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MICROCONTROLLER BASED STEP-UP DC-DC CONVERTER DRIVER WITH MPPT ALGORITHM IMPLEMENATION

Energy efficiency is one of most critical parameters in photovoltaic (PV) systems. Overall PV system efficiency improvement may be achieved by such means as topological changes, new generations of transistor switches and/or planar magnetic components use. But on the other hand whole system must follow the wheather changes such as solar energy delivery variation due to cloud shading as well as temperature fluctuations. In such conditions a driver should dynamically track maximum power point (MPPT) of a PV array. For the purposes of better understanding PV array performance the paper shows MatLab simulation of 3.2 kWp PV array. The driver discussed works with a range of different step up DC-DC converter topologies such as bridge based topologies as well as interleaved ones. The ASCII protocol which can be implemented in PC application is responsible for working parameters settings carrying and output data logging as well as current software status check. The paper presents practical implementation of the driver as a part of larger PV system where the interleaved DC-DC converter works with 3.2 kWp PV array of ten PV modules connected in parallel. Described MPPT algorithm takes advantage of modified Perturb and Observe (P&O) method. Presented are microcontroller hardware resources utilization, functional software architecture and developped MPPT algorithm which performance is shown on the plot.

KEYWORDS: MPPT algorithms, photovoltaic systems

1. INTRODUCTION

Photovoltaic (PV) energy has become more apparent for last years in such areas as domestic or agricultural applications. It seems to be a good solution for remote localizations with no electricity grid access. PV energy generation neither brings a pollution into the environment nor generates unwanted acoustic noise. Yet PV systems are not commonly used because of relatively high price in comparison to expected benefits. The cost of PV modules shares the majority of overall PV system price. However over a few recent years the price of PV modules constantly drops down it is still high enough to be commonly used.

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The new semiconductor technologies have slightly improve PV cells efficiency which reach up to 19%. Such relatively low amount of energy which comes from solar radiation should be carefully converted and transferred to the load. Therefore the converter topology and its driving method should assure maximum efficiency. Recently many power semiconductor technologies have been introduced among which silicon carbide (SiC) devices seem most suitable to aim at that target. Moreover robust maximum power point (MPPT) driving algorithm should be implemented within the driver to follow the solar radiation and temperature variations.

2. SYSTEM TOPOLOGY

PV energy system is depicted on Fig. 1. PV array consists of the array of ten PV modules 320Wp each in parallel which makes 3.2 kWp of total peak power. ower is delivered to the interleaved step-up DC-DC converter driven accordingly to the algorithm implemented. The driver is based upon STM32F107 microcontroller which drives up to 8 phases of interleaved step-up DC-DC converter. PC computer application controls over RS-232 interface the work of the driver as well as receives the measurement data and driver status upon the request.

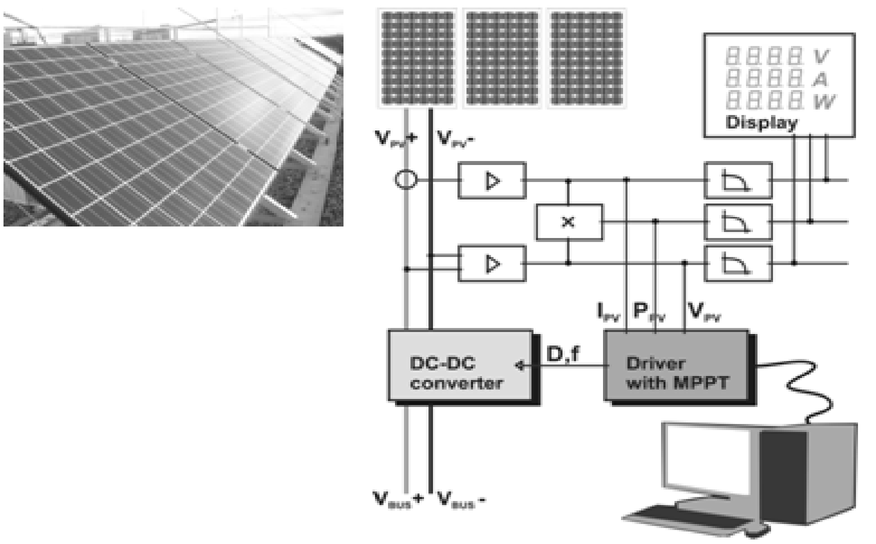

Fig. 1. Simplified PV energy system diagram (the inset shows 3.2 kWp PV array installed on the roof of Electrical Engineering Faculty building)

Measurement front-end delivers to the driver's ADC such parameters as instantaneous panel current, voltage and power calculated as product of multiplication of both parameters. Additionally LED display is available for the test purposes.

3. PV ARRAY

3.1 PV array description

The PV array consists of ten KYOCERA KD320GH-4YB PV modules connected in parallel. Total peak current generated in the panel I_{PV} reaches over 80A at the voltage V_{PV} in the range of 40 V to 60 V. The power generated in PV module strongly depends on environmental conditions such as solar radiation S [W/m^2], and is affected by ambient temperature T. Because of nonlinear I-V characteristic PV module cannot be considered neither as voltage nor current source.

Solar module manufacturers specify PV module parameters in Standard Test Conditions (STC) which are T = 25ºC and S = 1000 [W/m^2] at perpendicular direction of solar radiation. Table 1 collates main KYOCERA KD320GH-4YB module parameters [1].

Table 1. Specification of KYOCERA KD320GH-4YB module (STC)

No	Parameter	Designation [unit]	Value
1.	Peak power	P_{max} [kWp]	320
2.	Open circuit voltage	V_{oc} [V]	49.5
3.	Short circuit current	I_{sc} [A]	8.60
4.	Maximum power point voltage	V_{pm} [V]	40.1
5.	Maximum power point current	I_{pm} [A]	7.99
6.	Open circuit voltage temperature coef.	μ_V [V/ ºC]	-0.178
7.	Short circuit current temperature coef.	μ_A [V/ ºC]	$5.16{\bullet}10^{-3}$
8.	Number of PV cells in series x parallel	*Ns x Np*	20 x 4

3.2 MatLab Simulation of PV array performance

Single PV cell that a PV module is composed of can be presented as diode model depicted on Fig. 2 [2]. For the sake of I-V and P-V characteristics generation serial and parallel cell resistances R_s and R_p (Fig. 2) were calculated 22.4mΩ and 95Ω respectively.

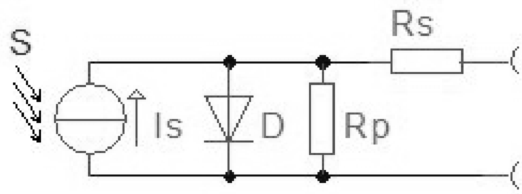

Fig. 2. Single PV cell model

For PV array composed of 10 parallel modules the operation equation for I-V characteristic can be formulated as:

$$I_{PV} = 10I_S - 10\{I_{sat}[e^{\frac{q}{AKT}(V_{PV}+R_{SS}I_{PV})} - 1] + \frac{V_{PV} + R_{SS}I_{PV}}{R_{pp}}\} \qquad (1)$$

where I_S is the current generated under given solar radiation, I_{sat} is diode saturation current, q is electron charge, K is Boltzman's constant, A is diode quality factor (usually between 1 and 2, assumed 1 in the simulation) and T is ambient temperature. R_{pp} and R_{ss} are total parallel and series resistances seen at PV array output which were derived from R_p and R_s according to parameter 8 from Table 1.

Fig. 3 and Fig. 4 show simulation results and reveal variance of PV module work parameters vs. environmental condition changes i.e. solar radiation S within the range of 1000W/m^2 down to 400 W/m^2 and ambient temperatures T of 5ºC, 25ºC and 55ºC. For given ranges of S and T maximum power point (MPP) of P-V curves (Fig. 4) varies across the array voltage V_{PV} from 33 V up to 53 V. To maximize yield of energy from the PV array appropriate MPPT algorithm should be implemented in converter driver.

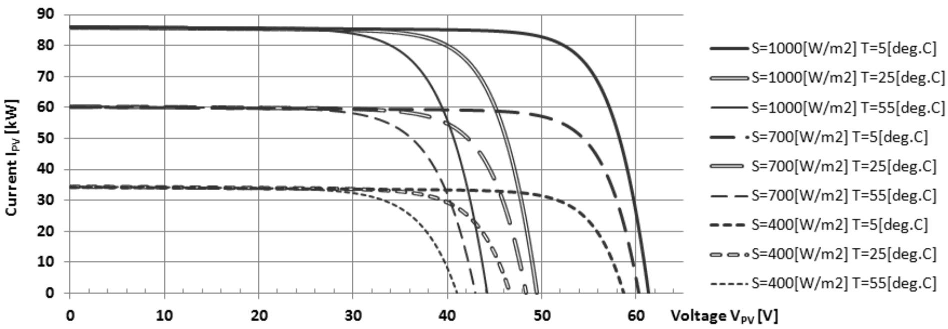

Fig. 3. The PV array I-V plot in different environmental conditions S and T

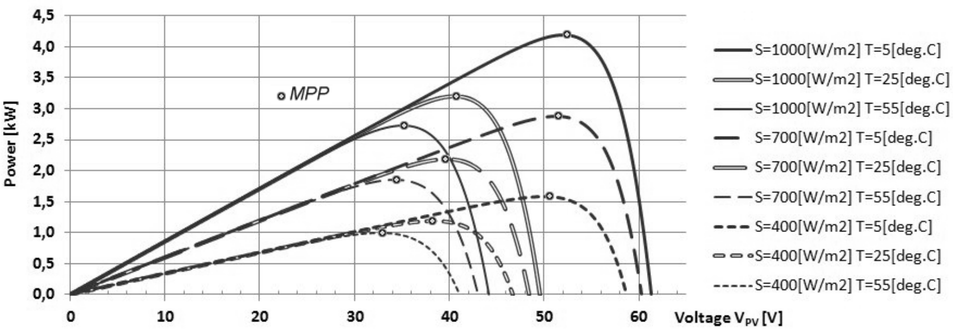

Fig. 4. The PV array P-V plot in different environmental conditions S and T

4. STEP-UP INTERLEAVED DC-DC CONVERTER

A number of high efficiency step-up DC-DC converter topologies [3] can be utilized to boost PV array voltage V_{PV} up to the level of V_{bus} (Fig. 1) above 350 V. Therefore only the topologies with the capacity to gain the voltage 9 times and above should be considered in to work with PV modules connected in parallel.

The common thing among different step-up DC-DC converter topologies is that the voltage gain depends on driving signal duty cycle D. Converter input current which is effectively PV array output current I_{PV} rises with duty cycle increasing. In that manner by adjusting duty cycle D a step-up DC-DC converter is able to extract the energy from the PV array following the MPP changes which vary dynamically with environmental parameter changes.

5. STEP-UP DC-DC CONVERTER DRIVER

The driver consists of microcontroller based logic circuitry and optocouple separated power stage which consists of number of channels each driving individual transistor designed to drive commonly used step-up DC-DC converter topologies in hard-switched mode. Microcontroller STM32F107 is equipped in such peripherals as ADC, UART port, timers and i/o lines which were accommodated to build the driver upon. It is capable to generate PWM pulses which is control signal of MPPT. Table 2 collates key parameters of the driver and Fig. 5 shows examples of available driving strategies.

Table 2. Key parameters of step-up DC-DC converter driver

No	Parameter	Designation [unit]	Value
1.	Signal frequency	F[kHz]	15 to 55
2.	Duty cycle /step	D[%]	8 to 92 /1
3.	Max. number of phases (interleaved)	N_i	8
4.	Max. number of phases (bridge)	N_b	2

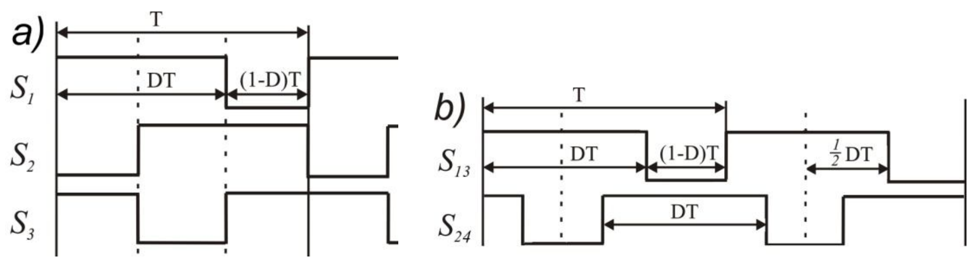

Fig. 5. Driving signals of 3-phase interleaved a), and bridge b) step-up DC-DC converter topologies. In both cases duty cycles of driving signal D are 66% of driving signal period T

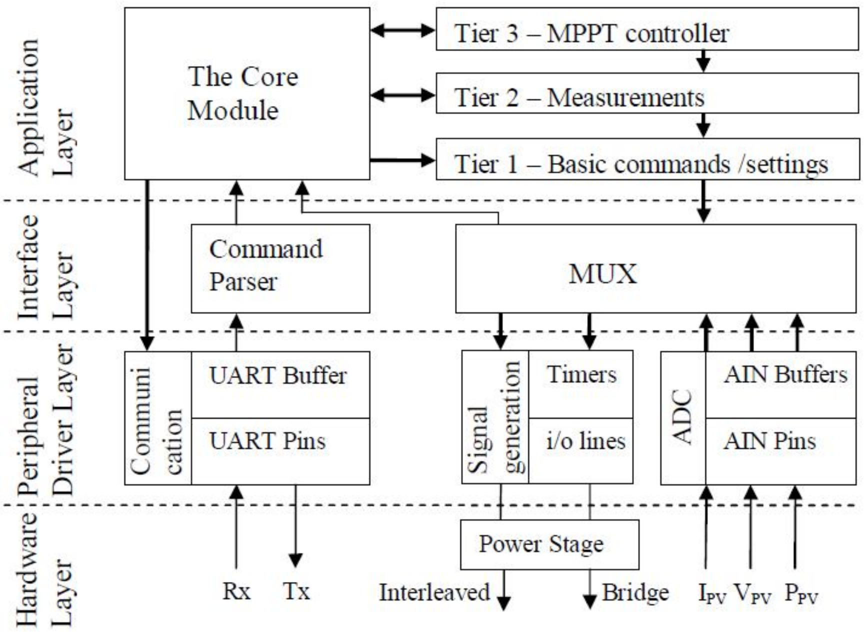

Fig. 6. Step-up DC-DC Converter Driver Software Layers

The software developped in object oriented C is divided into 3 functional layers. The peripheral driver layer is responsible for peripheral initialization and data or signal handling. Interface layer consists of task multiplexer (MUX) and command parser which recognizes ASCII protocol commands. Application layer secures software integrity and handles error events as well as releases the commands to "lower" layers (tier 1). Basic measurements such as several periodical sequences of voltage and current readouts as well as associated statistics are available (tier 2). Different MPPT algorithms which utilize pre-configured measurements from tier 2 can be implemented at the application layer into such software structure.

5. MPPT ALGORITHM

Many MPPT algorithms have been described so far [4]. P&O algorithm is the easiest one to implement and is most commonly used. The major disadvantage of that approach is that perturbation of duty cycle causes PV array to work round MPP not reaching maximum power. Proposed algorithm implemented in the driver utilizes full P-V curve estimation. Individual measurement (t = 0.33 s) consists of three power calculations at three different duty cycles: D_k, $D_k+\Delta D$ and

$D_k–\Delta D$ (Fig. 7). Algorithm utilizes P-V curve slope calculation and automatic ΔD correction to maintain fast tracking speed.

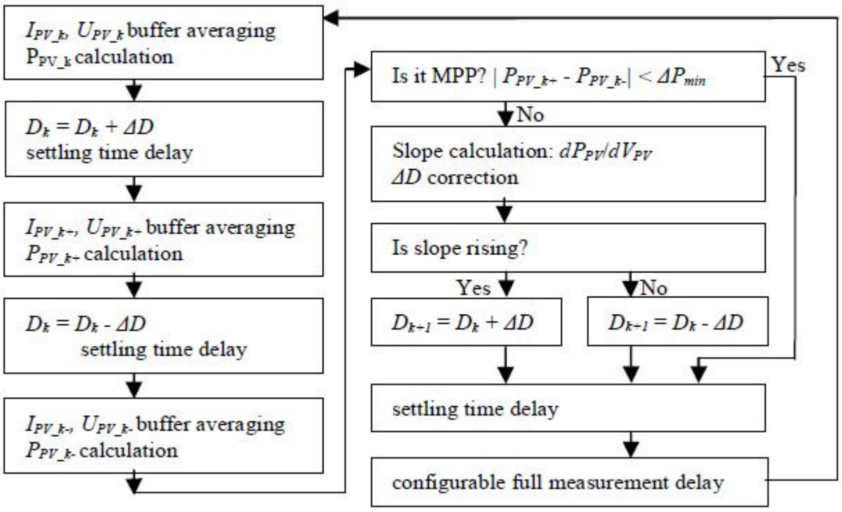

Fig. 7. MPPT algorithm diagram

Fig. 8 shows I_{PV}, V_{PV} measurements results, duty cycle values and calculated instantaneous PV array power P_{PV}. The driver worked with 5-phase interleaved step-up DC-DC converter. Developed MPPT algorithm tracks MPP following changes of working conditions of the PV array. It maximizes PV array output power delivered to the system.

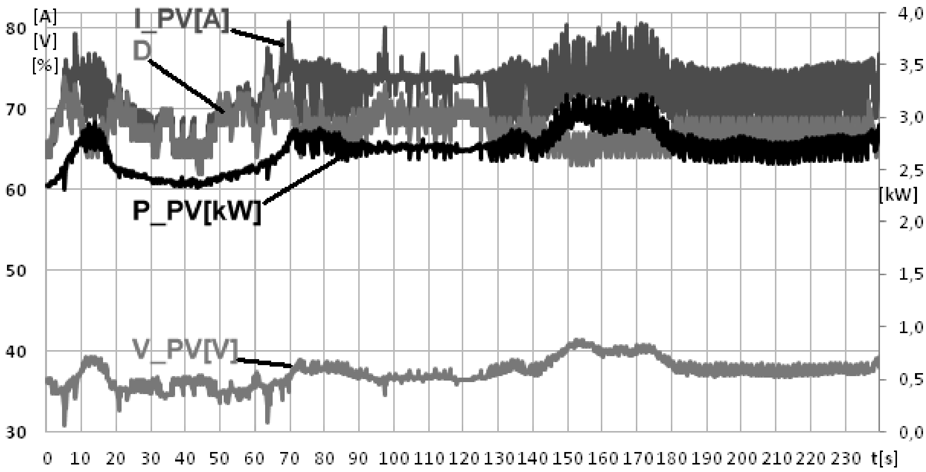

Fig. 8. MPPT algorithm performance plot, P_{PV} at the range of around 2.3 kW to 3.2 kW

6. CONCLUSION

The I-V and P-V characteristics have been discussed to bring the understanding of performance of 3.2kWp PV array and to draw the inputs to design MPPT system. The microcontroller used to build the driver has all the peripherals needed to acommodate analog signal measurement as well as PWM signal generation. The driver as well as step-up DC-DC converter were optimally designed and laboratory tested. Proposed MPPT algorithm achieved fast tracking speed maximizing PV array output power. Laboratory tests proved that whole PV system containing PV array, interleaved step-up DC-DC converter and the driver maintained high power efficiency.

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