Applied Energy 195 (2017) 23–35

Contents lists available at ScienceDirect

Applied Energy

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

Residential electricity cost minimization model through open well-pico turbine pumped storage system

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HIGHLIGHTS

- Utilizes domestic open wells for minimization of residential electricity cost in a dynamic electricity pricing environment.
- The operation of Pico hydro turbines (PHTs) and pump is optimally scheduled.
- The depth of the open well is effectively utilised as the working head of the PHTs.
- The feasibility of the proposed model is analysed in Indian context.

ARTICLE INFO

Article history:
Received 3 October 2016
Received in revised form 14 February 2017
Accepted 5 March 2017

Keywords:
Demand response program
Dynamic pricing
Open well
Optimal dispatch
Pico hydro turbine
Solar photo voltaic system

ABSTRACT

A residential electricity cost minimization model is proposed which can be implemented in a suburban setup where open wells are present for domestic needs. Here, a solar photo voltaic (SPV) system with pico hydro turbines (PHTs) and pump are used for minimizing the monthly electricity bill in a dynamic electricity pricing environment. Also, the available water in the open well is optimally used in order to minimize the residential electricity cost. In situations when either the price of the energy from the grid is low or when the available energy from the SPV system is in excess of the demand, the proposed model stores the energy in the form of gravitational potential energy of water in a reservoir. The stored energy is then retrieved using PHTs which feeds the load at the time when the energy price is high. The depth of the well is used as the working head for the operation of turbines and are optimally scheduled in order to minimize the water flow rate (WFR). The two fold objectives, i.e., minimizing the electricity cost and minimizing the WFR, is converted into a single objective function and is solved using particle swarm optimization (PSO). The payback period for the proposed system, if implemented, is also investigated as a case study in India.

1. Introduction

India's energy sector has grown tremendously in the last few decades, and its energy consumption has almost doubled since 2000. The potential for further rapid growth is enormous here and it is expected that India will contribute to about one quarter of world's additional energy demand in the near future. The sector wise electricity demand (%) of India in the year of 2014–15, and the projected demand (%) for the year 2040 is shown in Fig. 1 [1]. Presently, almost three quarter of this energy demand is met from fossil fuels. However, the energy mix is gradually becoming more diverse and the role of hydro power, nuclear power and modern renewable sources are increasing significantly.

On the generation side, the installed capacity as on December 31, 2016 was 290 GW, of which coal holds the largest share (60%), followed by hydropower (13.9%) and natural gas (8.2%) [1]. However, in spite of the increase in generation, India is still not in a position to meet its energy requirement and peak electricity demand. The peak power deficit in the year 2015–16 was 4903 MW (3.6%) and the shortage in terms of energy availability was 2.1% [2]. For residential consumers, this shortage is most evident and consequently they suffer from frequent load shedding. However, India possesses a large amount of untapped potential of conventional as well as renewable energy sources (RES). It has an estimated renewable energy potential of about 900 GW from commercially exploitable sources viz. wind – 100 GW (at 80 m hub height); small hydro - 20 GW; bio-energy – 25 GW and 750 GW solar energy [3]. In addition, there exists significant potential for decentralized, distributed generation using these RES and

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http://dx.doi.org/10.1016/j.apenergy.2017.03.020

Nomenclature

$a_j, b_j, c_j, \alpha_j, \beta_j, \gamma_j$	discharge coefficients of the jth pico hydro generation unit
q_{hjt}	water flow rate of jth PHT at interval t (L/s)
$q_{hj,\min}, q_{hj,\max}$	minimum and maximum flow rate of jth pico hydro generation unit (L/s)
P_{hyd}	hydraulic power (W)
q_{Pt}	pump flow rate (L/s)
ρ	fluid density (kg/m^3)
g	acceleration due to gravity (9.81 m/s^2)
h	differential head (m)
G	solar irradiance (kW/m^2)
V_{PV}	solar PV voltage (V)
I_{PV}	solar PV current (A)
P_{PV}	solar PV power (W)
η_P	overall pumping efficiency
P_T	pico turbine output power (W)
q_T	turbine flow rate (L/s)
η_T	turbine efficiency
Δt	dispatch intervals (s)
T	dispatch time horizon (h)
τ	ambient temperature (K)
x_t	binary parameter that denotes on/off status of the pump at interval t
$y_{j,t}$	binary parameter that denotes on/off status of the generation unit j at interval t
C_t	total energy consumption at interval t (kWh)
λ_t	electricity price rate at interval t (INR/kWh)
A_t	cost of electricity for interval t (INR)
ng	number of PHTs
w_1, w_2	weight functions
υ_p	volume price penalty factor
E_{Dt}/P_{Dt}	energy/power demand at interval t (kWh)/(W)
E_{Rt}/P_{Rt}	renewable energy/power at interval t (kWh)/(W)
E_{Ht}	energy from PHTs (kWh)
E_{Pt}	energy consumption of the pump at interval t (kWh)
E_{St}	energy storage at interval t (kWh)
$E_{S,\min}$	minimum level of energy storage (kWh)
$E_{S,\max}$	maximum level of energy storage (kWh)
P_{Lt}	power loss at interval t (W)
Vol_t	water volume at interval t (L)
$Vol_{\min}, Vol_{\max}$	minimum and maximum volume (L)
P_{Pt}	pump input power at interval t (W)
P_{hjt}	power output of jth PHT at interval t (W)
P_{Gt}/E_{Gt}	power/energy drawn from grid at interval t (W)/(kWh)
t	time index
j	PHT index

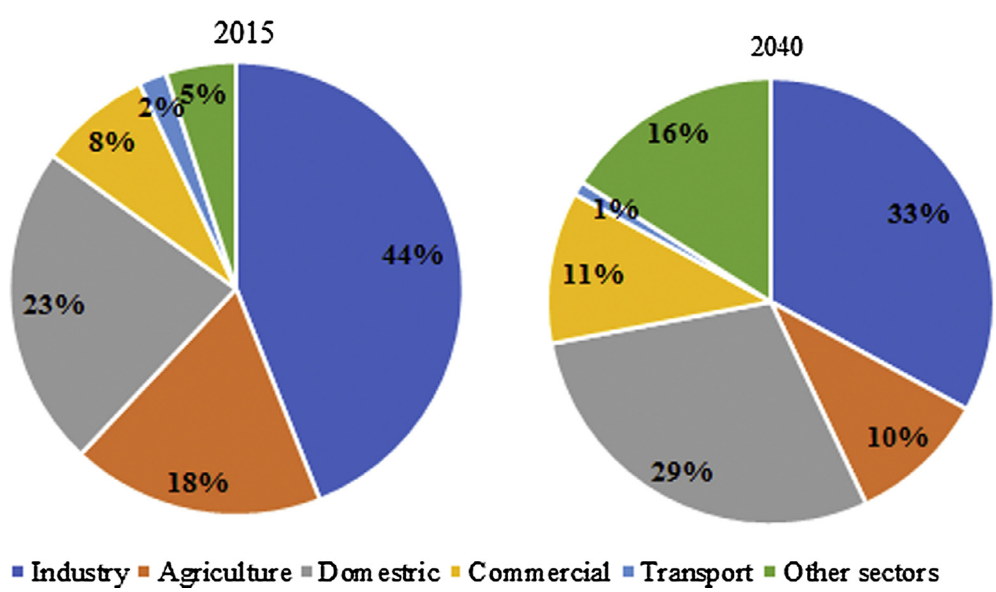

Fig. 1. Sector wise energy demand of India.

other locally available infrastructures. Therefore, this paper aims to introduce a system by which these untapped potentials can be utilised to generate power at the residential consumer end.

India is basically an agriculture dependent country and its economy relies heavily on rural agriculture. It depends mainly on ground water schemes such as open wells (dug wells) and tube wells to fulfil the irrigation and other domestic needs. In most villages, water is drawn from these open wells and stored in upper reservoir tanks. According to the latest available minor irrigation census data, the number of ground water schemes has increased significantly in various part of India. There are 9.2 million open wells in 609 districts of the country irrigating 15.6 million ha of land. Nearly 70% of these open wells are up to 20 m deep and are largely owned by marginal and small to semi medium farmers [4]. The region wise distribution of open wells in India is shown in Fig. 2. The highest concentration of open wells is found in the hard rock areas of Gujarat and Tamil Nadu.

The locally-produced and resource-specific technologies for electrification will reduce the need to import systems and in turn reduce the electricity cost. Therefore, it is always better to use the available infrastructures and resources in the consumer end more effectively. In rural and suburban areas, open wells with upper reservoir tanks are already available with majority of residential consumers. These local facilities, along with RES, can be enabled to develop a green power generation system using pico hydro turbines (PHTs) [5]. In [5], the PHT and open well with