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USING SOLAR/WIND ENERGY POWER SUPPLY IN THE AUTONOMOUS SYSTEM

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Abstract**—***Hybrid power system can be used to reduce energy storage requirements. In this paper, mathematical models for characterizing Photovoltaic module, wind generator and battery are proposed. This paper presents the optimal size of an autonomous hybrid PV/wind energy power supply for autonomous system and other application. Consideration of various types and capacities of system devices allows obtaining the configurations which satisfy the desired system reliability by changing the type and size of the system devices.*

Index Terms**—**Wind generator; battery; solar panel; hybrid system; energy; power supply.

I. INTRODUCTION

Energy is vital for the progress of a nation and it has to be conserved in a most efficient manner. Not only the technologies should be developed to produce energy in a most environment-friendly manner from all varieties of fuels but also enough importance should be given to conserve the energy resources in the most efficient way. In recent years, hybrid Photovoltaic (PV) /wind system (HPWS) has became real alternative to environmental protection requirements and electricity demands. With the complementary characteristics between solar and wind energy resources for certain locations, hybrid PV/wind system with storage banks presents an unbeatable option for the supply of small electrical loads at remote locations where no utility grid power supply. Since this system can offer a high reliability of power supply, their applications and investigations gain more concerns nowadays [1], [3]. To use solar and wind energy resources more efficiently and economically, the optimal size of hybrid PV/wind system with battery plays an important role in this respect. The mathematical model of hybrid PV/wind energy power supply, including PV modules, wind generators and batteries storage is developed.

II. PROBLEM STATEMENT

To increase the overall efficiency of the autonomous power supply system and for users without access to the utility grid it is proposed the combined system where the generation produced by wind turbines and solar panels, and the energy is stored in batteries. In such systems in order to optimize their own consumption the attention focused on the most expedient ratio between the amount of generated and stored energy.

Each of the alternative energy sources (both renewable and non-renewable) has not only advantages but also disadvantages. The main source of energy in the hybrid system is a wind turbine and, since it is almost two times cheaper than solar panels, installing the hybrid system is profitable option, if conditions allow. PV modules are an auxiliary source of energy that can produce energy for long periods of "calm".

The determination of the system components may optimize the system parameters for economic justification expediency of using hybrid system in the autonomous power supply.

III. BLOCK DIAGRAM OF A HYBRID AUTONOMOUS ENERGY SUPPLY SYSTEM

The hybrid system is a system that consists of a wind turbine, solar panels and battery, which combine the two types of energy: wind and solar. Their joint work can stably generate electricity during all seasons, in the worst weather conditions, when there is little sun, but the wind is much stronger, and in summer, when solar energy is much more than the energy of wind.

Wind turbines, PV array and the battery connected to a hybrid controller, which controls the charge of battery. To the output of the hybrid controller is connected inverter that converts the DC voltage to AC 220 V power supply for equipment. A block diagram of a hybrid PV/wind system is shown in Fig. 1.

IV. SELECTION OF THE COMPLEX TECHNICAL FACILITIES

Depending on the power consumption and working time the basic parameters of the system components are determined.

The calculating of autonomous energy supply system is very important to choose the capacity of the battery. Capacity, which should give the battery, is calculated based on the amount of electricity in Wh consumed from the battery in discharge mode.

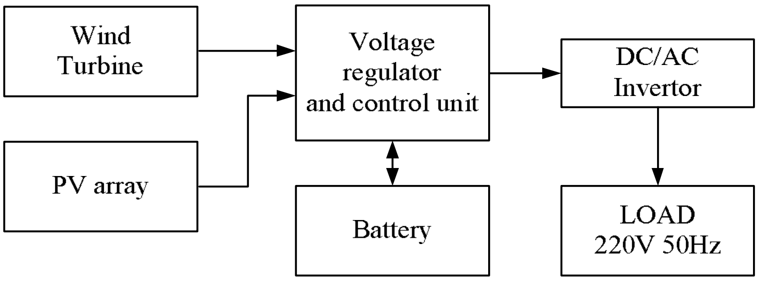

Fig. 1. Block diagram of a hybrid autonomous energy supply system

At any time the state of battery is related to the previous state of charge and to the energy production and consumption situation of the system during the time from $t-1$ to t. During the charging process, when the total output of PV and wind generators is greater than the load demand, the available battery bank capacity at time t can be described by [1]:

$$C_{\text{bat}}(t)=C_{\text{bat}}(t-1)(1-\sigma)+\left(E_{\text{PV}}(t)+E_{\text{WG}}(t)-\frac{E_{\text{l}}}{\eta_{\text{inv}}}\right)\eta_{\text{bat}}. \quad (1)$$

where $C_{\text{bat}}(t)$ and $C_{\text{bat}}(t-1)$ are the available battery bank capacity (Wh) at time t and $t-1$, respectively; η_{bat} is the battery efficiency (during discharging process, the battery discharging efficiency was set equal to 1 and during charging, the efficiency is 0.65 to 0.85 depending on the charging current); σ is the self-discharge rate of the battery bank. The manufacturer documentation gives a self discharge of 25% over six months for a storage temperature of 20°C, that is to say 0.14% per day. $E_{\text{PV}}(t)$ and $E_{\text{WG}}(t)$ are the energy generated by PV and wind generators, respectively, $E_{\text{l}}(t)$ is the load demand at time t and η_{inv} is the inverter efficiency.

On the other hand, when the load demand is greater than the available energy generated, the battery bank is in discharging state. Therefore, the available battery bank capacity at time t can be expressed as:

$$C_{\text{bat}}(t)=C_{\text{bat}}(t-1)(1-\sigma)+\left(\frac{E_{\text{l}}}{\eta_{\text{inv}}}-(E_{\text{PV}}(t)+E_{\text{WG}}(t))\right)\eta_{\text{bat}}. \quad (2)$$

At any time, the storage capacity is subject to the following constraints:

$$C_{\text{bat min}}(t)\le C_{\text{bat}}(t)\le C_{\text{bat max}}(t), \quad (3)$$

where $C_{\text{bat max}}$ and $C_{\text{bat min}}$ are the maximum and minimum allowable storage capacity. Using for $C_{\text{bat max}}$ the storage nominal capacity $C_{\text{bat }n}$, it is possible to write:

$$C_{\text{bat min}}=DOD\cdot C_{\text{bat }n}, \quad (4)$$

where DOD (%) represents the maximum permissible depth of battery discharge.

The total power $P_{\text{tot}}(t)$, generated by the wind turbine and PV generator at time t is calculated as follows:

$$P_{\text{tot}}(t)=P_{\text{PV}}(t)+P_{\text{WG}}(t), \quad (5)$$

where $P_{\text{PV}}(t)$ and $P_{\text{WG}}(t)$ are powers of PV generator and wind turbine accordingly.

Then, the inverter input power, $P_{\text{inv}}(t)$ is calculated using the corresponding load power requirements, as follows:

$$P_{\text{inv}}(t)=\frac{P_{\text{load}}(t)}{\eta_{\text{inv}}}, \quad (6)$$

where $P_{\text{load}}(t)$ is the power consumed by the load at time t.

During this operation of the hybrid PV/wind system, different situations may appear [2]:

a) the total power generated by the PV and wind generators is greater than the power needed by the load, P_{inv}. In this case, the energy surplus is stored in the batteries and the new storage capacity is calculated using (1) until the full capacity is obtained, the remainder of the available power is not used;

b) the total PV and wind generators power is less man the power needed by the P_{load}, the energy deficit is covered by the storage and a new battery capacity is calculated using (2);

c) in case of inverter input and total power equality, the storage capacity remains unchanged.

In case (*a*) when the battery capacity reaches a maximum value, $C_{\text{bat max}}$, the control system stops the charging process.

The wasted energy WE(t), defined as the energy produced and not used by the system, per time t is calculated as follows:

$$\mathrm{WE}(t) = P_{\mathrm{tot}}(t)\Delta t - \left(\frac{P_{\mathrm{load}}(t)}{\eta_{\mathrm{inv}}} \Delta t + \left(\frac{C_{\mathrm{bat\,max}} - C_{\mathrm{bat}}(t-1)}{\eta_{\mathrm{bat}}} \right) \right). \quad (7)$$

In case (*b*), if the battery capacity decreases to their minimum level, $C_{\mathrm{bat\,min}}$, the control system disconnects the load and the energy deficit, loss of power supply per time *t* can be expressed as follows:

$$\mathrm{LSP}(t) = P_{\mathrm{load}}(t)\Delta t - \left((P_{\mathrm{PV}}(t) + P_{\mathrm{WG}}(t))\Delta t + C_{\mathrm{bat}}(t-1) - C_{\mathrm{bat\,min}} \right)\eta_{\mathrm{inv}}, \quad (8)$$

where Δt is the step of time used for the calculations.

During that time, the powers produced by the PV and wind generators are assumed constant. So, the power is numerically equal to the energy within this time step.

The loss of power supply probability, LPSP, for a considered period *T*, can be defined as the ratio of all the (LPS(*t*)) values over the total load required during that period. The LPSP technique is considered as technical implemented criteria for sizing a hybrid PV/wind system employing a battery bank. The technical model for hybrid system sizing is developed according to the LPSP technique. This can be defined as:

$$\mathrm{LPSP}(t) = \sum_{t=1}^{T} \mathrm{LPS}(t) \Big/ \sum_{t=1}^{T} P_{\mathrm{load}}(t)\Delta t, \quad (9)$$

where *T* is the operation time.

If the hybrid energy systems are well designed, they provide a reliable service for an extended period of time.

A common inherent drawback of wind and PV systems is the intermittent nature of their energy sources. Wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Solar energy is present throughout the day, but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. These drawbacks tend to make these renewable systems inefficient. However by incorporating maximum power point tracking (MPPT) algorithms, the systems" power transfer efficiency can be improved significantly. A wind turbine power characteristic is derived from the mechanical power that is generated by the wind

$$P_m = 0.5\rho A C_p(\lambda, \beta) v_w^3. \quad (10)$$

The power coefficient (C_p) shown in Fig. 2 is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The TSR(λ), refers to a ratio of the turbine angular speed over the wind speed [4], [7].

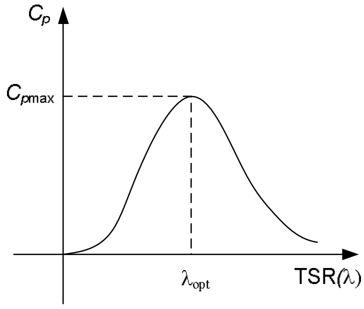

Fig. 2. Power coefficient curve for a typical wind turbine

The pitch angle β, refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis.

$$\lambda = \frac{R\omega b}{v_w}, \quad (11)$$

where *R* is turbine radius; ωb is angular rotations speed.

Power curve for a fixed pitch (β = 0) horizontal axis wind turbine is shown in Fig. 3. It can be seen from Fig. 3 that the power curves for each wind speed has a shape similar to that of the power coefficient curve. Because the TSR is a ratio between the turbine rotational speed and the wind speed, it follows that each wind speed would have a different corresponding optimal rotational speed that gives the optimal TSR.

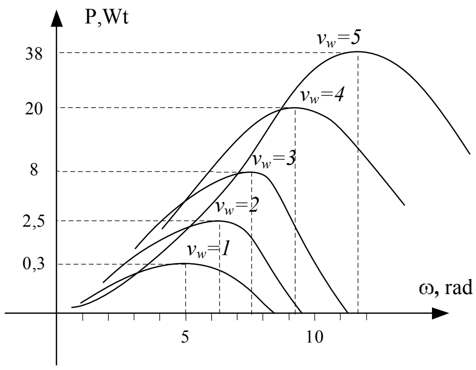

Fig. 3. Power curves for a 6 blades 300 W wind turbine

For each turbine there is an optimal TSR value that corresponds to a maximum value of the power coefficient ($C_{p\,\max}$) and therefore the maximum power. Therefore by controlling rotational speed, (by means of adjusting the electrical loading of the turbine generator) maximum power can be obtained for different wind speeds.

A solar cell is comprised of a *P-N* junction semiconductor that produces currents via the photovoltaic effect. The resultant ideal voltage-current characteristic of a photovoltaic cell is given by (12) and illustrated in Fig. 4.

$$I = I_{ph} - I_0\left(\exp\left(\frac{qV}{kT}\right) - 1\right), \qquad (12)$$

where I is module total current; I_{ph} is current generated by PV cell; $I_0(\exp(qV / kT) - 1)$ is the loses on *P-N* junction.

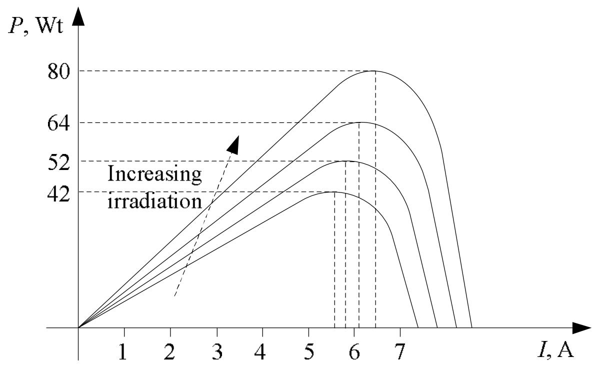

Fig. 4. Output power Vs output current curve for a 80 W PV cell

To select the power of the wind turbine and solar panel it's necessary to consider the annual average wind load factor and solar insolation. As used a hybrid wind solar system, the power of the wind turbine must cover at least 60% of daily energy expenditure and solar power as 60% of the daily rate.

V. Discussion and Results

Finding the optimal number of wind turbines and solar arrays to meet the load, as well as the optimal wind turbine height and rotor diameter, is object of interest, as well as testing for good complementary characteristics between the wind and solar power systems, and to assess the feasibility of using such hybrid system to power the autonomous system [5], [6].

However, we need a hybrid system only to take advantage of their complementary characteristics, because wind and solar radiation are not constant over the year as it is specified in test. It is shown in Fig. 5 wind turbines may not be able to meet demand on their own in summer, and may require another source to manage with the loss in power generation.

Figure 5 shows the solar radiation and the wind speed as a percentage of the maximum attainable from each resource separately, during a year. The generated data is plotted, and a best-fit line is drawn.

Graph presented in Fig. 5 suggests a need for a complementary relationship between the wind and solar systems, as the negative correlation between the two sources.

Monthly energy requirement for autonomous system is about 10 kWh. System that contains 6 bladed wind turbine with max power 300 W and solar panel with power 80W is used to measure the power output of the individual energy system components, and their combined total output, as shown in Fig. 6.

VI. Conclusion

Experiment is focused on designing the autonomous system that would allow finding the optimal system design parameters of a hybrid solar-wind system, taking into consideration the power of solar arrays and wind turbines, as well as the wind turbine rotor diameter and height.

Experiment result presents, a complementary relationship between both individual systems. During summer season, when solar radiation is abundant and there is not much wind energy, the solar arrays supply most of the required energy. During winter season, when wind velocities are higher and there is less solar radiation, the wind turbines supply most of the required energy, thus providing clear evidence of a complementary relationship between the two sources.

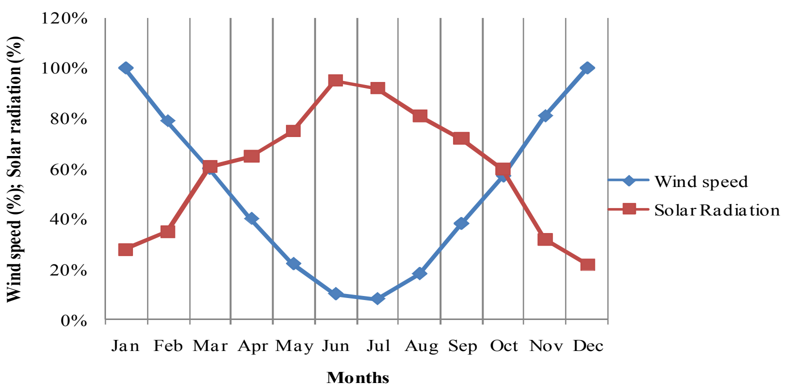

Fig. 5. Power Curves for wind turbine and PV-system

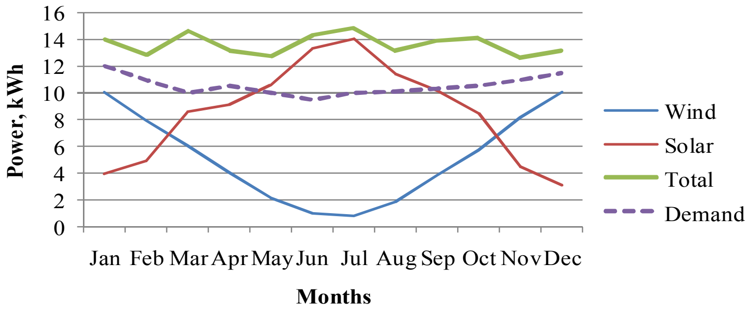

Fig. 6. Power generated from system components

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Б. І. Дмитренко. Використання сонячної та вітрової енергії для живлення автономних систем

Розглянуто характерні особливості використання гібридних вітросонячних установок. Запропоновано математичну модель для розрахунку оптимальних параметрів гібридної вітросонячної установки для живлення автономних систем. Проведено дослідження роботи гібридної вітросонячної автономної системи протягом року.

Ключові слова: вітрогенератор; сонячна панель; акумуляторна батарея; автономна система електропостачання.

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Б. И. Дмитренко. Использование солнечной и ветровой энергии для питания автономных систем

Рассмотрены характерные особенности использования гибридных ветросолнечных установок. Предложена математическая модель для расчета оптимальных параметров гибридной ветросолнечной установки для питания автономных систем. Проведено исследование работы гибридной ветросолнечной автономной системы на протяжении года.

Ключевые слова: ветрогенератор; солнечная панель; аккумулятор; автономная система электроснабжения.

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