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MODIFIED HILL CLIMBING MAXIMUM POWER POINT TRACKING CONTROL METHOD FOR SATELLITE ELECTRICAL POWER SUPPLY SYSTEM

The increasing of efficiency of the satellite electrical power supply system (PSS) is important engineering task. Modern satellite PSS widely use DC-DC converters under pulse-width controlling. Existing methods of maximum power point tracking of such systems not always can to search surely for maximum power point if there are existing some local maximums of power. It can be if illumination of few non-oriented solar panels are different. This paper present the modeling of modified hill climbing (HC) maximum power point tracking (MPPT). The aspect of the method is choosing initial point through open circuit voltage coefficient and next tracking by using of special function through digital differentiation of measured values of output power with scaling on actual power and special empirical coefficient. The simulation results revealed robust tracking of the main peak power at a sufficiently rapid convergence.

Keywords: *Satellite Power System, Solar Photovoltaic, Maximum Power Point Tracking, Hill Climbing Techniques.*

Introduction

One of bearings of advancement of space innovation is the utilization of complexes of multiple spacecraft, "main satellite"-"subsatellite". For example, "Sich-1M"- "KS5MF2" (Ukraine, 2004), "Sich-2M"- "Youth subsatellite" (Ukraine, at present being developed). Recent years have seen a technological in the use of renewable energy sources, particularly for satellites, generation of solar power is very convenient in space, especially because there are no clouds and the sun not absent.

Since the birth of the space age until the present time, the majority of satellites have been utilizing solar cells and batteries to generate and store the required power. Solar panels occupy a wide area and batteries are essentially heavy devices. At nowadays, the solar photovoltaic is still the most appropriate energy source. The energy produced nearly identifies with normal operation and life time particularly for satellite whose power is constrained by size and weight [1-2].

Solar radiation, temperature, load impedance and main bus voltage are the four factors which affect the maximum power extraction from solar PV module. I-V curve of PV module is a function of insolation and temperature which affects output current and voltage.

The increased intensity of solar radiation increases short circuit current (I_{SC}) while increased temperature decreases the open circuit voltage (V_{OC}). Therefore I-V and P-V curve changes according to the operating conditions which alters maximum power point. The relationship between the current and voltage of the photovoltaic cell is highly nonlinear and it can be observed that there is a unique maximum power point (MPP) at a particular environment, and this peak power point keeps changing with solar irradiation and ambient temperature. So it is important to match the PV source and load impedance properly for any weather conditions, to obtain maximum power generation. Therefore, PV power generation system a maximum power point tracker (MPPT) [3-5].

In this paper, the method for appreciating the mathematical model of solar array for satellite is proposed. Finally, by using hill climbing MPPT method is used in satellite developed by the Department of Space Technology and Alternative Energy Sources, «KhAI».

Proposed Satellite Electrical Power

The Satellite Electrical Power System SEPS is divided into three units. The overall plan of the system is illustrated in Fig. 1.

- Solar Power Unit (SPU),
- Power Generation Unit (PGU),
- Power Storage Unit (PSU).

Each and every unit has its own responsibilities and functions. A boost DC-DC converter is used in the

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(PGU) for adjusting the operating point of the (SPU). MPPT measures the voltage and current of the (SPU) and adjusts the duty cycle of the PWM signal applied to the converter in a way that, if required, the maximum possible power can be absorbed from the (SPU). In the (PSU), when the generated power exceeds the consumption demand, the battery is charged by the charger. On the other hand, when consumed power exceeds the maximum array power or when there is an eclipse, the battery is connected to the main bus, via the discharge diode, and supplies the required power.

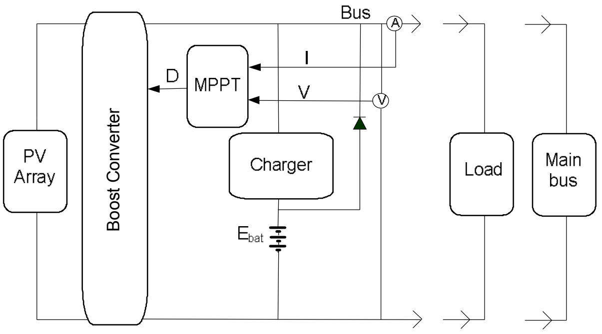

Fig. 1. Satellite Electrical Power schematic

For (PSU), A lithium-ion battery was adopted for storing energy. Batteries are typically charged with the maximum possible current that does not damage the battery.

Hill Climbing MPPT Algorithm (HC)

Hill climbing (HC) technique is widely applied in MPPT controllers because of their simplicity and simple usage. In this method, the duty cycle of the power converter can change and the power is absorbed from the array compared to the previous stage. If power increases, the duty cycle changes to the previous direction and if power decreases, the duty cycle changes to the opposite direction. The most common MPPT method in space applications is the hill climbing method owing to its high precision, simple structure, direct investigation of power, high reliability, and independence from sensors such as radiation and temperature sensors [3-6]. This method has three major disadvantages:

Firstly tracking local peaks of the solar array voltage-power curve, secondly oscillations around the MPP and thirdly low speed.

The following equation may be employed for tracking the MPP by using hill climbing method as shown in Fig. 2:

$$dP/dD=0\,, \tag{1}$$

where dP - incremental power;

dD - incremental duty cycle.

$$dP/dD=d(I_{PV}\times D)/dD\,, \tag{2}$$

where I_{PV} - current of PV module;

D - duty cycle.

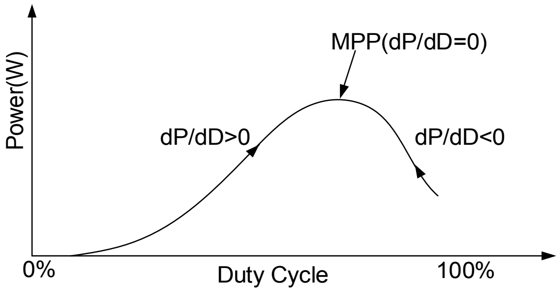

Fig. 2. The P-D curve diagram of PV modules

Substituting the value of D, for the boost converter leads to the following condition:

$$-I_{PV}+(1-D)\times dI_{PV}/dD=0\,. \tag{3}$$

From the Fig. 1

$$V_{PV}=(1-D)\times E_{bat}\,, \tag{4}$$

where, V_{PV} - voltage of PV module V;

E_{bat} - battery voltage V.

To solve the differential equation of Eq. (3), the partial term is rephrase. In this case the solar photovoltaic panel is formed by a series-parallel combination of appropriate solar cell in order to provide the voltage and current necessary under normal conditions, first I_{PV} is calculated by substitution of the following relations (derived from Fig. 1 and Eq. (5).

$$I_{PV}=N_p I_{ph}-N_p I_s\left[e^{\left(\frac{V_{PV}+I_{PV}R_s}{N_s A V_T}\right)}-1\right]-\frac{N_p(V_{PV}+I_{PV}R_s)}{N_s R_p}, \tag{5}$$

where N_P - parallel connections of PV module,

N_s - series connections of PV module,

I_{Ph} - Photovoltaic current A,

I_s - diode saturation current A,

R_s - series resistance of PV cell,

R_p - parallel resistance of PV cell,

A - ideality factor,

V_T - voltage temperature at T=25°C.

As a result, the following relation for I_{PV}/dD is derived:

$$\frac{dI_{PV}}{dD}=-N_pI_s\left(\frac{-E_{bat}+R_s\frac{dI_{PV}}{dD}}{N_sAV_T}\right)\times e^{\left(\frac{V_{pv}+I_{PV}R_s}{N_sAV_T}\right)}-$$

$$-N_p\left(\frac{-E_{bat}+\frac{dI_{PV}}{dD}R_s}{N_sR_P}\right)\times\frac{V_{PV}+I_{PV}R_s}{N_sR_P}. \tag{6}$$

Or

$$\frac{dI_{PV}}{dD}=\left(\frac{(N_pI_sE_{bat})\times e^{\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sAV_T}\right)}+(N_pE_{bat})\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sR_P}\right)}{(N_pI_sR_s)\times e^{\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sAV_T}\right)}+N_sAV_T+(N_pR_s)\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sR_P}\right)+N_sR_P}\right). \tag{7}$$

Substituting Eq. (7) into Eq. (3) leads to Eq. (4) which is a mathematical equation without any differential terms. dP_{out}/dD

$$\frac{dP_{out}}{dD}=I_{PV}-(1-D)\times$$

$$\times\left(\frac{(N_pI_sE_{bat})\times e^{\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sAV_T}\right)}+(N_pE_{bat})\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sR_P}\right)}{(N_pI_sR_s)\times e^{\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sAV_T}\right)}+N_sAV_T+(N_pR_s)\left(\frac{(1-D)E_{bat}+I_{PV}R_s}{N_sR_P}\right)+N_sR_P}\right). \tag{8}$$

According to Eq. (8), the tracker should modify the duty cycle D and measures the current Ipv until the conditional case “dP/dD =0” is achieved. In practice, reaching this condition is not applicable due to the discontinuity of the duty cycle. Therefore, the best operating point is where the magnitude of dP/dD becomes minimum (as close as possible to zero). It should be noted that Eq. (8) is valid for the boost converter

For the (PGU) the proposed MPPT algorithm is depicted in Fig. 3, where D is the duty cycle of the power converter, Ppv is the array power, Vpv is the array voltage, and Ipv is the array current.

Simulation results

The power system was simulated in two variants – single (autonomous) power system worked on own load with R=25, 50, 100 Ohm and power system worked in parallel on main bus with stable voltage 40, 45, 50 V. Dependence P_{out} from duty cycle D for both variants are shown on Fig. 4 and Fig. 5 respectively.

The function dP_{out}/dD for both variants is shown on Fig. 6 and Fig. 7 respectively.

This function can be used for calculation of ΔD but needed in scaling and cropping. Scaling is performed on the value of P_{out} and scale coefficient K_{sc}. Thus ΔD is calculated as $\Delta D_{i+1}=\frac{P_i-P_{i-1}}{D_i-D_{i-1}}\times\frac{2}{P_i+P_{i-1}}\times\frac{1}{K_{sc}}$.

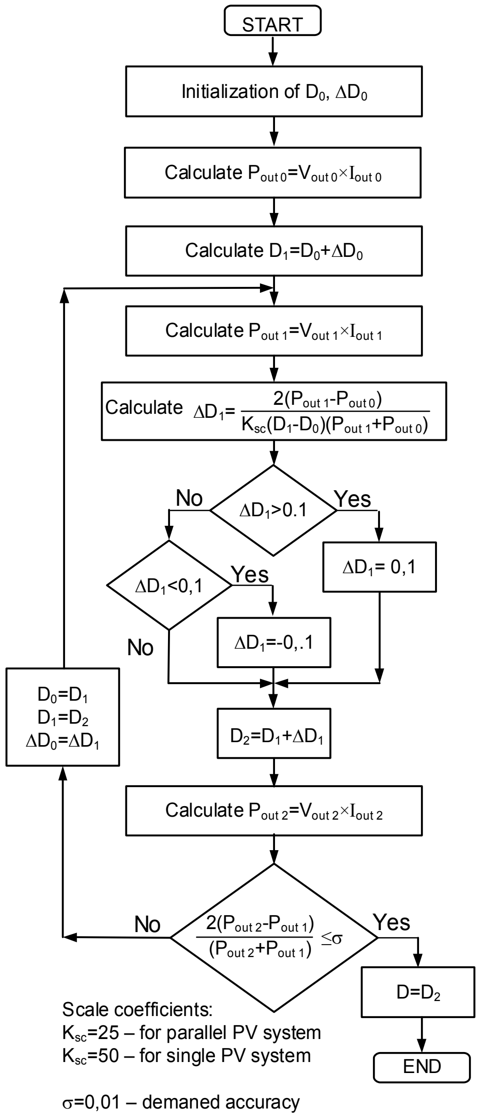

Fig. 3. Flowchart of MPPT algorithm

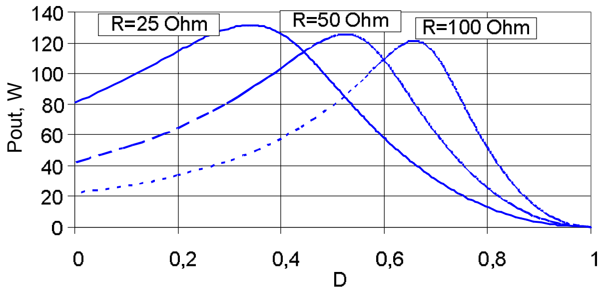

Fig. 4. Dependence P_{out} from duty cycle D
for single system

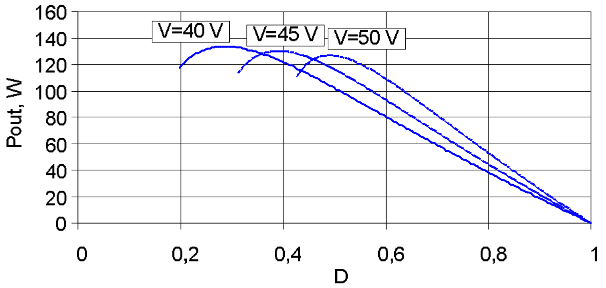

Fig. 5. Dependence P_{out} from duty cycle D
for parallel system

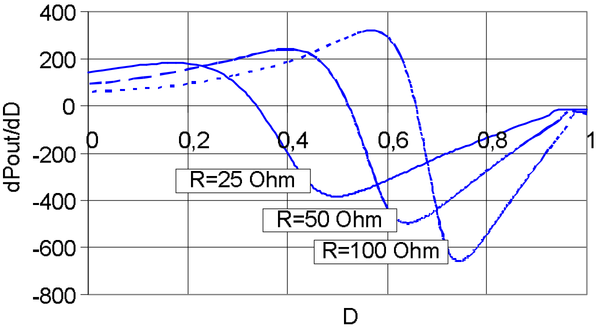

Fig. 6. Dependence dP_{out}/dD from duty cycle D
for single system

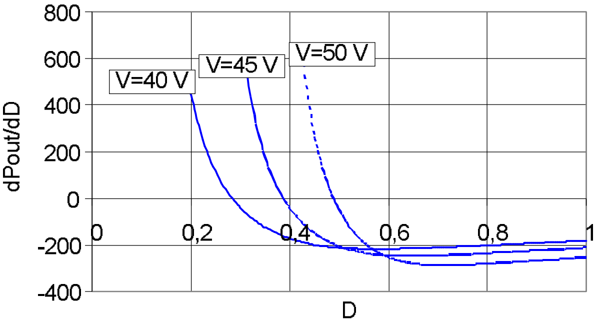

Fig. 7. Dependence dPout/dD from duty cycle D
for parallel system

Cropping is performed in borders from -0,1 to 0,1. Modified function for calculation of ΔD is shown on Fig. 8 and Fig. 9.

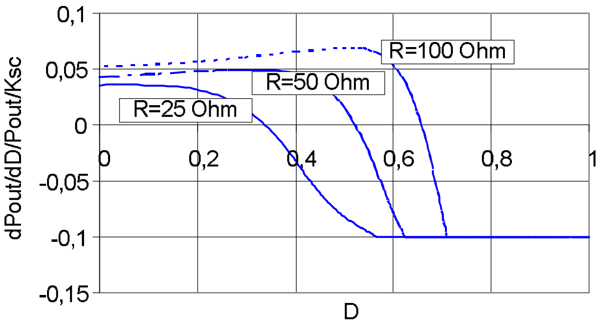

Fig. 8. Modified function for calculation of ΔD
for single system

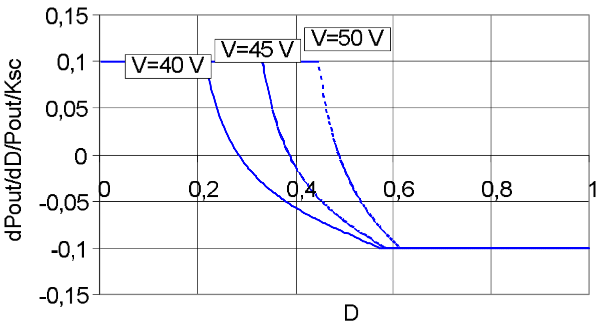

Fig. 9. Modified function for calculation of ΔD
for parallel system

Algorithm convergence from extreme positions of initial D=0 and D=1 is illustrated on Fig. 10 and Fig. 11.

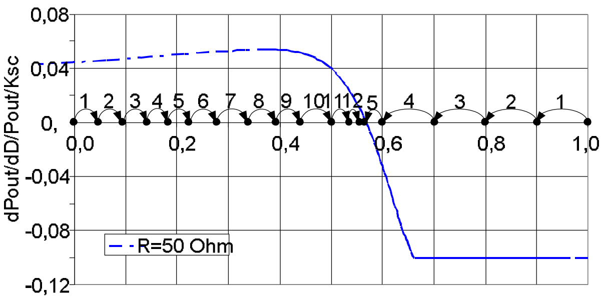

Fig. 10. Convergence from extreme positions
of initial D for single system

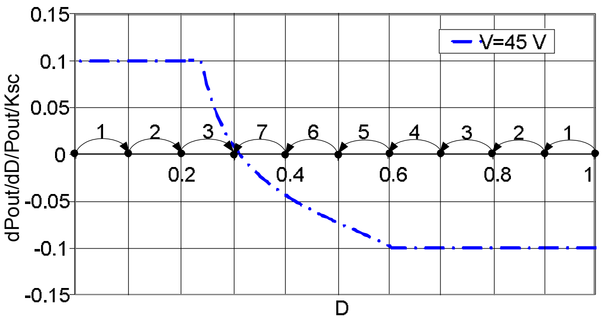

Fig. 11. Convergence from extreme positions
of initial D for parallel system

As we can see on Fig. 10 and Fig. 11 convergence from extreme positions for single system does not exceed the 12 steps. Convergence from extreme positions for parallel system does not exceed the 7 steps. When initial value of D is chosen from condition *open circuit voltage coefficient equal to 0,88* then convergence does not exceed the 3 steps for both variants.

Conclusions

This paper present the modeling of modified hill climbing (HC) maximum power point tracking (MPPT). The aspect of the method is choosing initial point through open circuit voltage coefficient and next tracking by using of special function through digital differentiation of measured values of output power with scaling on actual power and special empirical coefficient. The simulation results revealed robust tracking of the main peak power at a sufficiently rapid convergence.

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МОДИФИЦИРОВАННЫЙ МЕТОД ВОСХОЖДЕНИЯ ПО ВЫПУКЛОЙ ПОВЕРХНОСТИ ПРИ ОТСЛЕЖИВАНИИ ТОЧКИ МАКСИМАЛЬНОЙ МОЩНОСТИ СИСТЕМЫ ЭЛЕКТРОСНАБЖЕНИЯ СПУТНИКА

Али М. Джасим

Повышение эффективности использования спутниковой системы электроснабжения (СЭС) является важной инженерной задачей. Современные спутниковые СЭС широко используют DC-DC преобразователи с широтно-импульсным управлением. Существующие методы слежения за точкой максимальной мощности таких систем не всегда позволяют уверенно отслеживать точку максимальной мощности, если существует несколько локальных максимумов, что может иметь место при различной освещенности нескольких неориентированных солнечных панелей. В статье представлены результаты моделирования модифицированного метода восхождения по выпуклой поверхности при отслеживании точки максимальной мощности. Особенностью метода является выбор начальной точки посредством коэффициента напряжения холостого хода и последующее отслеживание при помощи специальной функции через цифровое дифференцирование измеряемых значений выходной мощности с масштабированием по фактической мощности и специальным эмпирическим коэффициентом. Результаты моделирования показали надежное отслеживание основного максимума мощности при достаточно быстрой сходимости.

Ключевые слова: спутниковая система электроснабжения, солнечная фотовольтаика, отслеживание точки максимальной мощности, метод восхождения по выпуклой поверхности.

МОДИФІКОВАНИЙ МЕТОД СХОДЖЕННЯ ПО ОПУКЛІЙ ПОВЕРХНІ ПРИ ВІДСТЕЖЕННІ ТОЧКИ МАКСИМАЛЬНОЇ ПОТУЖНОСТІ СИСТЕМИ ЕЛЕКТРОПОСТАЧАННЯ СУПУТНИКА

Алі М. Джасім

Підвищення ефективності використання супутникової системи електропостачання (СЕС) є важливою інженерною задачею. Сучасні супутникові СЕС широко використовують DC-DC перетворювачі з широтно-імпульсним керуванням. Існуючі методи стеження за точкою максимальної потужності таких систем не завжди дозволяють впевнено відстежувати точку максимальної потужності, якщо існує декілька локальних максимумів, що може мати місце при різній освітленості декількох неорієнтованих сонячних панелей. У статті представлено результати моделювання модифікованого методу сходження по опуклій поверхні при відстеженні точки максимальної потужності. Особливістю методу є вибір початкової точки за допомогою коефіцієнта напруги холостого ходу і подальше відстеження за допомогою спеціальної функції через цифрове диференціювання вимірюваних значень вихідної потужності з масштабуванням за фактичною потужністю і спеціальним емпіричним коефіцієнтом. Результати моделювання показали надійне відстеження основного максимуму потужності при досить швидкій збіжності.

Ключові слова: супутникова система електропостачання, сонячна фотовольтаїка, відстеження точки максимальної потужності, метод сходження по опуклій поверхні.

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