OPTIMIZING ALTERNATIVE BACKUP POWER SUPPLIES WITH WIND GENERATOR TO SUPPLY ISOLATED LOADS

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ABSTRACT

The energy output of a wind generator (WG) is variable due to the variation of wind speed at the installation site through the day hours and year months. Therefore, a back-up power supply (BUPS) is necessary for operating WG to supply isolated loads. These BUPS may be diesel generator (DG) and /or alternative sources of renewable energy system (RES) which is available at the installation site.

In this work, these BUPS$_S$ are optimized and assessed for operating with WG to supply isolated loads. The alternatives of RESs used here are photovoltaic power system (PVPS) and /or battery storage (BS). So, a hybrid model is presented here incorporates the added futures of dynamic modeling and graphic user interface in the power system block set and matlap program to assess the capacity of these BUPSs for operating with WG to supply isolated loads. Also, an economical model has been introduced to optimize the considered BUPSs from economical point of view. These models are applied numerically to estimate the capacity of alternative of WG/ DG, WG/PVPS/BS and WG/ PVPS/DG generation systems to supply an isolated load of a tourist village on the Egyptian coast of Red Sea. Also, these alternatives are optimized economically to supply the studied load .

1. INTRODUCTION

Egypt is endowed by huge wind energy potential where the coastal areas particularly the Red Sea Coast and the South Western parts of the country have high wind velocities reaching 10 m/s and 7 m/s respectively. Wind resources in these areas of Egypt have proven to be feasible for electricity generation. Several organizations directed efforts towards utilization of such resource [1,2]. However, for small single village applications hybrid photovoltaic power systems (PVPSs) may play an economical role, particularly when used in combination with other technologies in a hybrid scheme and when adequate power storage is available [3,4].

Correct sizing of remote area power system (RAPS) is very important, particularly if wind or solar energy is used. The size of the system is depending on the electrical load. The availability of wind and solar energy will also determine the size and type of system used. [5,6]. So, In this work, hybrid system of wind generator, photovoltaic power system and /or battery storage and diesel generator has been designed and operated to supply isolated load at a site in Egypt using a suggested design model. Also, an economical model is presented to optimize different alternatives of this hybrid generation system.

2. OPERATING WG WITH ALTERNATIVE BUPS

Alternative generation systems of WGs and these BUPS may be installed to supply isolated loads as:

Alternative 1 : WG /DG generation system, Figure (1).
Alternative 2: WG / BS generation system, Figure (2).
Alternative 3:WG/PVPS/BS system, Figure (3).
Alternative 4:WG/ PVPS/DG system, Figure (4).

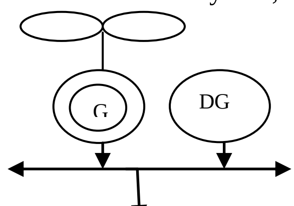

Figure (1) Line diagram of WG/DG generation system

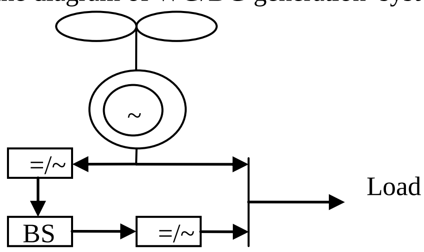

Figure (2) Line diagram of WG/BS generation system

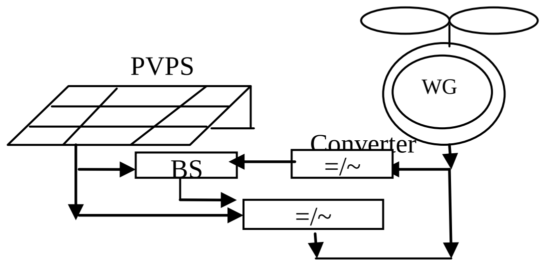

Figure (3). Line diagram of WG / PVPS/BS generation system.

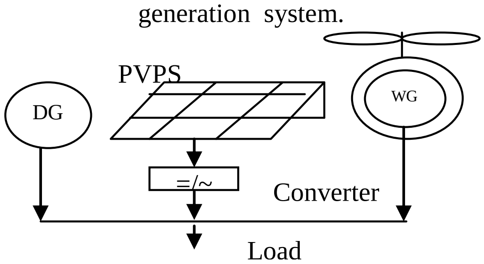

Figure (4). Line diagram of WG / PVPS/DG generation system

The WG generation curve can be used with the load curve at the study site to assess the number and rate of DG capacity of BS and sizing the photovoltaic array for supplying isolated loads.

2.1 Alternative 1:

The number and rate of the (DG) used with WG to supply isolated loads can be assessed as a function of the wind and load demand curves, in addition to the operation periods of DG throughout the day of maximum deficit of the wind generation . Also, The economy of the WG is developed as a function of the annual capital cost (ACC_{WG}) , annual operation cost (AOC_{WG}) and unit energy cost (UEC_{WG}). These costs are given as:

$$ACC_{WG} = DR_{WG} * C_{WG} * P_{WG} \quad (1)$$

$$AOC_{WG} = C_{OWG} * E_{WG}(a) \quad (2)$$

$$UEC_{WG} = (ACC_{WG} + AOC_{WG}) / E_{LWG}(a) \quad (3)$$

Where; P_{WG} is the rated power of the WG used, C_{WG} is the capital cost per 1 kW of P_{WG} , C_{OWG} is the operation cost per 1 kWh of the annual generation of the WG, $E_{WG}(a)$, $E_{LWG}(a)$ are the annual energy supplied to the load ($E_L(a)$) of WG, and DR_{WG} is the annual discount rate of the WG capital cost and developed as a function of the interest rate (r) and the WG life-time (n) as [7] :

$$DR_{WG} = r(1+r)^n / [(1+r)^n -1] \quad (4)$$

The economy of the DG is stated as following [8] :

$$CC_{DG} = C_{DG} * P_{DG} \quad (5)$$

$$ACC_{DG} = DR_{DG} * CC_{DG} \quad (6)$$

$$AOC_{DG} = \sum_{i=1}^{t_o} [(C_f + C_{ft} + C_{fs}) F_i + M_i] \quad (7)$$

$$UEC_{DG} = (ACC_{DG} + AOC_{DG}) / E_{LDG}(a) \quad (8)$$

Where, C_{DG}, C_f, C_{ff} & C_{fs} are the costs of the DG per 1 kW rate of P_{DG}, the fuel, fuel transportation and fuel storage respectively, M_i is the hourly maintenance cost of the DG, $E_{LDG}(a)$ is the annual energy supplies to the load from DG and F_i is the fuel required for i th hour of the annual operation hours (t_o) in liter and given by [9]:

$$F_i = 7.33*10^{-3} + 7.48*10^{-4} P_i + 4.53*P_i^2 \quad (9)$$

Where; $32 \leq P_i \geq 400$ Kw

UEC_{WG} of the WG/DG generation system is given by :

$$UEC_{WD} = (UEC_{WG}*E_{LWG}(a) + UEC_{DG}*E_{LDG}(a)) / E_{L(a)} \quad (10)$$

2.2 Alternative 2:

In this case the battery charged from WG when; $P_{WG}(i) > P_L(i)$. Also, the capacity and charge / discharge cycle of BS are depending on both of wind generation and load curves. To assess the capacity of these BUPS, the following load balance equation may be stated:

$$P_{WG}(i) \pm P_B(i) = P_L(i) \quad (11)$$

Where; $P_{WG}(i)$, $P_B(i)$ are the hourly power supplied by WG and BS, and $P_L(i)$ is the hourly load demand. Hence, the energy supplied to the load by this battery (E_{BS}) is:

$$E_{BS} = E_{WG} - E_L \quad (12)$$

Where, E_{WG} and E_L are the output energy of WG and energy requirement for the load respectively. The capacity of BS in this case is given as a function of overall efficiency of BS (η_{BS}) and consists of long-term BS capacity (LTBS) and short-term BS capacity (STBS). These capacities are developed as follows [10]:

$$STBS = E_{def}(m)_{max} / N_{cd}(m) * \eta_{BS} \quad (13)$$

$$LTBS = [\sum^m (E_{def}(m)/\eta_{BS})] - STBS \quad (14)$$

$$BS = STBS + LTBS \quad (15)$$

$E_{def}(m) = E_{WG}(m) - E_L(m)$ at $E_L(m) > E_{WG}(m)$, and,

$E_{WG}(m)_{max}$, $E_{WG}(m)_{min}$ the monthly maximum and minimum output of WG

$[E_{WG}(m) - E_L(m)]_{max}$: the maximum difference between WG output and load demand through the month m of the year ($E_{def}(m)_{max}$).

$N_{cd}(m)$: the number of charge-discharge cycles through the month m.

The unit energy cost (UEC_{WB}) of WG/ BS generation system may be developed as a function of economy of WG and BS as follows:

$$ACC_{WB} = ACC_{WG} + ACC_{BS} \quad (16)$$

$$ACC_{BS} = DR_b * C_b * CB \quad (17)$$

Where, $ACC_{WB,}$ CB is the capacity of BS, C_B is the annual capital, capital cost of 1 kWh of BS, and DR_b is the annual discount rate which is depend on the interest rate (r) and life time(n) as in equation (4).

$$AOC_{WB} = AOC_{WG} + AOC_{WB} \quad (18)$$

$$AOC_{BS} = m * ACC_{BS} \quad (19)$$

Where; AOC_{WB}, The annual operation cost, m is a percentage of capital cost of storage battery. Thus, the total annual cost (TAC_{WB}) and UEC_{WB} of this generation system are:

(5) (5)

$$TAC_{WB} = ACC_{WB} + AOC_{WB} \quad (20)$$

$$UEC_{WB} = TAC_{WB} / E_L(G) \quad (21)$$

$$E_L(a) = \sum_{i=1}^{8760} P_L(i) \quad (22)$$

Where $P_L(i)$ is the hourly load demand.

2.3 Alternative 3 :

At deficit generation of WG through the sunshine periods, the load is supplied from a PVPS in this case. While the battery storage is charged by either of WG and /or PVPS. So, Eqn. (11) is modified as:

$$P_{WG}(i) + P_{pv}(i) + P_{bs}(i) = P_L(i) \quad (23)$$

Also, the annual energy supplied of PVPS ($E_{pv}(a)$) is developed as a function of annual electric generation of WG and load demand during the sunshine periods as [8] :

$$E_{pv}(a) = \sum^{t_s} (P'_L(i) - P'_{WG}(i) \quad (24)$$

Where: $E_{pv}(a) = E_{pv(d)}(a) + E_{pv(s)}(a)$ (25)

and $E_{pv(d)}(a)$ and $E_{pv(s)}(a)$ are the annual energy supplied directly to the load and from BS charged by PVPS.

$P'_L(i)$ and $P'_{WG}(i)$ are the hourly load demand and wind generation through the annual sunshine hours t_s.

The array size of PVPS to generate $E_{pv}(a)$ is developed from the deficit generation of WG to satisfy the energy requirement through the sunshine periods of the year months, monthly solar radiation received on this array, $H_t(m)$, at the installation site and the efficiencies of PV array (η_c) and power conditioner (η_{pc}). The monthly $S_v(m)$ is given as:

$$S_v(m) = [E_L(m) - E_{WG}(m)]_{sp} / [H_t(m) * \eta_c * \eta_{pc}] \quad (26)$$

,and the global PV array size (S_{pv}) is:

$$S_{pv} = \sum^m S_{pv}(m) / N_m \quad (27)$$

Where $[E_L(m) - E_{WG}(m)]_{sp}$ is the difference between E_L and E_{WG} through the sunshine periods of the month m and N_m is the number of the months have this difference. Corresponding to S_{PV}, the monthly generation of *PVPS*, *$E_{pv}(m)$*, is given by:

$$E_{pv}(m) = S_{pv} * H_t(m) * \eta_c * \eta_{pc} \quad (28)$$

The LTBS and STBS are developed as the following:

$$STBS = [E_{WG}(m) + E_{pv}(m) - E_L(m)]_{max} / [N_{cd}(m) * \eta_{BS}] \quad (29)$$

$$LTBS = \sum^{m} \{[E_{WG}(m) + E_{pv}(m)]_{max} - E_L(m)_{min}\} / \eta_{BS} \quad (30)$$

To assess the unit energy cost (UEC_{WPVB}) of this generation system, the economy of WG, PVPS and BS are determined in terms of ACC, AOC and TAC. These costs are determined for WG and BS as in alternatives 1 and 2. While these costs are evaluated for PVPS as follows [10]:

1.Chosen the PV module used, the number of PV modules, N(m), and peak power of PVPS, P_{pv}, as:

$$N(m) = S_{pv} / S_{pv}(m) \quad (31)$$

$$P_{pv} = N(m) * P_{pv}(m) \quad (32)$$

Where, $S_{pv(m)}$ and $P_{pv(m)}$ are the net area and peak power of the PV module respectively.

2.The ACC, AOC and TAC of PVPS are given by:

$$AOC_{pv} = C_{opv} * E_{pv}(a) \quad (33)$$

$$ACC_{pv} = DR_v * C_{pv} * P_{pv} \quad (34)$$

$$TAC_{pv} = ACC_{pv} + AOC_{pv} \quad (35)$$

Where; Cpv and Copv are the capital cost of 1kW of P_{pv} and operation cost per 1kWh of the annual energy supplied by PVPS, Epv(a), respectively. Thus, the total annual cost (TAC_{WPVB}) and unit energy cost (UEC_{WPVB}) of WG /PVPS /BS generation system are:

$$TAC_{WPVB} = TAC_{WG} + TAC_{BS} + TAC_{pv} \quad (36)$$

$$UEC_{WPVB} = TAC_{WPVB} / E_L(a) \quad (37)$$

2.4 Alternative 4 :

BS in alternative 3 is represented here by a DG. So, the rated power of the DG required in this alternative is developed from the maximum energy supplied from this BS through the i th hour of the year, is defined as:

$P_{WG}(i) + P_{pv}(i) + P_{DG}(i) = P_L(i)$ (38)

, and $E_{WG}(a)+E_{pv}(a)+E_{DG}(a) = E_L(a)$ (39)

Where, $E_{pv}(a)$ equals to ($E_L(a)$- $E_{WG}(a)$) through the sunshine hours of the year.The unit energy cost (UEC_{WPVD}) of this generation system (WG/ PVPS/ DG) is deduced as a function of the UEC_{WG}, UEC_{PV} and UEC_{DG} as in the previous alternatives and UEC_{WPVD} as:

UEC_{WPVD} = (UEC_{WG} *$E_{LWG}(a)$)+ UEC_{PV}*$E_{LPV}(a)$+ UEC_{DG} * $E_{LDG}(a)$) /$E_L(a)$ (40)

UEC_{WD}, UEC_{WB}, UEC_{WPVB} and UEC_{WPVD} are compared to define the optimal BUPS of the study of BUPSs to be used with the WG to supply the isolated load at the considered site.

3. CASE STUDY:

The proposed model, section 2, is applied here using Matlab software to optimize different WGMs and alternative BUPSs used to supply an isolated load of a tourist village on the Egyptian coast of Red Sea (Hurghada). These wind generator modes (WGMs) have rates of 100 and 300 kW. The average hourly load demands through a day of Winter and Summer seasons using the methodology of Ref [8] shown in Figure (5). the hourly generation curve of different WGMs through a day of Winter and Summer seasons at Hurghada site are determined and shown in Figure (6).

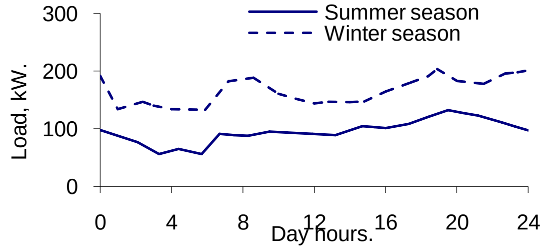

Figure (5) The daily load demand for the tourist study village through a day of different year seasons [9].

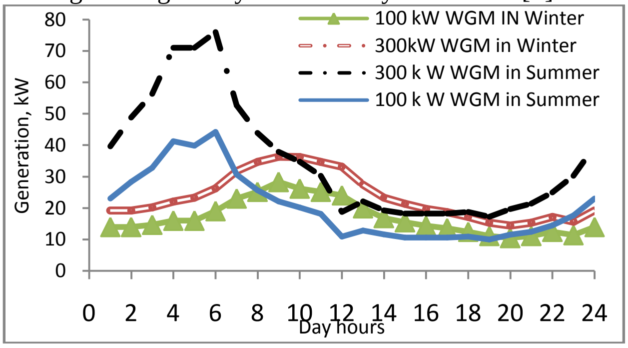

Figure (6) The average daily generation of different WGMs at Hurghada through the year seasons.

The following assumptions are taken into consideration through carrying out the optimization of the studied alternatives of BUPSs with these WGMs [4, 10]:

1. The capital costs of WG, DG, BS &PVPS are $700 /kW, $200 /kW, $40 /kWh , & 5$/W_p respectively, while the capital cost of rectifier and inverter is $ 400 /kW. The operation cost of WG, BS & PVPS are 1.0 ¢/ /kWh 5% of CC_{BS} & 0.2 ¢/ kWh respectively.
2. The life times of DG, WGBS &PVPS are 100,000 hours, 15,5 & 20 years respectively, while the interest rate for all of these power sources is 10%.
3. The fuel and fuel transportation costs are $ 0.04 / liter and 0.005 / liter respectively, while capital cost of the fuel storage tank is $8 /gallon storage with a storage tank of 20 years old.
4. The annual maintenance cost is $ 0.053/ kW of P_{DG}.

4. APPLICATIONS

The generation of the study WGMs at Hurghada site had been determined and shown in Figure 6. This figure gives the average generation of 100 and 300 kW-WGMs through the Winter and Summer seasons . The results of figure 6 are compared with the studied isolated load,figure 5 and concluded that:

Alternative 1 : WG/ DG generation system:

1. 2*300 kW- WGM is more suitable than 6*100 kW-WGM because the daily deficit generation is minimum. Also, UEC_{WD} of alternative 1 is developed and given as 21.5 and 18.4 ¢/ /kWh for 6*100 and 2*300 kW- WGMs respectively.

2. These results concluded that 2*150 kW-DG with 2*300 kW- WGM is the best WG/DG generation system may be used to supply the studied isolated load.

Alternative 2 WG/BS Generation System**:**

1. Capacities of BS required are 148 and 144 MWh with 100 and 300 kW- WGMs espectively.
2. The economy of these hybride generation systems is obtained in terms of unit energy cost (UECwb) and given as 26.3 and 21.8 $/ /kWh)

Alternative 3; WG/PV/BS Generation System:

The proposed model of alternative 3, section 2, with the results of Figures (5) and (6) are used to optimize the number of each WGM study in terms of the deficit generation through the sunshine periods of different year seasons. These deficits are used with the seasonally solar radiation at Hurghada site [12,13] and the design model of Ref [14] has been applied to estimate the seasonally and global PV array sizes used with the solar radiation at the study site to determine the generation of PVPS to meet the deficit generation of WGMs and /or charge the BS, Figure (3). Also, the UEC_{WPVB} is determined. The results of this application are summarized as follows:

1. 6*100 or 2*300 kW- WGM with 7.18 or 17.27 kW peak of PVPS can be used.
2. The economy of these hybrid generation systems are 7.5 and 6.7 ¢/kWh

Alternative 4; WG/PVPS/DG Generation System:

The capacity of BS in alternative 3 is replaced here by a DG with the proposed model of alternative 4, section 2, the desiel generator rate and UEC_{WPVD} are obtained and given as :

WGM, kW	No of WG	PVPS size		P_D, kW	UEC_{WPVD}, (¢/kWh)
		S_v, m^2	P_v, kW_p		
100	6	79	7.18	1*100	5.0
300	2	190	17.27	1*50	4.9

4. CONCLUSIONS:

A hybrid generation and economical models are presented for operating alternatives of DG and /or renewable energy sources as a back-up- power supply with wind generator to supply isolated loads. These models are applied to assess and optimize the generation of hybrid generation systems of WG/DG, WG/ BS, WG/ PVPS/ BS and WG/PVPS/DG have alternative of WGMs to supply the load of a tourist village on the Egyptian coast of Red Sea. The remarkable results of this applications are:

1- For WG/DG generation system, 2*300 kW-WGM with 2*150 kW-DG is the economical ones to supply the studied load.

2- For WG/ BS generation system; two wind generators of 300 kW rate with 140 MWh BS capacity is the optimal hybrid generation system in this case (UEC=21.8 ¢/ kWh) at Hurghada site.

3- For WG/ PVPS/ BS generation system, 2*300 kW-WGM rate , PVPS have a peak power of 17.27 kW and 33.8 MWh BS capacity is the optimal hybrid generation system in this case (UEC=6.7 ¢ / kWh) .

4- The WG/PVPS/DG generation system 2*300 WGM with 17.27 kW_p – PVPS and 1*50 kW - DG is more economical than other study WG/PVPS/DG generation system. Also, this generation system is the most economical one of the study BUPSs with WG to supply the studied isolated load.

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