



Optimal scheduling of the RIES considering time-based demand response programs with energy price



Yongli Wang, Yujing Huang^{*}, Yudong Wang, Ming Zeng, Haiyang Yu, Fang Li, Fuli Zhang

School of Economics and Management, North China Electric Power University, Changping District, Beijing 102206, China

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ABSTRACT

With the revolution of the traditional economic and social pattern based on centralized fossil energy consumption, the regional integrated energy system (RIES) has gained rapid development in recent years for achieving higher energy efficiency. This paper expands the Demand Response (DR) concept to the RIES and presents an optimal operation model of RIES considering the DR mechanism on the energy price. In this paper, a comprehensive DR strategy combining energy price and different loads is firstly developed to exploit the demand flexibility of RIES in the DR model established. Based on the DR modeling of the RIES, an operation optimization model with environmental, economic benefits and energy supply reliability as objective functions has been firstly established in detail. Secondly, a complete scheduling scheme is built based on the energy consumption characteristics and system operation characteristic of the integrated energy system. The model presented could reduce the cost of system without causing a significant amount of environmental pollution, and improve the energy efficiency of the RIES efficiently. Besides, the scheduling strategy proposed could also provide support for the operation strategy of integrated energy system under the energy development. Hopefully, this paper will provide reference for future research and engineering projects on DR programs in the RIES.

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1. Introduction

Energy is the material basis for human survival and is a prerequisite for social development and advancement of civilization. However, the leap-forward development of social productivity has led to a sharp rise in energy demand. Traditional fossil energy is facing serious problems of over-exploitation and near-exhaustion. Traditional energy utilization systems need to be transformed and upgraded. Therefore, comprehensive optimizing and using energy, thermal energy and natural gas and other energy sources to establish an Regional Integrated Energy System (RIES) which will be an important way to increase energy efficiency and achieve sustainable energy development [1,2]. The main objective of the optimal dispatch and operation of RIES is to improve the overall energy efficiency, enhance the operation reliability, reduce the energy cost and reduce the system pollutant emission [3,4].

In the research of coupling complementary on energy systems, Li Gang et al. built models from three levels of functional modules,

subsystems and regional integrated energy systems, in-depth studying the various energy utilization technologies and the coupling optimization process of multiple energy forms of cold, heat, and electricity [5]. Zhu Chunping et al. propose a new operating mechanism for the regional energy internet based on the domestic and international energy internet and multi-energy complementarity [6]. In view of the characteristics of multi-energy flows in an integrated energy system, Zhao et al. propose a hierarchical distributed coordination control method to coordinate the direct-tuning resources in the campus and the user demand response resources to perform comprehensive peak clipping [7]. Hao Ran et al. propose a multi-subject two-layer game interaction strategy composed of energy suppliers, distribution networks and users [8].

In the establishment and solution of the energy network equations, Dong J et al. propose a method for the joint transportation of natural gas and electricity so that natural gas transmission and power transmission can be performed “in the same way” [9]. Based on the smart grid technology, Li Peng et al. propose a joint control method between thermoelectricity and wind energy, and the simulation results show that the proposed method can help wind turbines increase their grid connection capacity [10]. Hou S

^{*} Corresponding author.

E-mail address: yjh_2018_beijing@ncepu.edu.cn (Y. Huang).

Nomenclature

RIES	Regional integrated energy system	$P_{g_max}(t)$	the maximum power of the NG network to supply NG to the system, kW
DR	Demand response	$P_{ese_max}(t)$	the maximum output power of equipment, kW
CCHP	Combined Cooling, Heating and Power	$H_{h_st_max}$	the upper limit of the remaining capacity
WT	Wind turbine	DG	Distributed generation
E-load	Electric load	NG	Natural gas
$Q_{E,i}$	the electrical load after demand response, kW	PV	Photovoltaic
$Q_{NG,i}$	NG load after demand response, kW	AC	Air conditioner
$\mathfrak{I}_{NG-E}$	the influence coefficient of NG load on the electrical load	T-load	Thermal load
γ_{ele-dr}	the electricity price of DR, yuan/kWh	$Q_{E,i0}$	the electrical load before demand response, kW
C_{op}	the operation cost, yuan	$Q_{NG,i0}$	NG load before demand response, kW
P_i	the output of the DG system, kW	$\mathfrak{R}_{E-NG}$	the influence coefficient of electrical load on NG load
∂_{fuel}	NG price, yuan/m ³	$\partial_{fuel-dr}$	the NG price of DR, yuan/m ³
$C_{bat,dep}$	the charge/discharge depreciation cost of EES, yuan/kWh	LHV_{NG}	the low calorific value of NG, kWh/m ³
C_{EB_grid}	cost of power mitigation for systems and power grid, yuan	$E_{EES}(t)$	the rated capacity of the battery, kWh
$H_{h_st_start}(t)$	the remaining capacity of The start time and the end time in a scheduling period	SOC(t)	the remainder of the battery after the T period
$P_{EES-dis}(t)$	the discharging power of the battery, kW	η_{sch}, η_{sdis}	the charge and discharge efficiency of the battery, %
P_{EES-ch}	the charging power of the battery, kW	$H_{h_st}(t)$	the power of the TES to store heat, kW
$Q_{CCHP}(t)$	the exhaust residual heat of the gas turbine at time t, kW	ζ_{EC-p}	the penalties for the punishment of pollutants
δ_{CCHP}	the state parameter of the gas turbine	LESP(t)	the ratio of system power failure to total energy demand at time t, %
E_{CCHP_max}	the fuel power consumed by the gas turbine at full load operation, kW	$E_{supply,t}$	the total energy demand at time t, kWh
$H_{h_grid}(t)$	the thermal exchange between heating company and RIES, kW	$P_{e_grid}(t)$	the power exchange between power grid and integrated energy system, kW
$H_{CCHP}(t)$	thermal output power of CCHP, kW	$P_{dis}(t)$	the discharge power of battery, kW
$L_{h_re}(t)$	the power of the cold accumulator to release cooling load, kW	$P_{load}(t)$	the total load within the system, kW
$L_{h_st}(t)$	the power of the cold accumulator to store cooling load, kW	$H_{AC}(t)$	the output power of AC, kW
$P_{ng_st}(t)$	the power released by the NG stored in the system, kW	$H_{load}(t)$	the thermal load within the system, kW
$P_{e_min}(t)$	the minimum power exchange between power grid and RIES, kW	$L_{load}(t)$	the cooling load within the system, kW
		$P_{ng_grid}(t)$	the power of the NG network to supply natural gas to the system, kW
		$P_{ng_life}(t)$	The domestic gas power in the RIES, kW
		$P_{g_min}(t)$	the minimum power of the NG network, kW
		$P_{ese_min}(t)$	the minimum output power of equipment, kW
		ϖ_{BA-s}	the efficiency of battery charging
		$H_{h_st_min}$	the upper limit of the remaining capacity

et al. study the building-type multi-energy flow system and propose a variety of energy management operating modes of system [11].

In the research of the energy efficiency evaluation model for integrated energy systems, it mainly focuses on the energy efficiency evaluation of production capacity equipment and the analysis of influencing factors of system energy efficiency. Ding Yujuan et al. analyze the applicable range of energy efficiency standards, energy efficiency evaluation parameters, energy efficiency levels, and energy conservation evaluation values of lithium bromide absorption chiller units [12]. Xu Ting et al. propose an energy-efficiency performance analysis framework for wind turbines based on energy flow to achieve a comprehensive evaluation of energy efficiency performance [13]. Zou Bin et al. propose a new type of heating system in which a trough type solar collector is coupled with a gas boiler [14]. Sun et al. propose a gas boiler coupled with absorption heat transfer for district heating and demonstrated, the system can fully utilize low-grade heat sources [15]. Dušan Gvozdenac et al. compare the parameters of a cogeneration power station with a non-cogeneration power station and evaluate the energy efficiency of cogeneration systems [16]. Alves O et al. comprehensively consider factors such as region, operating

status, and technical level, and propose several common parameters [17]. The optimal control strategy of the multi-energy RIES is one of the important issues studied. A reasonable optimization program can reduce the operating costs and give full play to the advantages of the RIES. Gu et al. study the optimization problem of the CHP system [18–20]. Saha T et al. study the effects of operating characteristics of diesel generators, fans, and accumulators on system power generation costs, and propose an optimal control method of wind-diesel combined power system [21]. Jin et al. analyze the characteristics of randomness of wind and light output, the method proposed can reduce the negative impact of new energy volatility and optimize the operating costs of RIES [22–24]. Based on the perspective of DR, Colson C et al. propose a load translation solution strategy to improve the matching of new energy output and load [25]. Gburczyk P et al. propose an energy management optimization algorithm for the controllable DG to improve the economic and environmental friendliness of the micro-grid [26].

With the promotion of experts, scholars and policy support, multi-source coordination and optimization system of RIES has been developed in China. Cities such as Beijing and Shanghai already have a number of projects that demonstrate strong vitality

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