^{-1}
The investment cost of unit length	1200	Ten million km^{-2}
Operating maintaining expenses of unit capacity	50	Ten thousand kV A^{-1}
The investment cost of unit capacity	33	Ten thousand kV A^{-1}
The proportion of the integration of RERs	0.07	1
Coefficient2	7.50	1

is rising, the benefit of grid enterprises will gradually improve and the integration of RERs will promote the economic operation of power grid.

CONCLUSION

Based on system dynamics, from the perspective of changes of cost and benefit of grid enterprises caused by the integration of RERs in the building of system flow chart of economical operation of grid enterprises, this study considers the impact of the integration of the integration of RERs on economical operation of grid enterprises. And the effect trend of the integration of RERs on economical operation of power grid for one province in the next ten years is simulated. The simulation results show that with the technological development of RERs generating technology and transmission supporting technology, the gross output continues to increase, optimizing the economical operation of grid as well as increasingly prominent benefits brought by grid enterprises. Therefore, in the long term, the province should reinforce the development of RERs and constantly promote constant technological progress and development of the integration of RERs, relying on technology and management. Then, the installation proportion of RERs increases, further optimizing economical operation of power grid.

ACKNOWLEDGMENT

The study described in this study was Supported by the National Science Foundation of China (NSFC) (71271082).

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