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OPERATION FEATURES OF THE CONVERTERS OF AN AUTONOMOUS POWER SUPPLY SYSTEM

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Abstract: The article consideres the problem of extraction of maximum energy from a solar panel in an autonomous power supply system working with renewable sources under the condition of constant joint operation of a solar panel and a diesel generator. It is proposed to solve the problem taking into account the nonlinearity of the external characteristics of energy sources. It has been shown that in order to improve the energy efficiency of power supply system the solar panel should operate in a current source mode and the diesel generator should have the external characteristic of a controlled current source.

Key words: autonomous power supply system, renewable energy sources, solar panel, diesel generator, extraction of maximum energy.

1. Introduction

Constructing an energy efficient autonomous power supply system based on renewable sources causes the necessity of solving the problem of matching of energy generation mode and consumption mode [1, 2]. The study of energy conversion and distribution processes in autonomous systems for optimizing its operation modes as well as developing efficient control algorithms is an urgent task [3, 4]. Since the efficiency of converting the primary energy of wind turbines and solar panels largely depends on operating modes, the control of generated power value allows us to leverage actual potential of primary energy carriers. A lot of studies are devoted to the issue of maximum energy extraction [5-8], but the issue of improving energy efficiency under the joint operation of several renewable sources has not been studied sufficiently. Therefore, the aim of the article is to determine the conditions of ongoing joint operation of the solar panel and diesel generator with the use of equivalent circuits and the consideration of the features of external characteristics to improve the energy efficiency of the power supply system.

2. The equivalent circuit of an autonomous power system

A diesel generator is used in the autonomous system as a source of guaranteed power supply [9] and it can significantly reduce the impact of external factors on the level of energy consumption. The stochastic character of the energy of renewable sources requires the presence of a storage system and a specialized control system within the power system to fulfill the conditions of maximum energy extraction and energy-efficient operation mode of the system.

Fig.1 shows us a simplified circuit of the power supply system operating on direct current with substitution schemes based on the idealized elements, which allows us to establish the dependencies between input and output parameters of voltage and current. The solar panel (SP) is presented by the equivalent current source J (conducting the current in one direction only) and the conductivity g_J. Taking into account, that, in the direct current circuit the controlled rectifier (C_2) is connected to the output of the diesel generator (DG), the DG is presented by the equivalent scheme of a voltage source E (conducting the current in both directions) and internal resistance r_E ($E = const$, $r_E = const$). The connection of the energy storage is standard and is not shown in Fig.1.

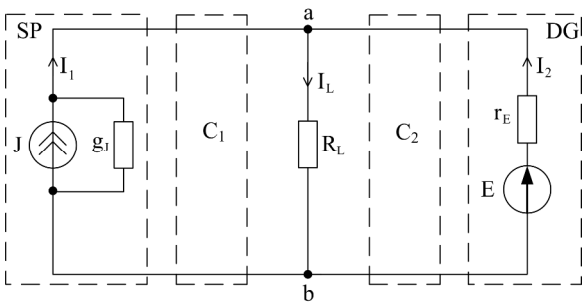


Fig. 1. Simplified equivalent circuit of an autonomous power system.

The converter C1 is a DC voltage regulator that provides the SP operation in the mode of maximum energy extraction. Since in different instants the ratio between r_J and R_L can be both $r_J \geq R_L$ and $r_J \leq R_L$, the converter, being a DC-DC transformer, matches the solar panel internal resistance to the load: $r_J = n^2 R_L$, $n = U_L / U_{\max W}$, where U_L is the load voltage, $U_{\max W}$ is the voltage value at the point of maximum energy extraction.

The converter C_2 can operate in two modes: as a rectifier with a control angle a that should vary in the

range of $0° \le a \le 90°$, or as an inverter driven by the grid. In the article the case when the rectifier does not switch to the inverter mode and the diesel generator current I_2 does not change its direction is considered. Otherwise the diesel generator switches to the electricity consumption mode or is disconnected from the grid, what is unacceptable while providing energy efficient system operation.

The necessary real time monitoring and control of the energy flow in the system that requires analysis of currents I_1, I_2 and fulfillment of conditions $U_L = const$, $I_2 > 0$ should be implemented in order to provide the condition of maximum energy extraction from the solar panel and the required level of load voltage.

From the condition of current balance: $I_1 + I_2 = I_L$, where I_L is load current, $I_1 = \left[ER_L - E_J\left(R_L + r_E\right)\right] / \left[r_J R_L + r_J r_E + r_E R_L\right]$ is solar panel current, where $E_J = Jr_J$, $r_J = 1/g_J$, the diesel generator current depending on the load resistance and ratios of SP conductivity g_J and DG internal resistance r_E, is calculated and defined as follows:

$$I_2 = \frac{E_J R_L - E\left(R_L + r_J\right)}{r_J R_L + r_J r_E + r_E R_L}. \qquad (1)$$

In the borderline case, when the load resistance $R_L \to 0$, the system operates in a short circuit mode, the load current is given by $I_L\big|_{R_L \to 0} = \left(E_J r_E + E r_J\right)/r_J r_E = J + \left(E/r_E\right)$, that is, the sum of short circuit currents of individual sources $I_2\big|_{R_L \to 0} = -\left(E/r_E\right)$. In another borderline case, when $R_L \to \infty$, the system operates in an open-circuit mode, in which the voltage between the nodes *ab* is limited $U_{ab}\big|_{R_L \to \infty} = \left(E_J r_E + E r_J\right)/\left(r_J + r_E\right)$, the diesel generator current being $I_2\big|_{R_L \to \infty} = \left(E_J - E\right)/\left(r_J + r_E\right)$. If the SP conductivity $g_J \to \infty$, the diesel generator current tends to short-circuit current $I_2\big|_{r_J \to 0} = -\left(E/r_E\right)$. If $g_J \to g_{J\min} \approx 0$, the diesel generator current $I_2\big|_{r_J \to \infty} = \left(JR_L - E\right)/\left(R_L + r_E\right)$. With the decrease in illumination level (i.e. in the equivalent current source conductivity) and the increase in the load resistance the diesel generator current increases.

To maintain the connection of the diesel generator to the grid and the direction of the current I_2, the condition $R_L > Er_J/\left(E_J - E\right)$ should be fullfilled.

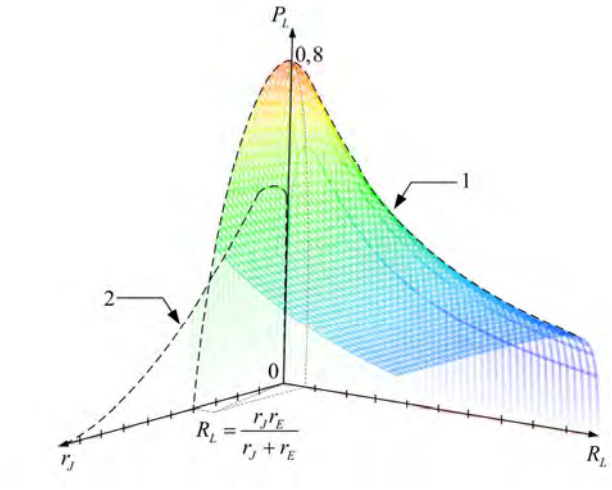


Fig. 2. The dependence of the load power on the load resistance and solar panel conductivity (internal resistance).

The energy power

$$P_S = \frac{\left(E_J r_E + E r_J\right)^2}{\left(r_J + r_E\right)\left(r_J R_L + r_J r_E + r_E R_L\right)} \qquad (2)$$

is consumed during the joint operation of the solar panel and diesel generator, and the energy power

$$P_L = \frac{\left(E_J r_E R_L + E r_J R_L\right)\left(E_J r_E + E r_J\right)}{\left(r_J R_L + r_J r_E + r_E R_L\right)^2} \qquad (3)$$

is transmitted to the load.

The energy storage provides the fulfillment of the condition $I_L = I_1 + I_2 + I_b$ with $R_L = r_J r_E / \left(r_J + r_E\right)$, that allows us to extract maximum energy from the solar panel. For making the presentation of results more convenient the power value is shown on a graph (Fig.2) in relative units, where the value of sources maximum power $P_{S\max}$ is taken for basic power.

For example, at ratios $E_J/E = 4$ and $r_J/r_E = 2$ the load power is at the level of 0.8 from maximum that illustrates the need of the regulation of the external characteristic of the diesel generator for fulfilling the condition of maximum energy extracting from the solar panel.

Curves 1 and 2 on Fig. 2 show the dependences of the load power on the values of load resistance and internal resistance of the current source respectively. On the power curve the maximum value $P_{L\max} = \left[R_L\left(Jr_E + E\right)^2\right] / 2r_E$ corresponds to the load resistance value $R_L = r_J r_E / \left(r_J + r_E\right)$.

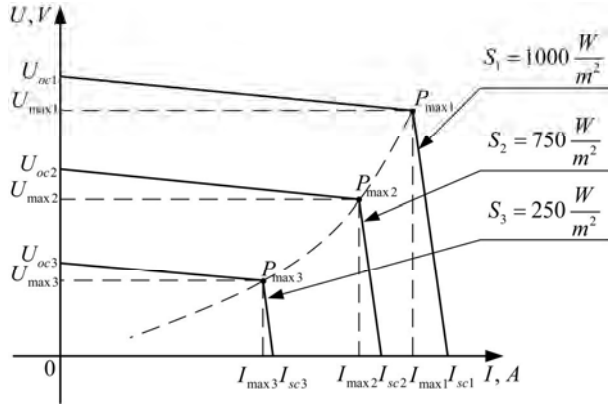
The inclusion of an additional generator into the system and taking into account the nonlinearity of the external characteristics of the sources leads to a reduction of the energy transmitted to the load.

3. The consideration of the nonlinearity of external characteristics

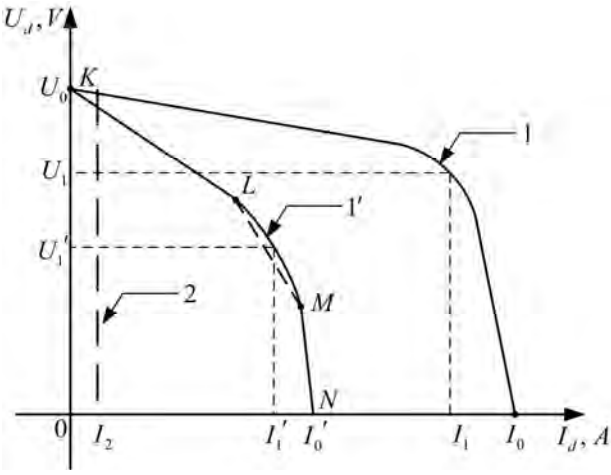
The external characteristics of the sources considered under ideal conditions are linear functions but under real conditions the external characteristics of the solar panel as well as the external characteristics of the diesel generator are nonlinear (Fig. 3a, b).

The current-voltage characteristic of the solar panel, depending on the power of solar radiation, S is given by the expression [10]: $i(u) = i_P - i_D(e^{lu} - 1)$, where $1/l = kTb/\bar{e}$; k is the Boltzmann constant; T stands for temperature; $\bar{e}$ is electron charge; b is a value that characterizes the semiconductor material; i_P and i_D are photocurrent density and dark current density, respectively. External characteristics have the pronounced maximum with coordinates $I_{\max}$, $U_{\max}$ occuring in the voltage range of 0,6...0,8 of the open-circuit voltage U_{oc}, and the current range of 0,85...0,95 of the short-circuit current I_{sc} [11].

The external characteristic of the diesel generator is a family of dependencies at different values of the excitation winding current and power factor that is shown with curve 1 in Fig. 3, b.



a)



b)

Fig. 3. External characteristics of the sources.

With the active character of the load, the generator voltage decreases with current increasing; therefore, the characteristic has a negative slope throughout the range.

The external characteristic of the controlled rectifier connected to the output of the diesel generator (curve 1' in Fig. 3, b) at $a < p/6$ consists of at least three adjacent segments *KL*, *LM* and *MN* described by the equations:

$$U_d = \frac{3\sqrt{3}}{p} U_o \left(\cos a - \frac{I_d r_E}{\sqrt{3} U_0} \right) \qquad (4)$$

while $g < p/3$;

$$\frac{4I_d^2 r_E^2}{3U_0^2} + \frac{4p^2 U_d^2}{81U_0^2} = 1 \qquad (5)$$

while $g = p/3$;

$$U_d = \frac{9}{p} U_o \left(1 - \frac{I_d r_E}{U_0} \right) \qquad (6)$$

while $g > p/3$. When $p/6 \le a < p/3$, the elliptical segment *LM* disappears from the external characteristic and only the first (4) and the third (6) straight line segments remain; when $a > p/3$, the external characteristic can be described by the expression (4) [12]. The external characteristic depends on the duration of the current flow through each of the valves, the number of valves that are simultaneously conductive, the character of the load, and the phase winding inductance.

The increase in steepness of the external characteristic of the output rectifier leads to increased flow of the solar panel current into the diesel generator, which reduces the system efficiency. To prevent this phenomenon it is necessary to ensure (through the use of the output rectifier) the operation of the diesel generator in a current source mode with the controlled external characteristic (curve 2, Fig.3) as well as a certain level of load energy generation.

4. Conclusion

In order to provide the extraction of maximum energy in the autonomous power supply system under ongoing joint operation of a diesel generator and solar panel it is required that the solar panel operate in the current-source mode and the diesel generator have the external characteristic of a current source that is controlled according to the ratios of the solar panel current and storage current and the required level of load voltage.

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ОСОБЛИВОСТІ РОБОТИ ПЕРЕТВОРЮВАЧІВ АВТОНОМНОЇ СИСТЕМИ ЕЛЕКТРОЖИВЛЕННЯ

Валерій Жуйков, Катерина Осипенко

Розглянуто проблему відбору максимальної енергії від сонячної батареї в автономній системі електроживлення з відновлювальними джерелами за умови постійної сумісної роботи сонячної батареї та дизель-генератора. Запропоновано вирішення цієї проблеми шляхом врахування нелінійностей зовнішніх характеристик джерел енергії. Показано, що для забезпечення енергетично ефективного режиму роботи системи необхідно забезпечити роботу сонячної батареї в режимі джерела струму і дизель-генератор повинен мати зовнішню характеристику керованого джерела струму.

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