Journal of Energy and Power Engineering 11 (2017) 528-536
doi: 10.17265/1934-8975/2017.08.004

An Optimization Approach for Unit Commitment of a Power System Integrated with Renewable Energy Sources: A Case Study of Afghanistan

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Received: May 15, 2017 / Accepted: July 18, 2017 / Published: August 31, 2017

Abstract: This paper focused on generation scheduling problem with consideration of wind, solar and PHES (pumped hydro energy storage) system. Wind, solar and PHES are being considered in the NEPS (northeast power system) of Afghanistan to schedule all units power output so as to minimize the total operation cost of thermal units plus aggregate imported power tariffs during the scheduling horizon, subject to the system and unit operation constraints. Apart from determining the optimal output power of each unit, this research also involves in deciding the on/off status of thermal units. In order to find the optimal values of the variables, GA (genetic algorithm) is proposed. The algorithm performs efficiently in various sized thermal power system with equivalent wind, solar and PHES and can produce a high-quality solution. Simulation results reveal that with wind, solar and PHES the system is the most-cost effective than the other combinations.

Key words: Generation scheduling, unit commitment, renewable energy sources, GA.

1. Introduction

Thermal unit generation requires extensive use of burning fossil fuels, which is expensive since the price of fuel is increasing. Moreover, fuel burning produces emission of gases such as CO_2, SO_2 which have negative effect on environment. Therefore, concerns regarding alternative sources of energy and power that are cheaper in price, stamp environmental friendly feature are growing.

Renewable energy sources are therefore receiving significant importance in recent researches and studies due to the lower electricity generation price and positive effect on environment. However, because of their highly unpredictable nature and fluctuating power production, these sources are not yet in the position of fully replacing the fuel-based thermal generation. Among these energy sources, solar and wind power are widely investigated, and their integration with thermal power systems has been studied [1-5]. This paper considers generating renewable energy connected to a power system to minimize the total thermal units operation cost plus total imported power tariffs.

The generation planning problem also known as UC (Unit Commitment) is a typical optimization problem which plays a prominent role in power system operations planning that aims at determining which generating units are the most cost-effective to be dispatched in order to meet the demand and spinning reserve requirement over time horizons ranging from one day to one week. Several technical constraints and economic factors such as generating unit minimum up and down times, start-up costs and shutdown cost, etc., should be taken into consideration in the solution, making the UC of thermal units one of the most difficult optimization problems in power system

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operation. A variety of numerical optimization approaches [6-13] can be found in the literature to solve the UC problem. Quite promising results in terms of fuel cost savings have been reached in most works. However, among these works imported power tariffs were not involved in the generation scheduling problem and at the same time renewable energy system was not considered.

The main novelty of this paper is that it involves a power system having thermal units, hydro units, and imported powers which electrify Northeast region of Afghanistan with high thermal operation costs and imported power tariffs during summer. As a result, wind, solar and PHES are considered to schedule all units power output so as to minimize the total operation cost of thermal units plus aggregate imported power tariffs during the scheduling horizon.

2. Problem Formulation

The generation system under study is shown in Fig. 1. It consists of thermal system, hydro system, imported powers from Tajikistan and Uzbekistan, wind, solar and PHES (pumped hydro energy storage) systems. In this research, the main objective of solving short-term generation scheduling problem considering wind, solar and PHES is to find the optimal amounts of generation power for all units as well as to determine the startup/shutdown status of thermal units over the study period so that the total operation cost of thermal units plus the total tariffs of imported power is minimized. It can be formulated as follows:

Objective function

$$Min.TC \quad (1)$$

where,

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{NG}\left[FC_i(P_{i,t}) + SC_i(1 - U_{i,t-1})\right]U_{i,t} + \sum_{t=1}^{T}\sum_{z=1}^{Z} c_{z,t}\cdot PF_{z,t} \quad (2)$$

where, TC is the total cost (thermal units operation cost plus buying or importing power cost) over the study time. FC_i is the fuel cost of the ith thermal unit which can be expressed as quadratic function of real power generation.

$$FC_i(P_i) = a_i + b_iP_i + c_i{P_i}^2 \quad (3)$$

where, a_i, b_i and c_i are the fuel coefficients. $P_{i,t}$ is power output of the ith thermal unit at hour t, SC_i is the start-up cost for unit i and it is defined as follows:

$$SC_i = \begin{cases} hcost_i: MDT_i \le X_{i,off} \le MDT_i + cshour_i \\ ccost_i: X_{i,off} \ge MDT_i + cshour_i \end{cases} \quad (4)$$

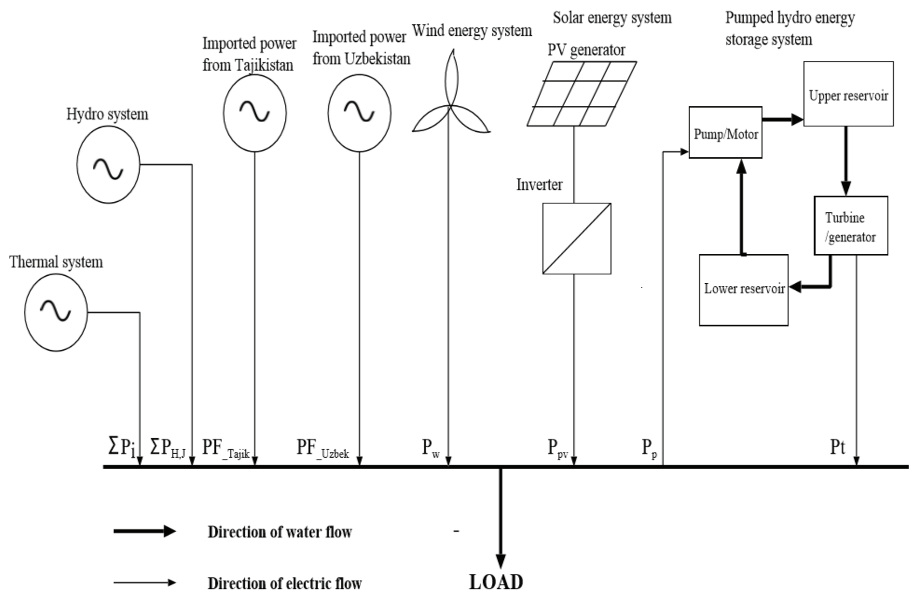

Fig. 1 Generation system under study.

where $hcost_i$ and $ccost_i$ denote the hot start-up cost and cold start-up cost of thermal unit i respectively. MDT_i shows the minimum down time of unit i, $X_{i,off}$ depicts duration of unit i being continuously off, $cshour_i$ represents the cold start hour of unit i. $U_{i,t}$ depicts the on/off [0, 1] status of unit i at hour *t*; $c_{z,t}$ is cost of power/MWh import of Afghanistan from country z. $PF_{z,t}$ is power flow (import) from country z to Afghanistan at time *t*.

2.1 System Constraints

(1) Power balance constraint

$$\sum_{i=1}^{NG} P_{i,t} + \sum_{j=1}^{J} P_{H,j} + P_{w,t} + P_{PV,t} + P_{T,t} = D_t + P_{P,t} \quad (5)$$

where,

$P_{H,j}$: Output power of the jth hydro unit at hour *t*;

$P_{PV,t}$: Power supplied by solar energy at time *t*;

$P_{w,t}$: Wind generator output power at hour *t*;

$P_{T,t}$: Power produced by the motor/generator unit at time *t*;

$P_{P,t}$: Input power from the system to the pump at time *t*;

D_t: System load demand at hour *t*.

(2) System spinning reserve requirements

For the sake of generalization this study uses an approximation of spinning reserve amount 10% of the load demand which is expressed as follows:

$$\sum_{i=1}^{NG} \left(U_{i,t} \cdot P_{i,t,max}\right) \geq 1.1 D_t \quad (6)$$

2.2 Generator Physical Constraints

(1) Generating unit limit

The active power output of each generating unit must be within its minimum and maximum limits:

$$P_{i,min} \leq P_{i,t} \leq P_{i,max} \quad (7)$$

where, $P_{i,min}$ and $P_{i,max}$ are the minimum and maximum real power output respectively.

(2) Units minimum up and down time constraints

Owing to operational limitations, once a unit is committed/decommitted it should be kept stable for a minimum period before a transition:

$$T_i^{on} \geq MUT_i \quad (8)$$

$$T_i^{off} \geq MDT_i \quad (9)$$

where,

T_i^{on}: The total up-time of ith unit;

MUT_i: The minimum up-time of ith unit;

MDT_i: The minimum down-time of ith unit.

(3) Ramp rate up/down constraint

The change of the generating units output power is not increasing or decreasing instantaneously. The change of this power output is restricted by ramp rate limits:

$$P_{i,t} - P_{i,t-1} \leq UR_i, \; if\ generation\ increases \quad (10)$$

$$P_{i,t-1} - P_{i,t} \leq DR_i, \; if\ generation\ decreases \quad (11)$$

In the above equation, UR_i and DR_i show the ramping up and ramping down of ith unit respectively.

2.3 Modeling of PV, Wind Generator and Pumped Hydro Energy Storage Subsystem

In this paper, the mathematical model of PV and wind is adopted from Ref. [14] and for PHES the mathematical models used in Refs. [15, 16] are employed in this research.

3. GA (Genetic Algorithm)

GA is based on natural selection, the process that drives biological evolution. It is an algorithm for the solution of both constrained and unconstrained optimization problems. In every iteration, GA randomly selects individuals from the current population called parents and uses them to produce next generation called children. After successive iterations, the population evolves toward an optimal solution. The following section shows how GA works.

3.1 How GA Works

GA works as the following steps:

Step 1: Initial Population

GA starts with the creation of random initial populations. The default value of population size in the population options is 20 individuals. However, one can change the population size as he wants.

Step 2: Calculation of Fitness Function

The individuals are putted into fitness function and its value is calculated.

Step 3: Creating Next Generation

At each step, GA uses the current population to create the children that make up the next generation. GA creates three types of children for the next generation: (1) Elite children; (2) Crossover children; (3) Mutation children.

Step 4: Stopping Conditions for GA

If the stopping condition is met, the algorithm is stopped and the fitness values are selected as optimal solution, otherwise steps 2-3 are repeated.

4. Simulation Results and Discussions

4.1 Simulation Inputs

The proposed system shown in Fig. 1 consists of three thermal units, three hydro units, two sources of imported power, one equivalent wind energy system, one equivalent solar energy system and one equivalent PHES system. The data for generating units are given in Table 1. The hourly load demand is shown in Fig. 2. The solar radiation and wind velocity data are shown in Figs. 3 and 4, respectively. The MATLAB software is applied to code and simulate the GA to get the optimal values of the decision variables to make the objective function minimized. In order to observe the effectiveness of the proposed system we consider three cases to simulate.

Case 1: The thermal generating system, hydro system and imported power from Uzbekistan and Tajikistan are used to supply load demand.

Case 2: Thermal, hydro, imported powers, wind energy and solar energy are connected to supply load demands. In this case, the PHES is not connected to the system.

Case 3: All generating systems, including the PHES are connected to supply load demands.

4.2 Simulation Results

The simulation results (Figs. 5-16) obtained by running the proposed method, for Cases 1-3 are discussed below.

In Case 1, the hydro units, thermal units and imported powers are employed to supply the load demands. The results include the total cost TC = \$5.2 × 10^5 (fuel cost TC = \$8.8 × 10^4, startup cost SC = \$480 (Fig. 8), and total imported tariffs = \$4.3 × 10^5). Fig. 5 depicts the output power of each unit and hourly load. It is observed from the results in Fig. 5 that the total generation meets the load demands.

In Case 2, wind and solar renewable energy systems are included in the system in Case 1 to supply the load demands. The results include the total cost TC = \$3.7 × 10^5 (fuel cost TC = \$8.0 × 10^4, startup cost SC = \$1040 (Fig. 9), and total imported tariffs = \$2.99 × 10^5). Fig. 6 depicts the power generation of each unit and the load demand. The results in Fig. 6 show that the total thermal power output and imported power can be reduced by adding wind and solar renewable energy systems. This is to say that the total cost can be saved.

Table 1 Data for the UC problem.

	(T-1)	(T-2)	(T-3)	(H-1)	(H-2)
P_{max} (MW)	105	22	23	22	66
P_{min} (MW)	15	5	5		
a (\$/h)	680	660	665		
b (\$/MWh)	16.5	25.92	27.27		
c (\$/MW^{2}h)	0.00211	0.00413	0.0022		
MUT (h)	4	1	1		
MUD (h)	4	1	1		
h-cost (\$)	560	30	30		
c-cost (\$)	1,120	60	60		
cshour (h)	4	0	0		
Initial status (h)	4	1	1		

	(H-3)	PF_Tajik	PF_Uzbek
P_{max} (MW)	100	300	300
P_{min} (MW)		0	0
a (\$/h)			
b (\$/MWh)		20	60
c (\$/MW^{2}h)			

T-1: thermal unit 1; T-2: thermal unit 2; T-3: thermal unit 3; H-1: hydro unit 1; H-2: hydro unit 2; H-3: hydro unit 3.

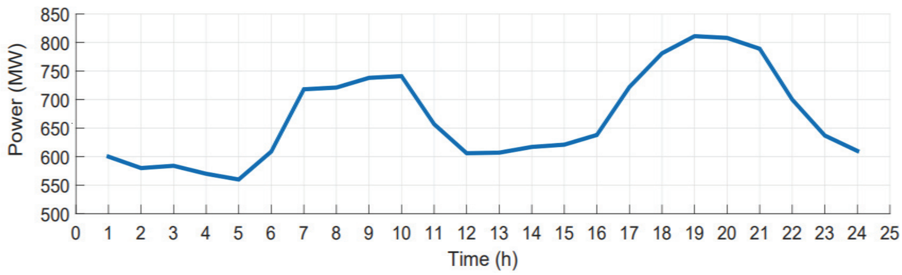

Fig. 2 Daily load demand.

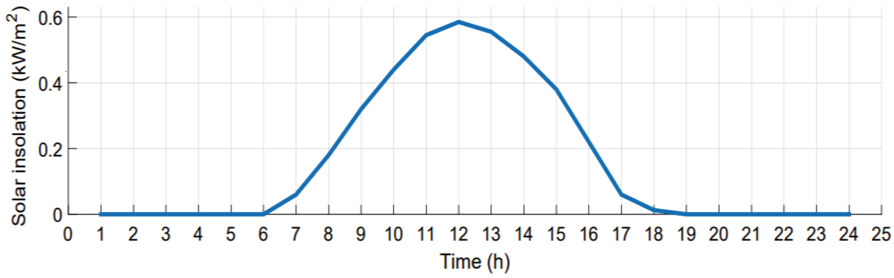

Fig. 3 Daily solar radiation.

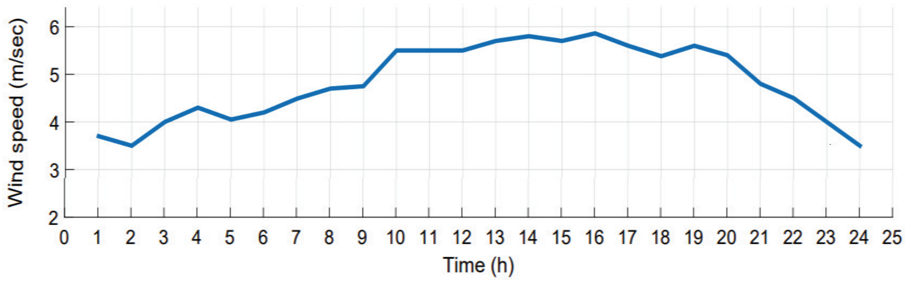

Fig. 4 Daily wind speed.

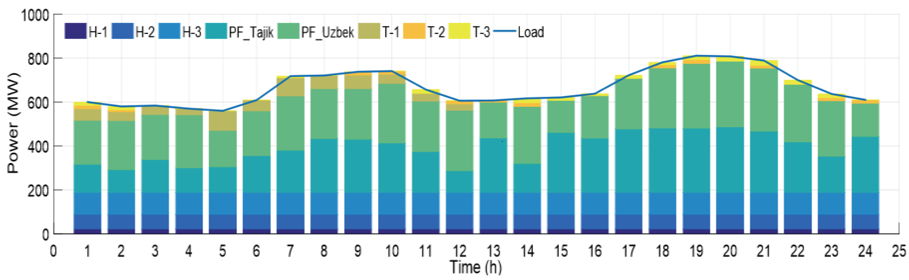

Fig. 5 Output power of units: Case 1.

In Case 3, the generation system that includes all generating units (with PHES) is used to supply load demands. Now we get the total cost TC = \$3.02 × 10^5 (fuel cost TC = \$7.5 × 10^4, startup cost SC = \$920 (Fig. 10), and total imported tariffs = \$2.26 × 10^5). Fig. 7 illustrates the total output power of each unit and the load demand. Figs. 11 and 12 indicate the total thermal power (thermal power output plus imported power) and the total cost (thermal units operation cost plus buying or importing power cost). Figs. 13-15 illustrate the on/off status of each thermal unit for Case 3. Fig. 16 illustrates the total wind, solar and PHES system power output over the 24 h scheduling period. From Fig. 16 the negative generating power output indicates the pumping operation for the PHES plant during the light load period.

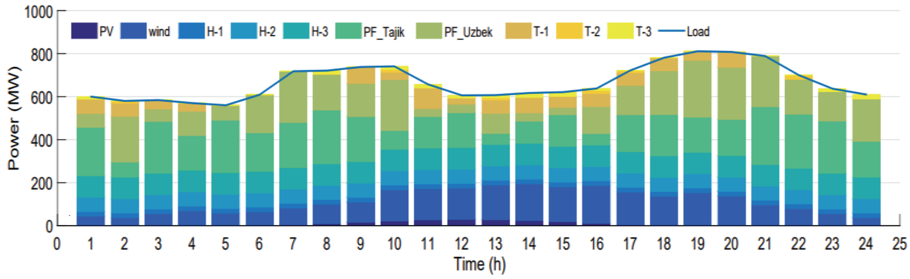

Fig. 6 Output power of units: Case 2.

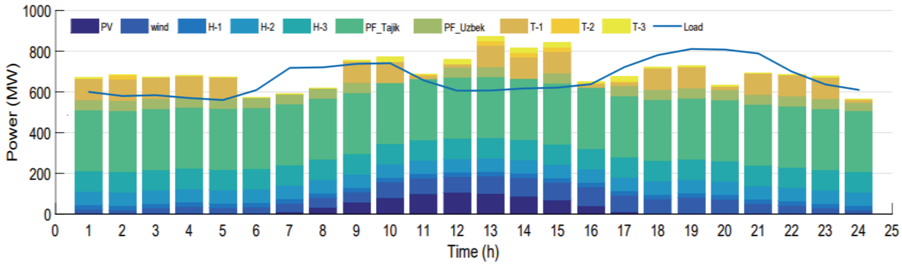

Fig. 7 Output power of units: Case 3.

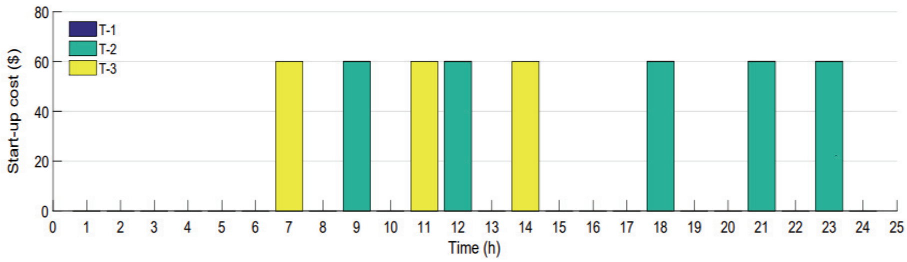

Fig. 8 Start-up cost of thermal units: Case 1.

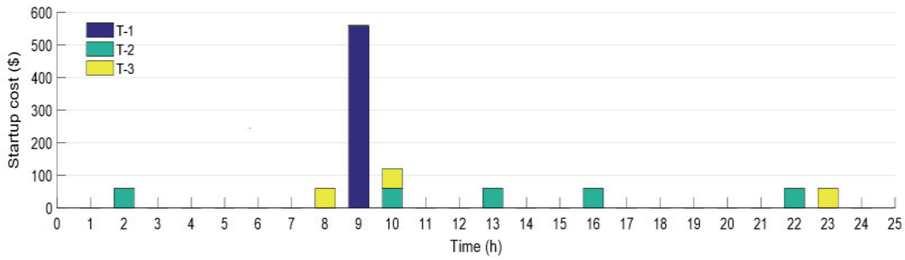

Fig. 9 Start-up cost of thermal units: Case 2.

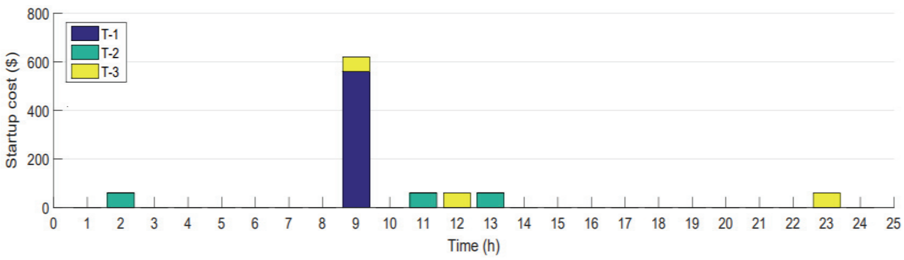

Fig. 10 Start-up cost of thermal units: Case 3.

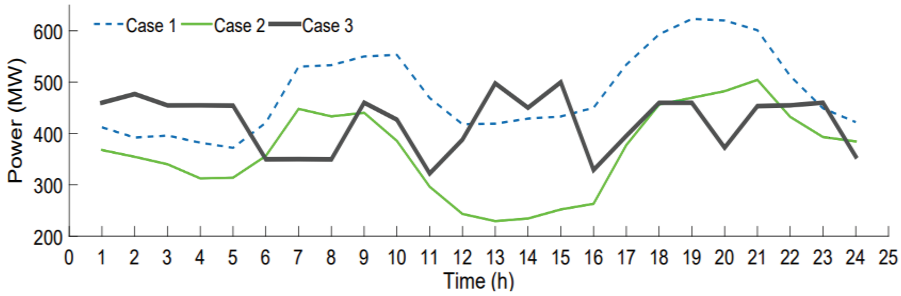

Fig. 11 Thermal power output plus imported power.

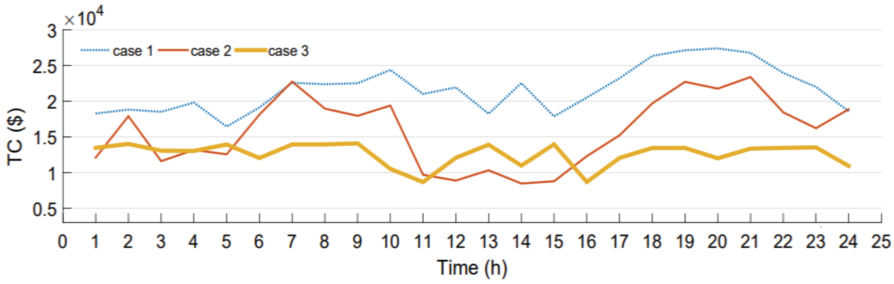

Fig. 12 Total cost (thermal units operation cost plus buying or importing power cost).

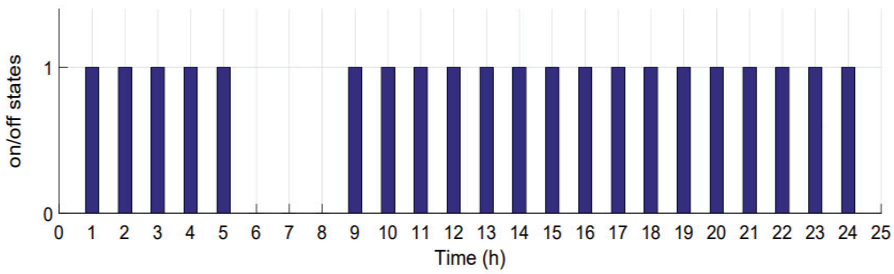

Fig. 13 On/off schedule of thermal 1: Case 3.

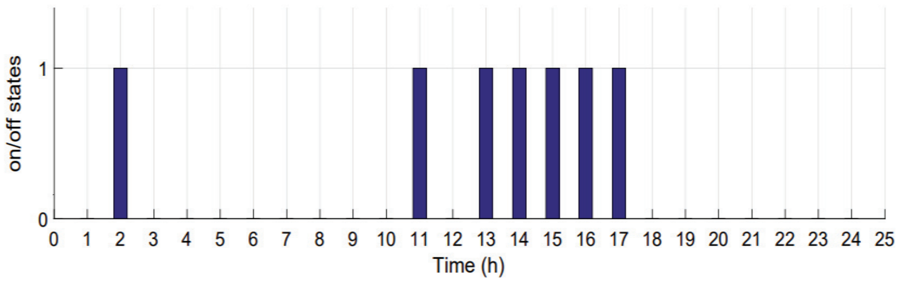

Fig. 14 On/off schedule of thermal 2: Case 3.

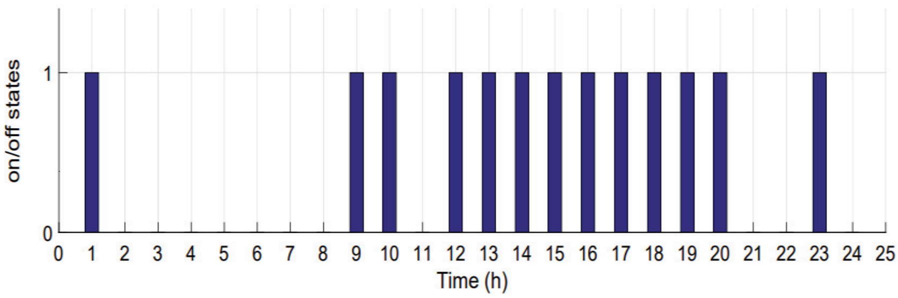

Fig. 15 On/off schedule of thermal 3: Case 3.

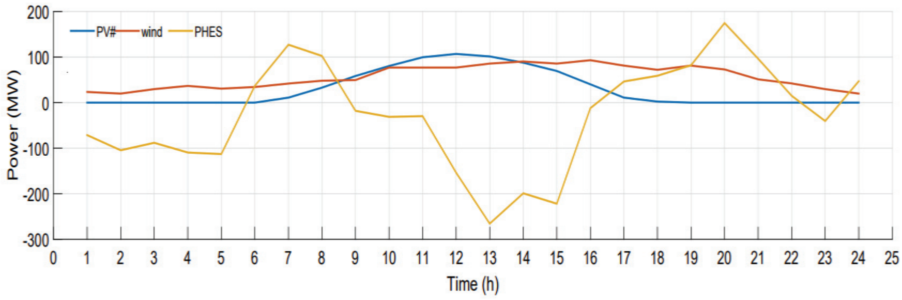

Fig. 16 Output power of PV, wind and PHES: Case 3.

From the results above, the following observations can be made:

(1) Using case 1, hydro units, thermal generating system and imported power from Tajikistan and Uzbekistan are used to supply the load demand. The total cost which is comprised of fuel cost, start-up cost and imported power cost is the most expensive.

(2) Using case 2, the cost can be reduced by adding wind and solar renewable energy systems. The total cost is saved about $\$1.5 \times 10^5$ (Fig. 12).

(3) Using case 3, the total cost is the lowest among the three cases. The fuel energy for the thermal generating units can be significantly saved and imported power from Tajikistan and Uzbekistan can be decreased (Fig. 12).

5. Conclusions

An optimization model for electrifying the northeast region of Afghanistan was developed in this paper. For the proposed model, the generation scheduling problem considering wind, solar and PHES systems was solved. The GA was used to find the best values for decision variables to minimize the objective function subject to system and unit constraints. To demonstrate the effectiveness of the proposed control approach, three cases were considered. First, hydro, thermal and imported power system were used to supply load demands. Second, wind and solar energy were included in the system to cover the load demands. And third, wind, solar and PHES systems were added to the system. The simulation results revealed Case 3 is the most economic among the three cases and showed the ability of the proposed algorithm for producing optimum results.

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