"CORRELATION BETWEEN RENEWABLE ENERGY SOURCE’S ENERGY OUTPUT AND LOAD"

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ABSTRACT:

The common problem to all renewable energy sources (RESs) is the mismatch between their energy output and load demand. In remote areas, the solution of this problem is in general employing a small diesel-generator or a storage battery. But, the storage battery is a major cost element of RESs and small diesel-generator is unreliable and costly. Therefore, a proposed technique has been introduced in this work to determine correlation between the energy output of wind energy systems (WES) and isolated loads. Solar photovoltaic power system (PVS) and two of energy storage facilities are used here for this correlation. The proposed technique includes also two models for optimizing the generation and costs of WES accompanied with PVS, storage battery and water storage (reservoir) to accommodate an isolated load.

The proposed technique is applied with the dynamic programming to coordinate the energy output of a WES with residential and pumping load in remote area of Egypt. The results of this application reveal that minimization of both capacity of the storage battery and the whole power system cost are obtained.

1. INTRODUCTION

In remote areas, electricity is often supplied by a single diesel generator. But, this source is unreliable and costly[1]. Also, the unavailability of commercial fuels in remote areas offer a rewarding operation and utilization of locally available renewable energy sources (RESs). These sources can be used to supply residential electrical loads and water-pumping in rural and remote areas [2,3]. The main types of RESs pertaining the meteorological conditions of many of the world countries as well as Egypt are solar photovoltaic and wind energy systems (PVS & WES). The intermittency of the solar radiation and variation of wind speed are the main problem of these sources. Also, the mismatch between the energy output of PVS and WES and isolated loads is the more serious problem for operating these systems.
In previous publications [4], a proposed generation model has been introduced to develop the availability of employing PVS and WES to meet an isolated load. Also, a load management technique had been introduced to minimize the capacity of the storage battery. But, the effect of this technique on the whole power system cost is not determined. In other references [5,6], number of computer packages had been introduced for solving the correlation between the meteorological data and load demand, then planning RESs with conventional generation. The economy of these systems is not optimized.

In this work, a proposed technique has been introduced to assess the correlation between energy output of a WES and isolated load. Solar photovoltaic power system and two of energy storage facilities are used here to supply the load at the time of non-powering of WES. This technique includes two models for optimizing the generation and costs of WES accompanied with PVS, storage battery and water storage (reservoir) to supply an isolated load.

2. PROPOSED TECHNIQUE:

The proposed technique aims to find out the effect of energy storage facility used for the correlation between energy output of RES and load demand on the whole power system costs. The whole power system under investigation consists of the renewable energy source (RES), the energy storage facility and the load. The load comprises several individual loads, as residential and pumping loads. The energy storage facility such as a storage battery used with RES to supply residential loads and water storage (reservoir) used with pumping load. The RES is represented here by a wind energy system. Also, solar photovoltaic power system is used here with energy storage facilities to supply loads at unavailability output of WES. This technique includes two mathematical models, namely; generation and load model, and cost model.

a. General and Load Model:

Wind energy system (WES) may considered as the main generator, while PVS is accompanied with energy storage facilities for the correlation between the output of WES and load. The energy storage facilities are represented here by a storage battery and water storage (reservoir) as shown in Fig. 1. Thus, the generation system includes WES and PVS. The hourly output of this generation system through an average day of the year months (\( P_{\text{gen,0}} \)) may be stated as:

\[
P_{\text{gen,0}} = P_{\text{wes,0}} + P_{\text{wes,0}}
\]

(1)

where, the hourly output of WES through an average day of the year months (\( P_{\text{wes,0}} \)) is given by [4]:

\[
P_{\text{wes,0}} = K_{\text{w}} \times P_{\text{w}} (1 + U_{\text{f,0}} / U_{\text{r}})
\]

(2)
Where the constant $K_w$ is deduced as a function of the air density ($\rho$) at the installation site, the area swept of the rotor ($A$), the performance coefficient ($C_f$), and overall efficiency of the WES ($\eta$) as [7]:

$$K_w = \frac{1}{2} \rho AC_f \eta$$

The hourly output of standard PVS of 1 KW peak through an average day of the year months ($P_{WDL}$) is given by [8]:

$$P_{WDL} = m * \gamma + V_{CD} * I_{CD}$$

where;

$$V_{CD} = 24 - 2.1 \times 10^2 (T_{CD} - 25)$$

(4)

$$I_{CD} = 1.35 H(i,j) + 0.5 \times 10^2 (T_{CD} - 25)$$

(5)

The annual energy output of this standard system is used with the annual energy requirement for the load and annual energy output of the WES used to estimate the peak power of PVS required.

The mass balance equation between the hourly generation and load demand through the year months ($P_{LKL}$) may be stated as:

$$P_{WKL} = P_{WKL} + P_{LKL} + P_{WLK} + P_{WKL}$$

(6)

where,

$$P_{WKL} + P_{LKL} = P_{WKL} + P_{WKL} + P_{LKL} + P_{WKL}$$

(7)

Eqns.1-7 can be used with the dynamic programming [9] to provide a generation schedule over a certain period given the predicted insolation or effective wind speed, and the set of load. Also, management of the load and the storage facilities (storage battery and reservoir) is performed simultaneously, so that the trade-off between generation schedule and both of battery and reservoir sizing can be assessed.

b. Cost Model:

The cost model has been stated here to estimate the annual capital cost of power system. The power system in this work includes WES, PVS, storage battery and water storage (reservoir). The capital cost of these subsystems can be obtained as a function of rated or peak power of WES and PVS, and the capacities of the storage battery and reservoir. These powers and capacitances are previously determined, section 2.a. Thus, the proposed cost model can be stated as follow:

$$P_{SC} = D_r C_w * P_w + D_r C_v * P_v + D_r (C_{B} + C_{S} * E_{B}) + D_r C_f * P_f + D_r C_w * Q_w$$

(8)

where the discount rate ($D$) is given by [10]:

$$D = r (1+r)^s / [(1+r)^s - 1]$$

(9)
To develop the saving in cost relevant to the proposed technique, the annual capital cost of the power system (PSC) is determined with and without using this technique.

3. APPLICATION:

The power system in Fig. 1 has been used to supply an isolated load at a remote area in the western desert of Egypt. This load consists of residential and pumping loads as shown in Fig. 2. This figure gives the average daily load curve at the considered site. The meteorological data at this site (25° 27' N) has been collected by Meteorological Authority of Egypt and utilized with the published models [4,8] to estimate the solar radiation received on PVS array and wind speed through the year months. Consequently, the proposed technique, section 2, is used with the dynamic programming [9] to determine the generation schedule of WES and PVS, and the capacity of energy storage facilities used to meet the load demand. Then, the cost of this power system is assessed. The following information are taken into consideration through carrying out this application:

1. One of 200 kW wind-generator is used.
2. A storage battery is used to supply residential loads, while a water storage (reservoir) is used with pumping loads for irrigation at non-powering of WES and PVS.
3. The charge source for the pumping storage is restricted by the permitted loading on WES and PVS, while the storage battery is charged from PVS.
4. When operating the feeder pump, it can deliver 40% of the reservoir capacity in one hour. While, the irrigation plant's operation requires 20% of the reservoir capacity each hour.
5. The life-time of WES and PVS is taken as 20 years, while the life-time of the storage battery and reservoir is taken as 5 and 50 years respectively. The interest rate of these subsystems are taken as 10%.
6. The economical parameters of WES, PVS and storage facilities are taken from references 11,12 and 13.

Fig. 3. gives the daily energy output of WES and PVS through the year seasons. This figure concluded that the yearly energy output of WES and PVS are 490.56 and 42.34 MWh respectively. Also, the peak power of PVS is 21 KW.

The results of the dynamic programming and the proposed technique are shown in Fig. 4. This figure gives the hourly load fed from the generation system, storage battery and pumping storage (reservoir) through the year seasons. These results show that the capacity of the storage battery is 400 Ah, while the capacity of the reservoir is 1620 m³. Also, the annual power system cost in this case is 125,066 L.E. While this cost is 134,896 L.E. without using the proposed technique, where L.E. = $ 0.3.

CONCLUSIONS:

A proposed technique includes number of mathematical models is presented in this paper to determine the correlation between the energy output of a wind energy system (WES) and isolated load. This technique aims to minimize the whole power system cost by using solar photovoltaic power system (PVS) and two of energy storage facilities to
supply the load at the time of unavailability output of WES. The proposed technique is applied with the dynamic programming to coordinate the energy output of WES accompanied with PVS, storage battery and reservoir for irrigation to supply an isolated load in remote area of Egypt. The remarkable results of this application are:

1. The yearly energy output of the wind energy and solar photovoltaic power systems are 490.56 and 42.34 Mwh respectively.
2. The capacities of the storage battery and reservoir are 400 Ah and 1620 m$^3$ respectively.
3. The saving in the annual capital cost with utilizing the proposed technique is 7.29%.

**NOMENCLATURE:**

- $P_{m,j}$: the output of the generation system through the $i$th hour of the month $j$.
- $P_{m,j}, P_{w,j}$: the hourly output of solar photovoltaic and wind energy systems (PVS & WES) through an average day of the year months.
- $P_{m,j}$: the hourly power credits to the load of PVS & WES through the year months.
- $P_{m,j}$: the output power of the storage battery during the $i$th hour of the $j$th month.
- $P_{L,J}$: the load demand during the $i$th hour of the month $j$.
- $P_{w}$: the rated power of the wind-generator (WG) used.
- $P_{p}$: the peak power of the required solar photovoltaic system (PVS).
- $H_{m,j}$: the hourly solar radiation received on the PVS array through the average day of the year months.
- $V_{C(j)}$: the voltage of a PVS module through the $i$th hour of the $j$th month.
- $I_{C(j)}$: the current of a PVS module through the $i$th hour of the $j$th month.
- $T_{C(j)}$: the average temperature through the month $j$.
- $m$: the number of identical modules of the standared PVS.
- $\eta_{PC}$: the efficiency of power conditioner.
- $U_{c(j)}$: the hourly wind speed through an average day of the year months.
- $U_c, U_r, U_u$: the cut-in, rated and cut-out wind speeds of WG used.
- $P_{SC}$: the annual capital cost of the power system.
- $C_{P}, C_{w}$: the capital cost per 1KW of $P_{w}$ and $P_{p}$ respectively.
- $C_{p}$: the capital cost per 1 KW of rated power of the water-pump $P_{p}$.
- $C_{B}$: the capital cost of a battery of storage capacity $B$.
- $C_{b}$: the capital cost per 1 KWh of installed energy of the storage battery.
- $C_{w}$: the capital cost per 1 m$^3$ of the reservoir capacity $Q_{wp}$.
- $D_{P}, D_{w}, D_{b}$ & $D_{wp}$: the discount rate of PVS, WES, storage battery, water-pump and reservoir capital costs respectively.
- $r$: the interest rate, %.
- $n$: the life-time in years.
REFERENCES:


Solar System

Wind Energy System

Power Conditioner

Battery

Residential Loads.

Irrigation Plant

Reservoir

Pump

Fig. 1. The whole power system study.

Fig. 2. The average daily load curve of the isolated load study.
Fig. 3. The hourly output power of solar photovoltaic and wind energy systems through a day of different seasons.

(a) Summer season (July).
(b) Winter season (January).

Day Hours

Output Power, kW

0 20 40 60 80 100 120 140 160 180 200

PVs
WES
a. Winter Season (January).

b. Summer Season (July).

Fig. 4. The hourly power system schedule through the year seasons.