COST-EFFECTIVE OFF-GRID HYBRID (PV-WIND-DIESEL) SYSTEMS

E.S. Aronova, M.Z. Shvarts
Ioffe Physico-Technical Institute, 26 Polytechnicheskaya str., St.-Petersburg, 194021, Russia
Tel.: +7(812) 292 7394; fax: +7(812) 297 1017; e-mail: earonova@mail.ioffe.ru
Author for correspondence: Ekaterina S. Aronova

ABSTRACT: Presented are a method for and approaches to designing hybrid systems for power supply of remote users determining the optimum type of the structural scheme of the systems and selecting parameters of their elements, as defined by climatic characteristics of designated territories. Calculated and substantiated were parameters of the systems for 50 geographical locations with a portion of the direct sunlight from the total one from 35 to 67 % and the average annual wind velocity from 1.5 to 7.9 m/sec. Factors of the sun and wind regimes of the territories taking account for purposefulness of application of solar installations and wind turbines in PV-Wind-Diesel systems have been revealed. It has been shown that the use of installations based on renewable power sources allows obtaining cost-competitive and power-efficient systems, which compete actively with the traditional installations based on organic fuel.
Keywords: solar installation, wind turbine, off-grid hybrid system.

1 INTRODUCTION

A decrease in the explored reserves of organic fuel and rise in the cost of the traditional power result in active introduction of renewable sources (Sun and Wind) into the strategy of power development in different countries. Improvement of technologies, simplicity and reliability of modern power installations, reduction of their prices create conditions for development and promotion of economically effective and available for the user off-grid hybrid systems equipped with flat plate or concentrator solar photovoltaic installations (SPVI) [1, 2] and wind turbine (WT) [3]. The most promising for the wide spread of such systems are remote regions, where the connection to the centralized power supply network is difficult or expensive. For this reason, the systems are often the only power sources in these regions and should ensure reliable uninterrupted power supply of the proper quality.

Practice shows that designing the power-effective off-grid systems is possible only with the availability of plausible long-standing data on the climatic factors of places of their supposed operation, and also correct mathematical models, which determine the output power characteristics of solar and wind installations and other system elements in real operational conditions [4]. Development of a corresponding to these models procedure for optimizing the structural scheme and parameters of a system will allow creating economically effective and maximally accessible complexes for power supply of remote territories.

2 DESIGN OF THE OFF-GRID HYBRID SYSTEM

Reliability and quality of the power supply of autonomous users are achieved by combined usage of the renewable power sources (Sun and Wind) well complimenting each other. At the same time, reduction in the prime cost of solar and wind installations' power is accomplished by introducing storage batteries (SB) into systems, which accumulate the excesses of generated power and compensate its lack during night hours and in the periods of long-time cloudiness and calms. The use of a diesel generator ensures the additional reservation of generated power and allows obtaining a maximally reliable power supply system. The functional system elements pointed out should be most efficiently incorporated in accordance with the structural scheme shown in Fig. 1.

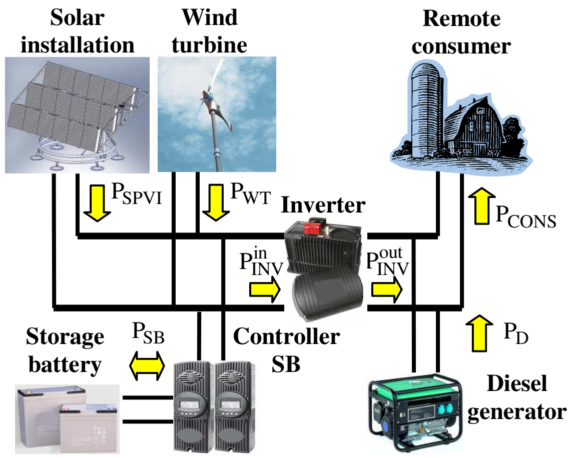

Figure 1: Structural scheme and composition of the off-grid hybrid system based on a concentrator solar photovoltaic installation

Analysis of the peculiarities in operation of the system elements presented in Fig. 1 has allowed determining its main regimes in dependence on the balance of circulating powers (Fig. 2). Particular attention was given to the parameters of operation of the storage batteries and to the requirements on the maximum and minimum state of charge.

The balance of powers in the system was determined for each hour interval and was mainly depended on the required for the user and generated by solar and wind installations electrical power at a considered day hour. It was taken into account that the uninterruptedly changing parameters (spectral composition and flux density) of the sunlight and also solar cell temperature depending on the meteorological situation and operation place (sunlight flux density, wind velocity and environmental temperature) affect mainly the solar installation operation. Taking into account the pointed out parameters was performed by the elaborated mathematical model [5, 6] allowing estimating the efficiency and power productivity of the installations in real weather conditions and obtaining the initial data for designing the hybrid systems. The output parameters of wind installations are determined by the wind flow velocity. For this reason, their power productivity was calculated by the output of a wind generator of a selected type.

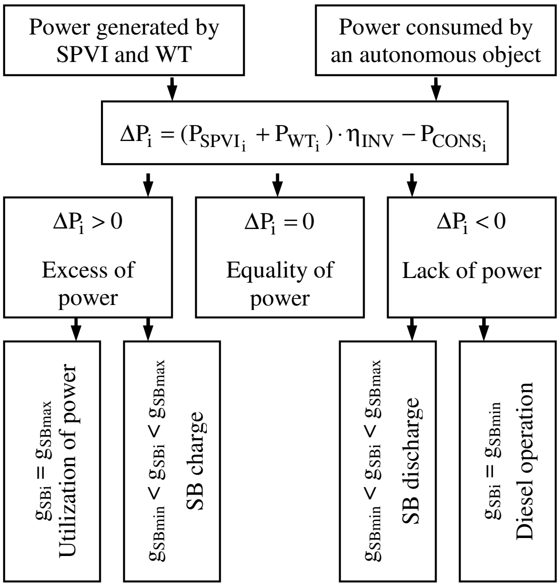

Figure 2: Regimes of operation of the off-grid power supply system elements

The off-grid power supply system elements composition may vary in dependence on climatic conditions of the system operation region, and some elements may be excluded or commutate in another way. The effect of the climatic factors of the operation region on the hybrid system configuration was estimated by simulating the system operation during a year. In this case, a search for the optimum structural scheme and parameters of the system elements at preset actinometrical and wind regimes of the territories was carried out. Determination of the structural scheme of the off-grid systems was based on the principle of priority of power installations with renewable power sources (Sun and Wind). Three main system structural schemes have been selected: solar and wind power installations and storage batteries. A system with diesel generator was taken as the reference for comparison in calculating the economical effect obtained from using installations based on renewable power sources in the system. As a result, the following structural schemes were considered: T1: SPVI + WPI + Storage Battery + Diesel; T2: SPVI + Storage Battery + Diesel; T3: WPI + Storage Battery + Diesel; T4: Diesel.

3 OPTIMIZATION

Selection of the optimum structural scheme and parameters of the system elements was performed according to the criterion of the minimum total costs for the system during whole its lifetime at preset operation conditions and power consumption regime:

$$C^{sys}_{\Sigma exp} = C^{sys}_{inv} + \sum_{t=1}^{T} \frac{C^{sys}_t \cdot (1+r)^t}{(1+d)^t} \to \min ,$$

where C^{sys}_{inv} are capital investments, \$; C^{sys}_t are operational costs, \$; r is inflation rate; t is the number of a rated year, \$; T is the planned lifetime of off-grid power supply system, years; d is the rate of discounting.

For each proposed scheme, a search for optimum parameters of the system elements was carried out by the elaborated two-level algorithm presented in Fig. 3.

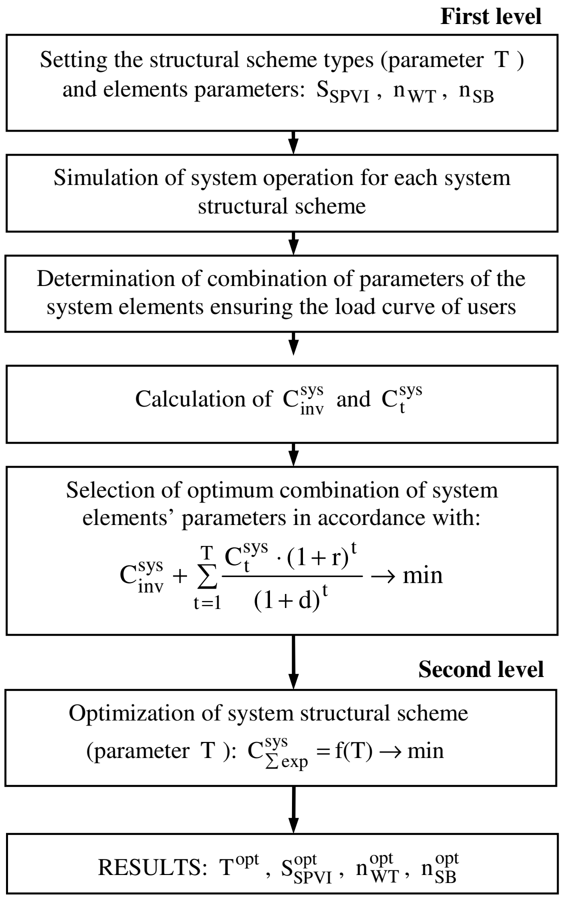

Figure 3: Two-level algorithm for selecting the optimum system structure

On the first level, the parameters of elements are optimized for each structural scheme by realizing the following steps:

– simulation of the system elements' operation for each of the system structural schemes being analyzed;

– determination of system elements' parameters combination ensuring the load curve of the user. Such parameters are: an area of a solar photovoltaic installation (S_{SPVI}), the number of wind installation (n_{WT}), the number of storage batteries (n_{SB}), the fuel volume required for operation of a diesel generator ($\overline{m_D}$);

– calculation of total costs (capital investments and operation costs) during the planned operation lifetime of the power supply system as a function of the area of a solar photovoltaic installation, the number of wind installation, the amount of storage batteries, an operation time and fuel consumption by a diesel generator for each system structural scheme being analyzed;

– selection of combination of parameters of the system elements corresponding to the minimum costs.

On the second level, the system structural scheme is optimized by the criterion of the minimum total costs for the system during the whole operation period.

4 RESULTS

In accordance with the elaborated procedure, optimization of the structural scheme and parameters of elements of off-grid power supply systems ensuring covering the standard daily schedules of the load in the amount of 10, 20, 30 kWh has been carried out [7]. The calculations were being performed for 50 geographical points of the Russian Federation territory with the portion of the direct sunlight of the total one (D*) from 35 to 67 % and average annual wind velocities (V) from 1.5 to 7.9 m/sec. The total costs for a off-grid power supply system were calculated on the base of average market showings on costs of system separate components. The results of calculations for 10 points determining the general regularities for application of the off-grid system structural scheme types being analyzed are presented in Fig. 4.

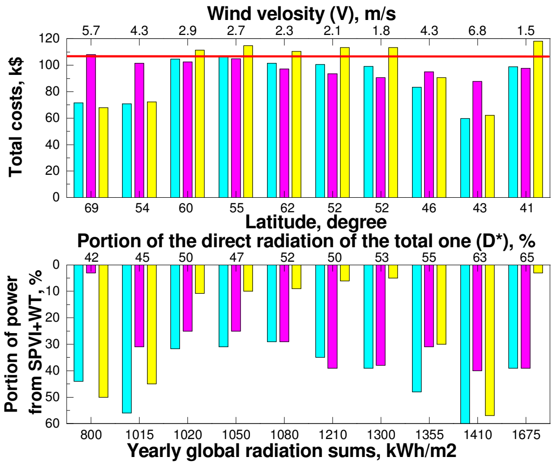

Figure 4: Estimation of the total costs per a system and portions of power generated by solar installations and wind turbines

Analysis of the curves for typical points allows retracing clearly the interrelation between the values of the power income from renewable sources and the expediency to use power supply systems of the considered types.

Thus, in the points with high solar and wind potentials (43° N. L.), the first type structural scheme should be applied, in which the combination of solar and wind installations are used. In this case, the portion of power from renewable sources can exceed 61 %, and the total costs per a system compared with the use of one diesel generator will be reduced almost in 2 times.

In the areas with low average annual wind velocities but with significant solar radiation (52° N. L.), it is worthwhile using the second type structural scheme with solar installations, which allows reducing the costs and bringing the portion of power from renewable sources up to 40 %.

In the territories with a high wind-power potential (69 °N. L.), it is promising to apply system of the third type structural scheme with including a wind installation, which will reduce the costs per a system in 1.5 times and increase the portion of power generated by renewable sources up to 50 %.

Estimations of the calculation results for 50 considered points have allowed making the following general conclusions:

1. Introduction of solar photovoltaic installations into the systems is economically justified for the territories with a portion of the direct sunlight from the total one higher than 44 %.

2. Application of wind installations in autonomous systems is economically justified at average annual wind velocities higher than or equal to 3.9 m/sec.

3. Application of solar installations in the medium and south latitudes allows replacing up to 51 % and combined application of solar and wind installations up to 61 % of power generated by a diesel generator at simultaneous reduction of total costs per a system.

5 CONCLUSION

The fulfilled investigation was aimed to develop methods for designing autonomous hybrid systems. The calculations carried out have shown that introduction of installations based on renewable power sources into power supply systems allows reducing total costs per a system for the whole period of its operation. The proposed approach for determining the autonomous system configuration gives a possibility to select the optimum structural scheme, to design and create cost-effective hybrid systems for power supply of autonomous users with allowing for climatic characteristics of territories of their location. The criteria for economically justified application of different type structural schemes of hybrid systems have been determined in dependence on the portion of the direct radiation of the total one (D*) and the average annual wind velocity (V):

§ D* > 44% and V < 3.8 m/sec – it is economically advantageous to use a system with a solar installations;

§ D* < 44% and V > 3.8 m/sec – it is preferable to use a system with a wind turbine;

§ D* < 44% and V > 3.8 m/sec – it is economically advantageous to use a system with a solar installations and wind turbine.

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