Energy Conversion and Management 103 (2015) 717–725

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Tri-generation based hybrid power plant scheduling for renewable resources rich area with energy storage

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ARTICLE INFO

Article history:
Received 14 May 2015
Accepted 8 July 2015
Available online 17 July 2015

Keywords:
Clean energy
Energy efficient
Power dispatch
Renewable energy
Tri-generation
Energy storage

ABSTRACT

Solving power system scheduling is crucial to ensure smooth operations of the electric power industry. Effective utilization of available conventional and renewable energy sources (RES) by tri-generation and with the aid of energy storage facilities (ESF) can ensure clean and energy efficient power generation. Such power generation can play an important role in countries, like Saudi Arabia, where abundant fossil fuels (FF) and renewable energy sources (RES) are available. Hence, effective modeling of such hybrid power systems scheduling is essential in such countries based on the available fuel resources. The intent of this paper is to present a simple model for tri-generation based hybrid power system scheduling for energy resources rich area in presence of ESF, to ensure optimum fuel utilization and minimum pollutant emissions while meeting the power demand. This research points an effective operation strategy which ensure a clean and energy efficient power scheduling by exploiting available energy resources effectively. Hence, it has an important role in current and future power generation. In order to illustrate the benefits of the presented approach a clean and energy efficient hybrid power supply scheme for King Saud University (KSU), Saudi Arabia, is proposed and analyzed here. Results show that the proposed approach is very suitable for KSU since adequate solar power is available during its peak demand periods.

1. Introduction

The global demand of fossil fuels (FF) for electricity generation is increasing while the reserve of these fossil fuels are decreasing [1]. FF based power plants contributes major share of total global greenhouse gas (GHG) emissions [2,3]. Moreover, in every year about 0.3 million people die globally due to the pollutant emission from the fossil fuel based power plants [4]. A conventional fossil fuel based power plant designed to generate electricity only wastes more than 60% of the fuel energy as heat [5]. However, tri-generation combines production of electric, heat and cooling power from a single energy source, simultaneously [6]. Thermodynamic analysis [7], theoretical and experimental study [8] and designing of optimum size [9] of tri-generation systems indicate that tri-generation is one of the alternates for the effective utilization of energy resources. In tri-generation, the heat produced as a by-product of electricity is used to produce heating and cooling power. Thus, the fuel utilization efficiency in tri-generation plant is high and it reduces a considerable amount of GHG pollutants emission [10]. The cogeneration side of tri-generation plant generates electricity and heat [11] while the cooling side produces the required cooling power with the help of absorption chillers [12].

Distributed generation (DG) produces electricity close to the end users with effectively utilizing the available energy resources. Hence, it can provide lower cost of electricity and higher power reliability [13]. Grid connected DG increases the level of penetration on electricity grid [14]. Experimental analyses show that proper scheduling of grid connected DG units can ensure optimum energy management [15] as well as economic and environmental benefits [16]. Energy efficient tri-generation method and effective utilization of renewable energy (RE) through energy storage facilities (ESF) can ensure an efficient and environmental friendly distributed generation [17]. Such clean and efficient power generation can easily applicable in energy resources rich countries, like Saudi Arabia. Saudi Arabia possesses plenty of fossil fuel and renewable energy resources. It is the world largest oil exporter and has vast rainless regions with world's highest solar irradiation. Saudi Arabia holds about 16% of the world's oil reserves and

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http://dx.doi.org/10.1016/j.enconman.2015.07.023
0196-8904/

Nomenclature

CEEPS	clean and energy efficient power scheduling
CC	combustion chamber
DG	distributed generation
ESF	energy storage facilities
FF	fossil fuels
GHG	global greenhouse gas
HPP	hybrid power plant
HRS	heat recovery system
ICE	internal combustion engine
KSU	King Saud University
RES	renewable energy sources
a_{Ti}, b_{Ti} & c_{Ti}	fuel utilization coefficients of ith tri-generation unit
E	energy at ESF
$F_{et}(P_{Ti})$	emission function
$F_{fut}(P_{Ti})$	fuel utilization function
N_T	number of tri-generation units
P	power
P_D^A	actual demand
P_D^T	total demand
P_r^d	delivered renewable power
P_r^g	generated renewable power
P_{Ti}	dispatched power by ith tri-generation unit
T	time period
x	renewable penetration level
y	fraction of the stored power to be dispatched
$\%\Delta F_{fut}^{HS}$	percentage saving of fuel utilization
$\%\Delta F_{et}^{HS}$	percentage reduction in pollutants emissions

Greek letters

α_{Ti}, β_{Ti} & γ_{Ti}	emission coefficients of ith tri-generation unit
η_{eTi}, η_{hTi} & η_{copi}	electrical, thermal and cooling efficiencies of ith tri-generation unit

Subscripts

b	fuel input
dl	delivered
sa	solar available
su	solar unavailable
st	stored
E	electrical
H	heating
C	cooling

world's fifth largest natural gas reserves [18]. Hence, the optimal and efficient use of available resources in the country is not only beneficial to the kingdom but to the entire world.

Several studies have surveyed the environmental and climatic effects of fossil fuel consumption [19], and the impacts of energy system transition from fossil fuel to lower-pollution energy, such as natural gas [3]. Some studies focus on energy based carbon emissions [20], and other studies found the mechanism of environmental effects and developed related mathematical models [21,22]. One of obvious conclusions is that renewable energy can reduce the pollutants and carbon emission, and increase environmental and climatic health. Natural gas may or may not achieve that with high uncertainty. A study with effective modeling of hybrid power systems scheduling could ensure optimum fuel utilization and minimum pollutant emissions while meet the power demand as well.

Optimum power dispatch scheduling problems for conventional thermal plant [23], tri-generation based thermal plant [24], hybrid plant [25] and hybrid plant with ESF [26] have been discussed in the early literatures. Such methods have not be adequately addressed for tri-generation based hybrid plants. However, in this paper, power scheduling of a hybrid power plant consisting of tri-generation and RE based generation units with ESF is proposed and modeled for King Saud University (KSU), one of the premier institutions of higher education in Saudi Arabia which was established in Riyadh, the capital city of the Kingdom in 1957. National Electrical Grid (NG) of Saudi Arabia supplies the campus energy needs through two substations: 100 MW old substation and 240 MW new substation. The old substation load reached its peak while the current load of the new substation is almost 80 MW and it is designed to supply for the expected higher demand by the future expansion of the campus. The region of KSU is enriched by the availability of solar [27] and some wind [28] resources. Also, high values of solar insolation are available during the peak demand periods of the university. Its load profile consists of high demands for cooling and heating loads. Therefore, tri-generation in the presence of renewable energy (RE) and energy storage facility (ESF) can play a significant role to facilitate a clean and reliable power supply to the KSU campus.

The optimization of clean and energy efficient power scheduling (CEEPS) proposed for KSU is carried out and analyzed with the aid of MATLAB simulations. Considerable amounts of fuel utilization and pollutants emissions are achieved by the analysis and these results indicate the effectiveness and applicability of proposed method in renewable resources rich areas.

2. Methodology and formulation

2.1. Proposed scheme

The power plant considered here consists of three tri-generation based thermal units (two diesel and one natural gas fired), two RES based generation units (1. Solar and 2. Wind) and one energy storage facility for supplying King Saud University (KSU) demand. Load scheduling at the proposed plant is carried out using one month (June 2014) load demand as well as applicable solar and wind data. Major share of University's electricity is contributed to supply cooling (air conditioning) and heating (hot water supply) demands. Hence, proposed approach has a significant role in fuel saving and pollutants reduction. Fig. 1 shows the current and proposed power scheduling scheme at KSU.

In current scheduling scheme, the electricity from National Electrical Grid contributes the required electric, heating and cooling power demands while in the proposed supply scheme, these demands are contributed by the optimum scheduling of tri-generation as well as renewable power units. Gas/diesel fired internal combustion engines are considered as prime movers for the tri-generation units. Let, P_b is the fuel input power of tri-generation plant. η_{eT}, η_{hT} and η_{cop} are the electrical and thermal conversion efficiencies and coefficient of performance of absorption chiller of tri-generation plant, respectively. While fuel burned in combustion chamber (CC), it drives the alternator and hence produces electricity ($\eta_{eT}P_b$). The exhaust hot gas from the CC is then captured using heat recovery system (HRS) which produces heating power ($\eta_{hT}P_b$). Some part (λ_1) of this heat is applied to absorption chillers to produce cooling power ($\lambda_1\eta_{hT}\eta_{cop}P_b$) and remaining ($(1-\lambda_1)\eta_{hT}P_b$) is supplied to meet heating power demand.