Photovoltaic Maximum Power Point Tracking based on an Adjustable Matched Virtual Load

M. Sokolov, D. Shmilovitz
School of Electrical Engineering, Tel-Aviv University,
Tel-Aviv 69978, Israel
e-mail: shmilo@eng.tau.ac.il

Abstract—This work is concerned with maximum power point tracking in photovoltaic systems. Under the suggested method, tracking of the maximum power point is accomplished partially by a linear control loop that emulates a nearly matched load line and partially by the fine tuning of this load line employing an iterative process similar to conventional MPPT methods. This way, excellent tracking is achieved both in steady state and in transient situations.

Index terms—Photovoltaic power systems, MPPT, dc-dc power converters, controlled transformer, emulated load, matched load, maximum power point tracking, photovoltaic, PV, solar energy, solar power generation.

I. INTRODUCTION

Tracking the maximum power point (MPP) of photovoltaic (PV) systems is an important part of most of the PV systems. Indeed numerous articles were published in this area [1]. In particular, it seems that this problem attracts much interest in recent years, especially with respect to the challenge of MPP tracking in special situations such as multiple maxima caused by partial shading and rapidly changing insolation conditions (such as in electric vehicles with PV installations).

This article presents a new approach to maximum power point tracking (MPPT) implementation, based on adjustable matched virtual load (AMVL). With this technique, the dc-dc power converter is controlled so as to reflect a virtual load towards the PV array. The virtual load is optimized to intersect with the PV generator's output characteristics in the vicinity of the MPPs even under varying irradiation conditions. The virtual load has a control parameter that is adjusted by the MPPT so that the PV array operates at the MPP. Despite significant change in irradiation conditions, the operating point will remain quite close to the MPP, and the MPPT will need to perform only a few steps till attaining convergence to the MPP. Furthermore, this approach allows for a small incremental adjustment value without sacrificing dynamic performance as with other MPPT techniques [1],[2].

II. PROBLEM STATEMENT

A. Tradeoff in choosing the incremental value

Two of the commonly employed algorithms for MPP search are the ‘Perturb and Observe’ (P&O) and the ‘Incremental Conductance’ (IncCond), [1]. Both algorithms rely on measurement of the PV array’s voltage and current and iteratively adjust a control parameter, typically by a constant incremental value. The dc-dc converter’s controller implements the decision of the MPPT for the successive iteration. The control parameter can be the PV array’s voltage or current or the dc-dc converter’s duty cycle. This implies a tradeoff in choosing the incremental value by which the controlled parameter is adjusted; small values decrease the losses in steady state due to small perturbations around the MPP, while large values improve the dynamic behavior in situations involving quickly changing irradiation conditions or load, [3]. Therefore, a few attempts were made recently to implement MPPT algorithms with varying step size, [4] (where, in a way fuzzy logic control based MPPT also belong to the varying step size algorithms category, [5],[6]). Nevertheless, these methods, [4]-[6], impose additional algorithm complexity and hardware and also imply an additional major computational load.

The AMVL suggested herein, combines the simplicity of constant step size algorithms and the improved performance of varying step size ones. This is achieved by the converter input emulating a linear load line in the vicinity of the MPP loci, along which the converter is forced to operate.

B. Hill climbing (and related methods) exhibiting load dependent tracking performance

In the case in which the control parameter is the dc-dc converter’s duty cycle such as in hill climbing method, the dynamic tracking performance depends on the load nature. While the duty cycle is kept constant the load is reflected toward the PV array through the converters transfer ratio as if it was a dc transformer. Therefore after an insolation variation, the next operation point will be at the intersection of the reflected load and the new PV array characteristic (associated with the varied insolation level). If the new operation point happens to be close to the new MPP the tracking process will take fewer steps and will therefore be faster. Moreover, even at constant irradiance, a change in the load’s characteristic will require a new MPP search. Some loads yield a reflected load line that might match the MPP loci closer than others, as shown on Fig. 1 (a), where an ideal battery emulator was connected as a load via a boost type dc-dc converter. The slight deviation from a constant voltage line represents a small resistance in series with the ideal battery. This series resistance accounts to wiring resistance and to the converter’s losses.
This, intentionally synthesized load line, is nearly never realized in practical situations, due to the fact that the load is either unknown and in most cases exhibits variable characteristics. Other loads might be even more difficult to match such as a pure resistor load line, as in Fig. 1 (b).

### III. THE PROPOSED METHOD

Fig. 2 presents the I-V curves of a PV panel at different insolation levels, where the MPP loci are marked as well. A linear virtual load line is also sketched which corresponds to

\[ V - r \cdot I - V_{\text{ref}} = 0. \]  

(1)

MPPT converter operation along this line (at the MPPT converter’s input) is achieved by the simple control loop depicted in Fig. 3, where (1) is accomplished by a current sensor with appropriate gain \( r \). Since the MPP loci is not on a straight line, the value of \( V_{\text{ref}} \) is also tuned (by the MPPT controller, most likely in software), so that the virtual load line moves to different locations, while maintaining its inclination (that is set by the gain \( r \)).

In this way, the PV generator is operated at the actual MPP at any given insolation. Tuning of \( V_{\text{ref}} \) is accomplished iteratively, by either P&O or IncCond algorithm. Operation along the virtual load line described by (1) is imposed by a fast control loop whereas adjustment of \( V_{\text{ref}} \) may be regarded as a steady state fine tuning, bringing the operation point from about the MPP to exactly the MPP. Thus, fast tracking (due to rapid variations of insolation level) is achieved mainly by the virtual load emulation. Further more, since around the MPP the power \( P(V) \) is quite insensitive to variations of the operation voltage, very little power is lost during the tuning of \( V_{\text{ref}} \). This process may be explained by Fig. 4 (a). Suppose the PV array was operating at MPP ‘1’ at insolation of 0.3 Sun. Then, right after insolation changed rapidly to 0.6 Sun the PV operates at point ‘2’, close to the new MPP. After a while the operation points moves to the actual new MPP ‘3’ via an iterative process. During the rapid change from ‘1’ to ‘2’ the size of the step in voltage and duty cycle changes, however it is not being explicitly computed. It is automatically generated by the control loop that implements (1). This process may be illustrated by comparing three cases, described in Fig. 4, where the case of simple duty ratio control immediately after a step in insolation is depicted in Fig. 4 (b) and the case of control through PV panel voltage (P&O), after a similar step in
insolation is depicted in Fig. 4 (c). In all cases, operation at
MPP prior to the insolation step is assumed, marked by ‘1’.
Operation point ‘2’ represents the operation point right after
the insolation step, before the response and convergence of the
MPP tracking takes place, and operation point ‘3’ is the final
operation point reached due to the convergence of the MPPT.

IV. SIMULATION RESULTS

Comparison in terms of dynamic response is performed by
means of simulation, see Fig. 5. A boost converter loaded by a
resistor is assumed. In the first case hill climbing algorithm is
applied (Fig. 5 (a)). The convergence due to P&O algorithm is
shown in Fig. 5 (b), and the convergence due to the newly
proposed AMVL method is shown in Fig. 5 (c). In order to
have an impartial comparison, converters with the same
dynamics were assumed in all cases. In addition, equivalent
step sizes were chosen, that produce the same ripple around the
MPP in steady state. The insolation intensity was stepped from
0.3 Sun to 0.6 Sun (at the step number marked zero). The
improvement in dynamic response due to application of the
AMVL is notable (it took the AMVL based system about 5
steps to converge to the new MPP, 10 times faster then the hill
climbing based system). It should be noted that this
comparison was made at the most difficult conditions for the
AMVL since the MPP at 0.6 Sun is the far most one from the
AMVL line, see Fig. 2.

Comparison in terms of steady state power ripple, is
performed by means of simulation, see Fig. 6. A boost
converter loaded by a resistor is assumed. In the first case hill
climbing algorithm is applied (Fig. 6(a)). The second case, Fig.
6 (b) shows convergence employing P&O algorithm, and the
third case (Fig. 6 (c)) applies to the newly proposed AMVL
method. Converters with the same dynamics were assumed in
all cases for this comparison as well. In addition, step sizes
were chosen, that yield the same convergence time after an
insolation step. The insolation intensity was stepped from 0.3
Sun to 0.6 Sun at zero-marked step. The improvement in
steady state power ripple due to application of the AMVL is
notable.

V. CONCLUSIONS

A new MPPT method was suggested, in which the MPP
tracking is accomplished mostly by a linear control loop and
partially by the fine tuning of this virtual load line employing
an iterative process. This way, fast response to transient
perturbations and small ripple about the steady state operation
point are achieved, without sacrificing one for the other, as
would be the case with most of the other MPPT methods.

Simulation results are provided in support of the theoretical
analysis.
Figure 5. Dynamic convergence after a 100% step change (0.3 Sun $\rightarrow$ 0.6 Sun) in insolation. Same steady state ripple. Top to bottom: insolation, PV panel voltage, PV panel output power. (a) Hill climbing based controller, (b) P&O based controller, (c) AMVL based controller.

Figure 6. Dynamic convergence after a 100% step change (0.3 Sun $\rightarrow$ 0.6 Sun) in insolation. Same number of steps till convergence. Top to bottom: insolation, PV panel voltage, PV panel output power. (a) Hill climbing based controller, (b) P&O based controller, (c) AMVL based controller.
REFERENCES


