Energy 113 (2016) 1018–1030

Contents lists available at ScienceDirect

Energy

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

Desalination plants and renewables combined to solve power and water issues

Yu-Ching Tsai [a, b], Chih-Pin Chiu [a], Fu-Kuang Ko [b], Tzong-Chyuan Chen [c], Jing-Tang Yang [a, *]

[a] Department of Mechanical Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei 10617, Taiwan
[b] Institute of Nuclear Energy Research, No. 1000, Wenhua Rd., Jiaan Village, Longtan Township, Taoyuan County 32546, Taiwan
[c] School of Management, Taipei Medical University, 20F, No. 106, Sec 2, Ho-Ping E. Rd., Taipei 10622, Taiwan

ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form
24 July 2016
Accepted 25 July 2016
Available online 3 August 2016

Keywords:
Desalination
Hydropower
Renewables
Operation model

ABSTRACT

To enhance the security and dispatch ability of a system to supply water and electricity in a cost-effective manner, we propose a model to integrate the operations of a reservoir, hydroelectric power, desalination and wind power. The effect of seasonal energy storage for intermittent wind power is taken into account such that desalination plants can increase power consumption during cold seasons in which wind power is abundant but power demand is small, and can then relieve the burden of water supply from existing reservoirs to enable full operation during peak hours in hot seasons. Our model differs from the combination of an energy-storage system, pumped hydropower, desalination and renewables commonly applied in preceding research. A case study of Taichung city shows that the proposed model can fulfill that water requirement in 2030; the capability of sharing the peak load of existing hydroelectric power units is greatly increased from 398 MW to 1368 MW with an addition of extra 342-MW units, which also eliminate the requirement for 979-MW gas-turbine power fired with natural gas, even though, according to the proposed model, the greater expense from desalination can become compensated by the decreased expense from the power sector.

1. Introduction

Renewables have played an important role in decreasing carbon emission from the power sector. According to REN21 [1], the renewable fraction of electricity by the end of 2014 was estimated to be 22.8%. Although most renewable electricity still comes from hydroelectric sources (16.6%), the contribution from wind power (3.1%) is no longer negligible and continues to increase. The intermittent nature of wind power, however, becomes a serious issue on integrating much wind power into an existing grid. As wind power increasingly penetrates the power grid, the fluctuation of wind power might cause difficulty in regulation and dispatch of power, and might cause a collapse of the grid system in the worst case [2]. For those countries at latitudes such as that of Germany, the seasonal variation of wind power supply matches the seasonal power demand profile [3], and the installed capacity of wind power can assist to relieve the demand from traditional power units. In contrast, for those counties at latitudes such as that of Taiwan, the peak demand for power occurs during summer, but the supply of wind power peaks during winter; this seasonal mismatch between supply and demand would result in little relief of traditional power units with increasing wind power.

The climate change affects both the power sector and the water sector. For example, although the annual rainfall apparently remains stable, the intensity of rainfall has increased in recent years; this uneven distribution of rainfall is becoming serious in southern Taiwan [4]. The current system of water supply, especially the reservoirs, will become challenged by the hazards caused by strong rainfall and a water shortage due to a seriously uneven seasonal distribution of rainfall. As most reservoirs in Taiwan face serious problems from silt deposits and as the average remaining effective capacity is only 66%, the water shortage will become worse with the aforementioned problems. From the perspective of the water policy proposed by Taiwan's Water Resource Agency (WRA) [5], 0.5 million cubic meters (Mm^3) per day (182.5 Mm^3 per year) of desalination water will be required in Taiwan by year 2031. Issues of water supply affect also the power supply. As most traditional units for hydroelectric power in Taiwan rely on the water discharged

* Corresponding author.
E-mail address: jtyang@ntu.edu.tw (J.-T. Yang).

http://dx.doi.org/10.1016/j.energy.2016.07.135
0360-5442/

Nomenclature

CC	combined cycle
CGT	conventional gas turbine
C_{des}	desalination unit capacity, $Mm^3\ h^{-1}$ (Million cubic meter per hour)
$C_{hydro,\ i}$	proposed hydro-turbine capacity of "i" unit, MW
$C_{hydro,design}$	designed flow for proposed Techi hydro-turbine, $Mm^3\ h^{-1}$
C_{sg}	Shigang reservoir effective capacity, Mm^3
C_{Techi}	Techi reservoir effective capacity, Mm^3
C_{wst}	WST capacity, Mm^3
E_{cgt}	power supported from CGT power plants, MWh
E_{des}	power required by desalination, MWh
E_r	output of hydropower for all units, MWh
$E_{r,i}$	output of hydropower of "i" unit, MWh
E_{wind}	output of wind power, MWh
$EL_{disc,i}$	elevation of hydro-turbine discharge of "i" unit, m
EL_{full}	reservoir full water level, m
EL_{hi}	above this elevation, hydropower is fully operated, m
EL_{hihi}	above this elevation, flushing is required, m
EL_{intake}	elevation of Techi hydropower intake duct, m
$EL_{noflush}$	below this water level, flushing is not possible, m
$EL_{r,i}$	water level of "i" reservoir, m
H_{design}	designed water head for proposed Techi hydro-turbine, m
η_{loss}	proposed hydro-turbine head loss, %
ϕ_{des}	specific energy consumption of desalination, kWh m^{-3}
$\phi_{hydro,i}$	proposed hydro-turbine efficiency at design point for "i" unit, %
$Q_{balance}$	balance of inflow and outflow in Shigang reservoir, $Mm^3\ h^{-1}$
Q_d	water demand, $Mm^3\ h^{-1}$
Q_{des}	water supplied by desalination plants, $Mm^3\ h^{-1}$
$Q_{desilting}$	desilting flow rate, $Mm^3\ h^{-1}$
Q_{eco}	outflow for ecological consideration, $Mm^3\ h^{-1}$
$Q_{flushing}$	flushing flow rate, $Mm^3\ h^{-1}$
Q_{hydro}	water through Techi hydro-turbine, $Mm^3\ h^{-1}$
$Q_{hydro,design}$	Proposed Techi hydro-turbine flow at design condition, $Mm^3\ h^{-1}$
$Q_{hydro,max}$	maximal flow for hydropower under a specified water level, $Mm^3\ h^{-1}$
Q_{Maan}	outflow from Maan unit, $Mm^3\ h^{-1}$
$Q_{rain,\ Techi}$	inflow of Techi reservoir, $Mm^3\ h^{-1}$
Q_{Techi}	outflow from Techi reservoir, $Mm^3\ h^{-1}$
$Q_{tributary}$	outflow from tributaries downstream of Techi reservoir, $Mm^3\ h^{-1}$
$Q_{typhoon}$	when inflow is above this flow rate, flushing activity is required, $Mm^3\ h^{-1}$
$Q_{wst,\ c}$	water charged to WST, $Mm^3\ h^{-1}$
$Q_{wst,\ d}$	water discharged from WST, $Mm^3\ h^{-1}$
S_{sg}	water amount in Shigang reservoir, Mm^3
S_{Techi}	water amount in Techi reservoir, Mm^3
S_{wst}	water amount in WST, Mm^3
t	time, h
$X_{pattern}$	output ratio of hydropower in specific hour, (0–1, dimensionless)

Subscripts

i	1 through 5 denote units for Techi, Chin-Shan, Guguan, Tianlun and Maan, respectively.

from reservoirs, the capabilities of peak-hour support are limited largely by the water supply duty of the reservoirs.

In recent years, some research has been proposed to improve the integration of renewables and a desalination plant to solve multiple issues. For example, an integration of desalination, a traditional power plant or battery system, wind power or solar power is modeled to enhance the benefits of water supply or the penetration of renewable energies [6–8]. Some research further includes pumped-hydro storage (PHS) or brine-operated PHS in their system [9–11] to improve utilization of intermittent renewables. Gude [12] reviewed various techniques for energy storage to maintain continuous desalination from intermittent renewables; the concept of using desalination as an energy-buffering system to mitigate the intermittence of renewables was investigated [13]. The link between renewable energy and desalination does not inevitably imply a direct use of power generated from renewables for desalination; for example, the annual power required for Sydney's desalination plant [14] is offset by the power production from a wind farm that is purposed to be built for it. Most previous research focused on applications in remote areas or islands and problems related to a short-term intermittence of the renewables. Even for a system that considered the long-term seasonal storage of energy [15], the target was achieved with hydrogen technology rather than with desalination.

Rather than a common combination of a desalination plant, a storage system (either a battery system or PHS) and wind power, we propose an operating model among desalination plants, a reservoir with traditional hydropower and wind power to solve the aforementioned seasonally related issues. The historical data of Techi reservoir and the water demand in Taichung city in Taiwan serve to demonstrate the feasibility of the model.

2. System description

Fig. 1 shows our studied system: offshore wind turbines,

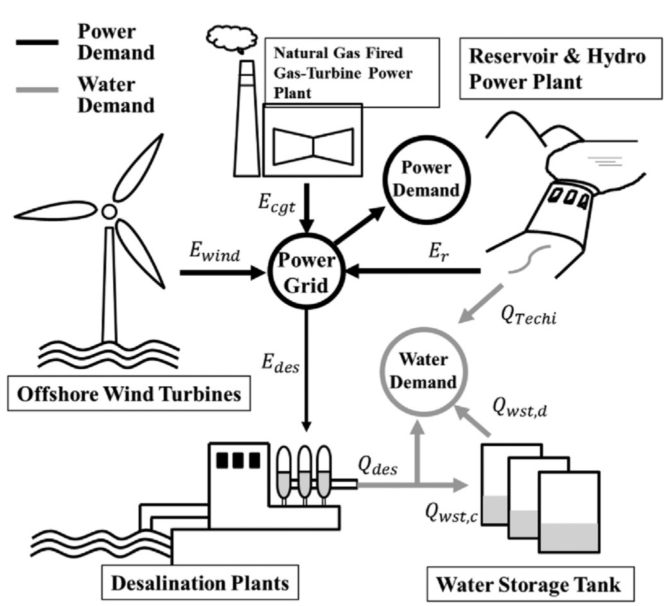

Fig. 1. Power and water supply system in this research.