Maximum power point tracking for PV generator feeding different DC motor drive systems

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A simple method of maximum power point tracking for photovoltaic generator feeding magnetoelectric DC-current motor in stand-alone photovoltaic drive system, without a buffer energy source, has been described in this paper. The specific quality of this method is assuring the maximum power working point of the generator in indirect way – by maximisation of motor input power. This method makes maximum power point tracking independent of generator cells temperature and insolation, and of any changes of generator output characteristic (voltage-current) curves caused by light cells aging and shading of some cells shaded with snow or dirt. This method was implemented in a laboratory stand for two similar versions (analogue and digital with microcontroller), some differing in a tracking method, and its results have been presented and compared herein.

Keywords: photovoltaics, maximum power point tracking, drive systems.

1. Introduction

Stand-alone photovoltaic (PV) drive systems are quite widespread in many countries, both in scientific research and in practical utilisation (e.g., for driving water pumps in irrigating systems). Operation of PV system without buffer source (e.g., accumulator) is often ussed because of its simplicity and reliability. The DC-current motor with permanent magnet excitement (simply: magnetoelectric motor) is the best kind of motor for operation in this system, especially if PV generator nominal power is not big (less than 0.5 kWp).

This type of motor has several good points when it is supplied from PV generator.

1. Its efficiency is quite high.
2. It doesn't require DC/AC inverter, which is necessary for AC motors, so a simple DC chopper may be just installed between generator and motor to control motor and generator parameters.
3. It is much cheaper than AC motor with inverter.
4. It has very good start-up properties – the electric power required for starting the motor is little, even for starting torque greater than nominal motor torque.
5. Its angular velocity may be simply changed only by changing one parameter – motor input voltage.
6. Simple regulators for controlling torque and velocity may be applied, because the output torque is almost proportional to input current, and velocity to input voltage.

The basic disadvantage of this kind of motor, when compared with induction motor, is periodical commutator and brushes maintenance necessity. Moreover, this type of motor cannot operate in strenuous environment (caustic, explosive or with high humidity).

2. Maximum power point tracking circuits for PV generators

Because of relatively high cost of PV generated energy, it is necessary to assure generator operation in PV drive system with maximum attainable output power in any time, independently of input generator parameters (mainly insolation and temperature). This is why the application of special units maximising generator power in the system, called maximum power point trackers (MPPT), allows for effective utilisation of generator energetic resources. Moreover, efficiency of some elements of the system depends on generator power – the greater power means the bigger motor and driven machine (e.g., centrifugal pump) angular velocity, which means higher motor and machine conversion eficiency.

Good MPPT methods and units should comply with the following requirements:

1. Assuring PV generator operation in its real maximum power point, independently of generator cells temperature and insolation, and of changes of generator output characteristic (voltage-current) curves caused by light aging of cells.
2. Proper circuit operation while worsening the operation of some generator cells, shaded by surging snow, dirt or any other objects.
3. Proper MPP tracking during slow and fast variations of PV generator input parameters (mainly insolation).

4. Power consumption and fabrication costs of MPPT unit as little as possible, its construction as simple as possible.
5. Interference resistance of the unit, and resumption of proper operation after strong interference causing temporary unsuitable operation. This requirement is particularly important for digital units with microcontrollers.

The most frequently applied principles and methods of MPP tracking are presented below in three groups:

1. Circuits with sensors representing PV generator operation parameters:
   a) with input (climatic) generator parameter sensors directly measuring temperature (e.g. thermistors) and insolation (e.g. pyranometers) of the whole generator,
   b) with output (electric) generator parameter sensors measuring open circuit voltage or/and short circuit current. These sensors represent indirectly electric parameters of the whole generator. Additional PV cells installed in one of the modules forming the whole generator are often implemented as sensors.
2. Circuits without sensors operating on the basis of output (electric) parameters of PV generator:
   a) circuits fixing MPP on the ground of present generator output voltage and current,
   b) circuits scanning on-line generator output V-I characteristic curve for searching MPP.
3. Circuits tracking MPP of generator indirectly – for example operating on the ground of signals from electric energy receiver (motor in drive system):
   a) circuits with positive feedback,
   b) circuits scanning receiver input power characteristic curve for searching maximum of its power.

Circuits of the first group mentioned above do not comply good with requirements 1, 2 and partly 4, because they calculate MPP parameters on the ground of sensors signals, and the sensors always operate in some different conditions than those of the whole generator. Moreover, there are always differences between individual cells forming the whole generator. These circuits also require additional conduit to transmit signals from sensors, which is important when there is a big distance between generator and motor (chopper, controlling and MPPT circuits are usually placed by motor).

Circuits of the second and third group satisfy requirements 1 and 2 much better, because their principle of operation ensures generator's real MPP tracking (not calculating).

The circuits from 3(a) group (in analogue version) and from 3(b) group (in digital version) are presented below.

3. Maximum power point tracker in analogue version

A simplified diagram of the system with MPP tracker in analogue version is presented in Fig.1. The principle of operation of a similar circuit has been described in Ref. 1, but that system was more complex and required providing motor with rate generator (tachometer).

This circuit enables MPP tracking for all kinds of motor's load L fulfilling the condition that in all range of the shaft angular velocity ω, the mechanical power P_M increases with ω increase. This requirement comply both centrifugal pumps and fans (loads of $T = k_L\omega^2$ type, where T is the mechanical torque, k_L is the load's L constant), because for them $P_M = T\omega = k_L\omega^3$, and for piston pumps and transporters (loads of T = const. = k_L type), because for them $P_M = T\omega = k_L\omega$. When this condition is obeyed, input

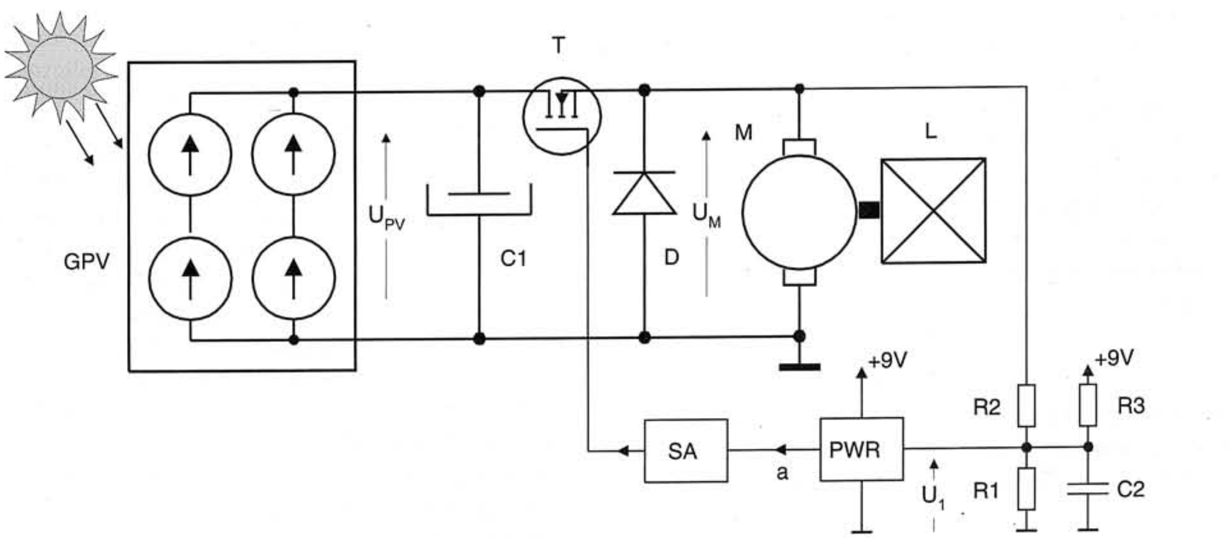

Fig. 1. Simplified diagram of stand-alone photovoltaic drive system with simple MPPT circuit. GPV – PV generator with nominal power P_{nPV} = 220 Wp composed of four modules ALFA55S; M – magnetoelectric motor with nominal power 85 W and nominal voltage 24 V; L – mechanical load of the motor; T, C1, D – p-channel MOSFET, capacitor and diode forming, together with motor inductance, DC chopper assuring proper co-operation between generator and motor, SA – separating amplifier; PWR – pulse width regulator circuit, controlling transistor T with rectangular signal. The filling factor a of the signal is proportional to U1 voltage: a = kU1, R1; R2, R3, C2 – elements forming MPPT circuit.

(electric) motor power P_E (that is almost proportional to P_M) will be increasing with U_M increase in all range of motor voltage U_M (that is almost proportional to ω). Finally, assuming that chopper efficiency is constant, we may find that motor input voltage U_M is proportional to generator output power P_{PV}, because P_E is proportional to P_{PV}. This is why searching for maximum power of the generator may be resolved into searching for maximum motor voltage.

As one can see in Fig. 1, only four elements form MPPT circuit, and among them R3 is only an auxiliary element – it enables the start-up of circuit operation. Capacitor C2 prevents arising any oscillations in the system and filters harmonics from motor rectangular voltage.

Basic equations describing circuit operation are

$$U \approx \frac{R1}{R1 + R2} U_M \quad \text{(when omitting R3)}, \qquad (1)$$

$$a = kU_1, \qquad (2)$$

$$U_M = aU_{PV} \quad \text{(when omitting chopper losses)} \qquad (3)$$

The detailed principle of circuit operation is as follows:

1. With absent R3, as soon as U_{PV} voltage appears, U_M voltage will be equal to zero because at first a= 0, so from Eq. (3): $U_M = 0$. For $U_M = 0$ we have: $U_1 = a = 0$ from Eqs. (1) and (2). This is why it is necessary to apply R3 in circuit structure to start its operation.
2. At first PV generator operates at no-load state, so $U_{PV} = U_0$, U_0 is the open circuit generator voltage. Owing to R3 presence: $U_1 > 0$ (in spite of initial $U_M = 0$), and then a > 0. According to Eq. (3), it makes U_M positive. This fact increases voltage U_1 according to equation (1), and owing to positive feedback gives further increase of a and U_M. During this process U_{PV} decreases, but P_{PV} increases.
3. As soon as U_{PV} has decreased to U_{MPP} voltage (generator's voltage corresponding to its maximum power point), further increase of a would cause decrease both U_{PV} and P_{PV}, and this would decrease U_M (that is proportional to P_{PV}), which finally would bring U_1 and a decrease. This is why maximum power point of the generator becomes a stable operating point of the circuit.

After working out the system of Eqs. (1), (2), and (3) we obtain

$$U_{PV} = \frac{R1 + R2}{kR1} \qquad (4)$$

which means that in theory generator operating voltage does not depend on the load of the motor and motor voltage, but only on the parameters of elements forming MPPT circuit.

Some advantages of the described circuit are:

- simplicity, reliability and very low cost of the circuit,
- real generator MPP tracking,
- very good dynamic properties – responses to fast and large insolation changes are very quick and without oscillations (see Fig. 2).

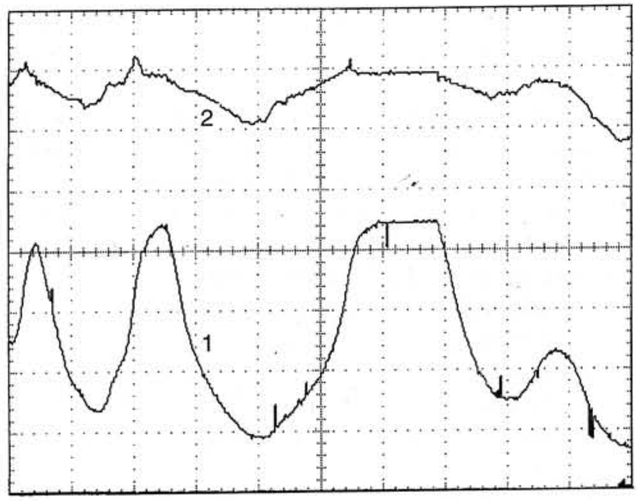

Fig.2. Generator voltage U_{PV} changes (curve 2 – 5 V/div) during insolation changes, represented by generator current I_{PV} changes (curve 1 – 0,5A/div). Time base: 1s/div.

The circuit faults are:

- need for selecting R2 and R3 values for each type of motor load.
- explicit dependence of U_{PV} on changes of torque load T for little P_{PV} values.

For generator P_{MPP} power greater than 10% of P_{nPV}, accuracy of P_{MPP} tracking is not less than 97%, but for example while P_{MPP} = 5 Wp (about 2% of P_{nPV}) and for little torque values (that means for greater U_M values) this accuracy drops to 90%. This fact results from unfavourable influence of R3 presence on circuit operation, which has not been taken into account in theoretical simplified calculations.

4. Microprocessor based MPP tracking circuit

A diagram of the system with microprocessor MPPT unit is presented in Fig. 3.

The operation principle of the circuit is similar to the previous one – it tracks maximum of DC motor armature voltage U_M. It continuously searches the $U_M = f(a)$ characteristic, changing parameter a and analising behaviour of U_M. For instance, if U_M increases with the increase of a, then the circuit continues increasing a, otherwise it decreases a. In this way after reaching MPP the system oscillates around it until PV generator parameters (e.g., insolation) are changed. Then the circuit searches for new MPP.

The CPU algorithm for MPP tracking is presented on a flowchart (Fig. 4). It starts with setting some initial values, and then goes to endless loop. This loop begins with measuring U_M (Um_in value), that is then compared with previous cycle measured U_M (Um value). On this basis a voltage trend flag (flag_dUm) is defined. It assumes value 1 when the two voltages are the same or there has been some increase in it, and value 0 when it has been decreased. The next step is to compare the two flags (flag_dUm and flag_dTw) and to adjust the trend lifting of output width pulse time Tw according to the table:

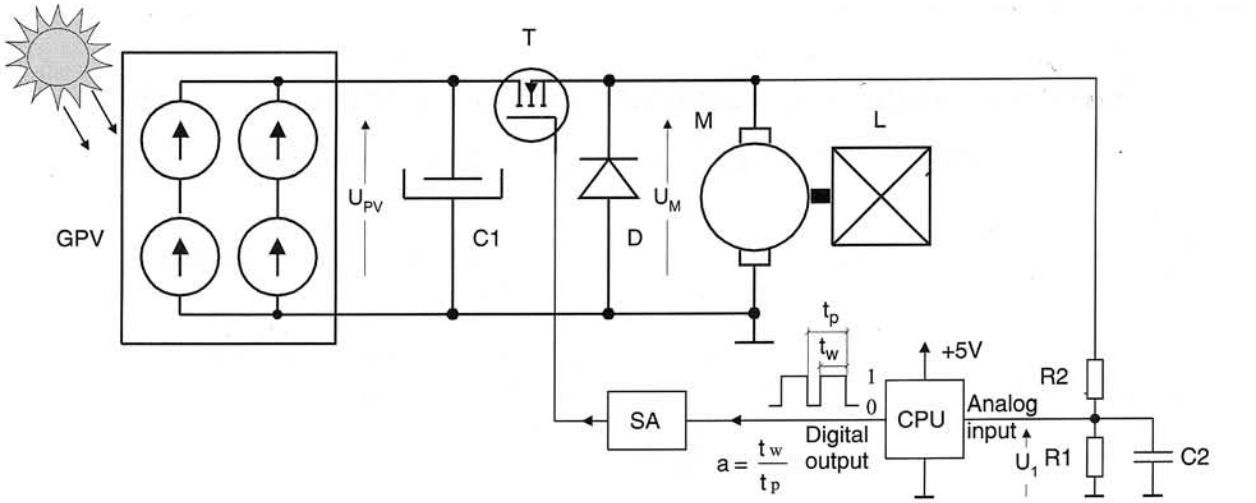

Fig. 3. Simplified diagram of stand-alone photovoltaic drive system with microprocessor MPPT circuit. CPU – SAB 80c535 microcontroller. The remaining elements like in Fig. 1.

		flag_dUm	
		0	1
flag_dTw	0	Change into increasing Tw	Continue decreasing Tw
	1	Change into decreasing Tw	Continue increasing Tw

The trend flag of output pulse time (flag_dTw) assumes values 0 and 1, corresponding to decrease and increase in time Tw. High level voltage is maintained on digital output port of processor during time Tw. The last step is to assume measured Um_in value as the previous value Um and to come back (after some time t_x needed for resulting of a change to U_M change) to the beginning of the loop.

The described algorithm has been applied to program microcontroller in the laboratory stand, but serious damage in the circuit hasn't allowed for presenting laboratory test results in this paper.

Probable advantages of microcontroller circuit, comparing with analogue version, should be:

- better MPP tracking accuracy,
- independence of tracking accuracy from motor load torque changes and generator insolation values.

The most essential faults are less reliability and bigger circuit costs.

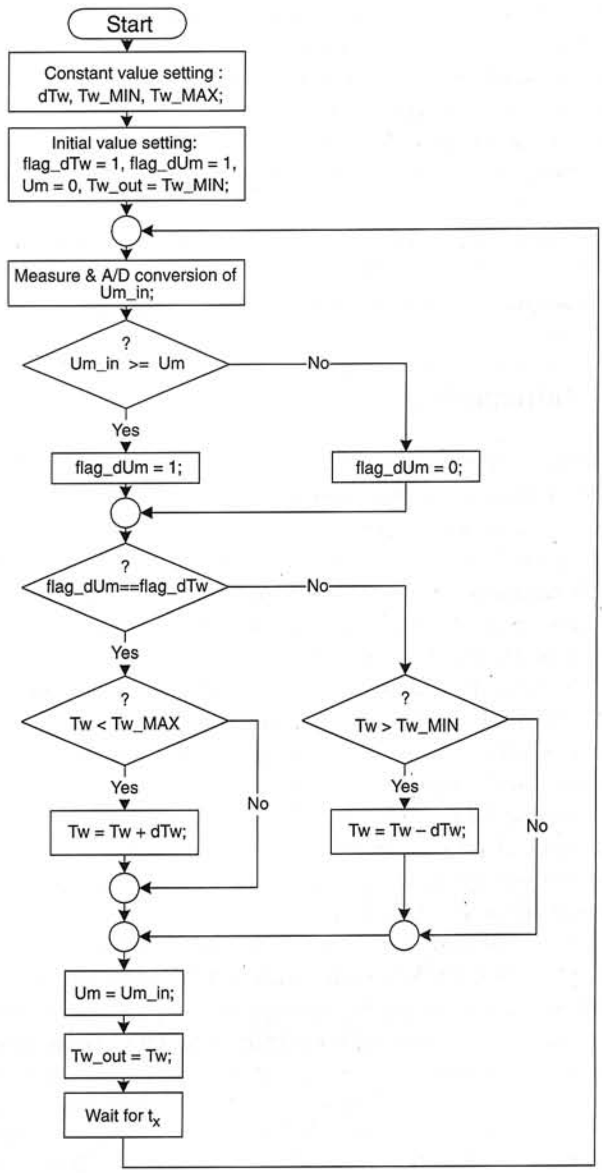

Fig. 4. CPU algorithm for MPP tracking.

References

1. K. Venkatesan and D. Cheverez-Gonzalez, "Matching DC motors to photovoltaic generators for maximum power tracking," APEC'97, *Proc. IEEE* **2**, 514–519 (1997).