MODELAREA MATEMATICĂ A SISTEMULUI ENERGETIC SOLAR NAVAL

MATHEMATICAL MODELLING OF THE NAVAL SOLAR POWER SYSTEM

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ABSTRACT: Lucrare analizează sistemului electroenergetic solar. Se iau în considerare modificările insolației în timpul zilei , a punctelor de putere maximă care își schimbă coordonatele. Procesele tranzitorii sunt mai lente față de cele eoliene, deoarece insolația nu se modifică aşa de rapid precum viteza vântului. Pentru adaptarea tensiunii la bateria solară se foloseşte un convertor curent continuu-curent continuu. [1,2,3,4]. Acumulatorul electric e modelat prin elemente rezistive şi capacitive.Coordonatele punctului de putere maximă (U-tensiune, I*-curent) sunt mărimi prescrise în sistemele de conducere şi realizarea lor se face prin comanda tiristoarelor/tranzistoarelor din convertorul curent continuu-curent continuu.*

*ABSTRACT: This paper analyzes the solar power system. We have considered the changes in insolation during the day, the maximum power points shifting coordinates. The transitional processes are slower than those of wind, as sunstroke does not alter as fast as the wind speed. In order to adjust the solar battery voltage we have made use of a DC-DC converter. [1,2,3,4]. The electric charger is modeled by means of resistive and capacitive elements. The coordinates of the maximum power point (U *- voltage, I *-current) are prescribed sizes within management systems and their implementation is performed through control over the thyristors / transistors of the DC-DC converter.*

1. Conducerea sistemului energetic solar naval

Caracteristicile externe U=f(I) ale bateriei solare se modifică în funcție de oră, de nebulozitatea din atmosferă şi pot fi de forma celor din figura 1. [5].

1. The management of the naval solar power system

The external characteristics U = f (I) of the solar battery change according to time, the cloudiness in the atmosphere and may be as those in Figure 1. [5].

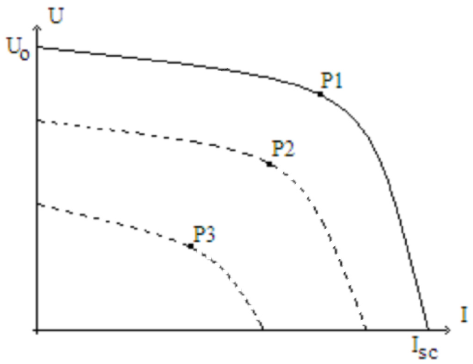

Fig.1 Caracteristici U=f(I) la bateria solară
Fig.1 Characteristics U = f (I) of the solar battery

Caracteristica cu punctul de putere maximă P_1 corespunde radiației solare

The feature with the maximum power point P1 corresponds to the maximum solar maxime: $E_1 = 1\left[kW/m^2\right]$ .Caracteristica cu punctul de putere maximă P_2 corespunde radiaţiei solare, de exemplu: $E_2 = 0.8\left[kW/m^2\right]$, iar cea cu putere maximă P_3 unei radiaţii solare $E_3 = 0.6\left[kW/m^2\right]$. Cu modificarea curentului de sarcină I puterea obţinută de la o baterie solară se modifică semnificativ, atingând o valoare maximală la curentul $I^*(U^*I^* = P_{max})$, figura 2.

Conducerea sistemului cu baterie solară trebuie să realizeze mereu funcţionarea la P_{max} , ştiind că această valoare se modifică în permanenţă în funcţie de gradul de insolaţie(nori,ceaţă,poluare).Coordonatele punctului de putere maximă, (tensiune U^*, curent I^*) ,depind de gradul de insolaţie.

radiation: $E_1 = 1\left[kW/m^2\right]$ The feature with the maximum power point P2 corresponds to the solar radiation, for example, $E_2 = 0.8\left[kW/m^2\right]$, and the maximum power point P3 to a solar radiation $E_3 = 0.6\left[kW/m^2\right]$.

The change in the load power I obtained from the solar battery triggers a significant alteration, reaching a maximum value for the current $I^*(U^*I^* = P_{max})$, Figure 2.

The management of the solar battery system must always operate at Pmax, knowing that this value is constantly changing depending on the degree of insolation (clouds, fog, and pollution). The coordinates of the maximum power point (U^* voltage, I^* current), depends on the degree of sun exposure.

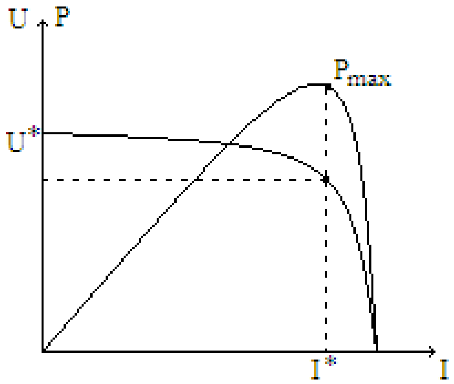

Fig.2. Caracteristicile bateriei
Fig.2. Battery characteristics

Cunoscând forma curentului generat de convertorul curent continuu-curent continuu, apar armonici, în principal de ordinele $1 \div 7$ (celelalte sunt de o mie de ori mai mici),figura 3.

Knowing the form of the current generated by the DC-DC converter, there are harmonics that appear mainly of the orders $1 \div 7$ (the others are a thousand times smaller), Figure 3.

2.Relaţiile de calcul ale armonicilor curentului

2. Numerical relations of the current harmonics

Curentul se descompune în armonici sub forma[6]:

The current is harmonically decomposed in the form [6]:

$$i(t) = \frac{I_0}{2} + \sum_{n=1}^{\infty} \sqrt{2} I_n \sin(n\omega t + \varphi) \qquad (1)$$

unde: where :

$$I_0 = \frac{1}{\pi}\int_0^{2\pi} i(x)dx = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)dx + \frac{1}{3.14}\int_4^{6.28}\left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)dx \qquad (2)$$

$$I_n = \sqrt{a_n^2 + b_n^2}$$

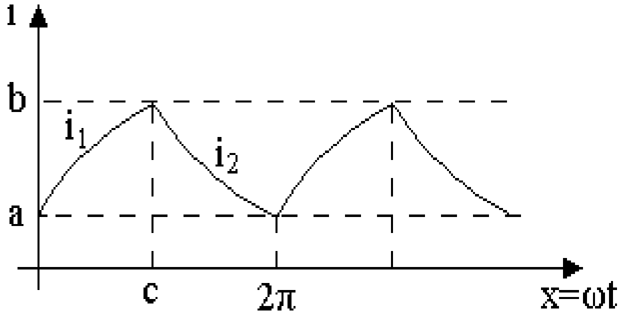

Fig.3. Variația curentului în timp
Fig.3. Current variation with time

Armonicile curentului sunt[7]: The current harmonics are [7]:

$$a_n = \frac{1}{\pi}\int_0^{2\pi} i(x)\cos(nx)dx = \frac{1}{3.14}\int_0^C \left(a + \frac{(b-a)(1-e^{-\beta x})}{1-e^{-\beta c}}\right)\cos(nx)dx + \frac{1}{3.14}\int_C^{6.28}\left(\frac{ae^{-\beta c} - be^{-\beta 6.28} + (b-a)e^{-\beta x}}{e^{-\beta c} - e^{-\beta 6.28}}\right)\cos(nx)dx \qquad (3)$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} i(x)\sin(nx)dx = \frac{1}{3.14}\int_0^C \left(a + \frac{(b-a)(1-e^{-\beta x})}{1-e^{-\beta c}}\right)\sin(nx)dx + \frac{1}{3.14}\int_C^{6.28}\left(\frac{ae^{-\beta c} - be^{-\beta 6.28} + (b-a)e^{-\beta x}}{e^{-\beta c} - e^{-\beta 6.28}}\right)\sin(nx)dx \qquad (4)$$

Schema electrică a sistemului energetic solar pentru $i_2(t)$ (curentul de sarcină) periodic, având variația dată anterior este prezentată in figura 4.

The wiring diagram of the solar power system for $i_2(t)$ (load current) periodically, with the prior variance, is shown in Figure 4.

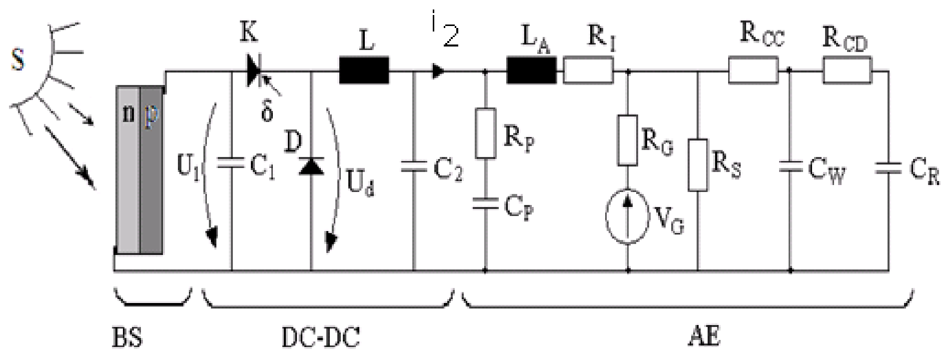

Fig.4. Schema electrică a sistemului energetic solar
Fig.4. Wiring diagram of the solar power system

Pentru componenta continuă, $\frac{I_0}{2} = 3[A]$, schema electrică se simplifică şi este redată în figura 5.

For the dc component, $\frac{I_0}{2} = 3[A]$, the circuitry is simplified and rendered in Figure 5.

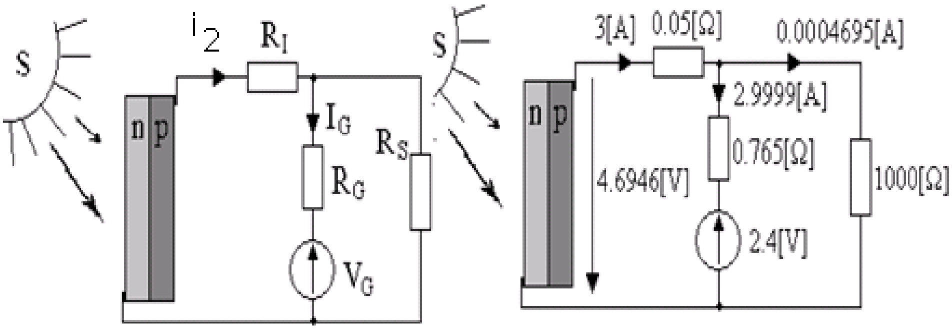

Fig.5. Schema electrică pentru componenta continuă
Fig.5. Circuitry for the dc component

Puterea furnizată pe o suprafața de 0,2m^2 din bateria solară, pe componenta continuă este:

$$P_{BS} = U_{BS} \cdot I_0 = 4.6946 \cdot 3 = 14[W]$$

Valorile efective ale curenților armonicilor de ordinul $1 \div 7$ se calculează din forma curentului i(t), care descompus în serie dă valorile:

The power supplied on an area of 0.2 m2 of the solar battery, along the dc component is:

$$P_{BS} = U_{BS} \cdot I_0 = 4.6946 \cdot 3 = 14[W]$$

The actual values of the harmonic currents of the order $1 \div 7$ are calculated from the shape of the current i (t), which serially decomposed gives the following values:

$$I_0 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)dx + \\ + \frac{1}{3.14}\int_4^{6.28}\left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)dx = 6.0571$$

$$a_1 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\cos x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\cos x dx = -0.75861$$

$$a_2 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\cos 2x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\cos 2x dx = -0.12280$$

$$a_3 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\cos 3x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\cos 3x dx = -1.0555 \times 10^{-2}$$

$$a_4 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\cos 4x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\cos 4x dx = -5.6258 \times 10^{-2}$$

$$a_5 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\cos 5x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\cos 5x dx = -1.2161 \times 10^{-2}$$

$$a_6 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\cos 6x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\cos 6x dx = -9.2771 \times 10^{-3}$$

$$a_7 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\cos 7x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\cos 7x dx = -1.9688 \times 10^{-2}$$

Calculul armonicilor curentului. Numerical Calculation

$$b_1 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\sin x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\sin x dx = -0.25799$$

$$b_2 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\sin 2x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28} \left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\sin 2x dx = 0.11575$$

$$b_3 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\sin 3x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28}\left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\sin 3x dx = -2.5789 \times 10^{-2}$$

$$b_4 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\sin 4x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28}\left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\sin 4x dx = -6.3852 \times 10^{-3}$$

$$b_5 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\sin 5x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28}\left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\sin 5x dx = 1.6515 \times 10^{-2}$$

$$b_6 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\sin 6x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28}\left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\sin 6x dx = -1.0844 \times 10^{-2}$$

$$b_7 = \frac{1}{3.14}\int_0^4 \left(2 + \frac{2(1-e^{-0.1x})}{1-e^{-0.4}}\right)\sin 7x dx +$$
$$+\frac{1}{3.14}\int_4^{6.28}\left(\frac{2e^{-0.4} - 4e^{-0.628} + 2e^{-0.1x}}{e^{-0.4} - e^{-0.628}}\right)\sin 7x dx = 2.8313 \times 10^{-3}$$

Valorile efective ale curenţilor se calculează cu relaţia[3]:

The actual values of the currents are calculated in the relation [3]:

$$I_n = \frac{\sqrt{a_n^2 + b_n^2}}{\sqrt{2}} \tag{5}$$

şi se obţin:

And we obtain:

$$I_1 = \frac{\sqrt{a_1^2 + b_1^2}}{\sqrt{2}} = \frac{\sqrt{0.75861^2 + 0.25799^2}}{\sqrt{2}} = 0.56828$$
$$I_2 = \frac{\sqrt{a_2^2 + b_2^2}}{\sqrt{2}} = \frac{\sqrt{0.1228^2 + 0.11575^2}}{\sqrt{2}} = 0.11968$$
$$I_3 = \frac{\sqrt{a_3^2 + b_3^2}}{\sqrt{2}} = \frac{\sqrt{1.0555^2 + 2.5789^2} \times 10^{-2}}{\sqrt{2}} = 1.9762 \times 10^{-2}$$
$$I_4 = \frac{\sqrt{a_4^2 + b_4^2}}{\sqrt{2}} = \frac{\sqrt{5.6258^2 + 0.63852^2} \times 10^{-2}}{\sqrt{2}} = 4.0155 \times 10^{-2}$$
$$I_5 = \frac{\sqrt{a_5^2 + b_5^2}}{\sqrt{2}} = \frac{\sqrt{1.2161^2 + 1.6515^2} \times 10^{-2}}{\sqrt{2}} = 1.4545 \times 10^{-2}$$
$$I_6 = \frac{\sqrt{a_6^2 + b_6^2}}{\sqrt{2}} = \frac{\sqrt{0.92771^2 + 1.0844^2} \times 10^{-2}}{\sqrt{2}} = 1.0121 \times 10^{-2}$$

$$I_7 = \frac{\sqrt{a_7^2 + b_7^2}}{\sqrt{2}} = \frac{\sqrt{1.9688^2 + 0.28313^2} \times 10^{-2}}{\sqrt{2}} = 1.417 \times 10^{-2}$$

3. Concluzii

Puterea primită de la Soare se modifică continuu şi sistemul energetic solar trebuie să fie astfel reglat încât să funcţioneze în punctul de putere maximă.

Funcţionarea sistemului energetic solar naval în punctul de putere maximă se poate realiza printr-o comandă potrivită a elementelor de comutaţie din convertorul curent continuu-curent continuu. Armonicile curentului prin acumulatoarele electrice au valori reduse, cele mai semnificative fiind armonicile 1 şi 2.

Amplasarea bateriei solare pe navă se poate face într-un sistem fix, când se pierde 37% din energia radiantă, sau mobil, situaţie în care se obţine maximul de energie, respectiv putere (aproximativ 1kW/m^2).

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3. Conclusions

The power received from the Sun is continually changing and the solar power system has to be adjusted in such a way that it performs at its peak power output.

Such a peak-power performance can be achieved by means of a proper management of the commutation elements within the DC-DC converter. The current harmonics in the electric chargers have low values, the most significant ones being the harmonics 1 and 2. The placement of the solar battery on board a ship may be made either within a fixed system, which triggers a 37% loss in the radiant energy, or within a mobile system, which would trigger a maximum power level (approximately 1kW/m^2).

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