

# IMPLEMENTATION OF MAXIMUM POWER POINT TRACKING ALGORITHM FOR RESIDENTIAL PHOTOVOLTAIC SYSTEMS

A. Yafaoui., B. Wu and R. Cheung  
Department of Electrical & Computer Engineering, Ryerson University  
Toronto, Ontario, Canada

**Type of Paper: Refereed**

## ABSTRACT

This paper presents the practical implementation of the real-time Estimate-Perturb-Perturb (EPP) algorithm for maximum power point tracking (MPPT) control in a photovoltaic (PV) system. The PV system usually consists of: a PV array that converts solar energy to electrical energy, a DC/DC converter that converts low dc voltages produced by the PV array to a high dc voltage, an inverter that converts the high dc voltage to a single or three-phase ac voltage and a digital controller that controls the system and implement the MPPT algorithm by controlling the current and voltage of the PV array. The MPPT algorithm is vital in increasing the efficiency of the system. A 1KW prototyping PV system was implemented with a boost dc-dc converter using a DSP controller to execute the proposed MPPT algorithm. Different hill-climbing MPPT algorithms were tested for fast changing environmental conditions, and the test results are analyzed and compared. It is demonstrated that the EPP method is a promising MPPT control scheme for residential PV systems.

## INTRODUCTION

Renewable energy sources such as solar energy are acquiring more significance, due to shortage and environmental impacts of conventional fuels. The photovoltaic (PV) system for converting solar energy into electricity is in general costly and is a vital way of electricity generation only if it can produce the maximum possible output for all weather conditions. The PV array has a highly non-linear current-voltage characteristic varying with the irradiance and temperature that substantially affects the array power output. The maximum power point tracking (MPPT) control of the PV system is therefore critical for the success of a PV system. MPPT algorithms, ranging from simple hill-climbing algorithms to fuzzy logic and neural network algorithms, have been considered extensively in the literature.

The hill climbing algorithm is widely used in practical PV systems because of its simplicity and because it does not require prior study or modeling of the source characteristics and can account for characteristics' drift resulting from ageing, shadowing, or other operating irregularities [1], [2]. The basic hill climbing algorithm is the P&O algorithm. Although the P&O algorithm works well when the irradiance changes slowly, it exhibits erratic behavior for rapidly changing irradiance level that causes incorrect or slow power tracking. This led to the development of the Modified Perturb and Observe (MP&O) algorithm [3]. The MP&O algorithm improves the P&O algorithm at the expense of speed of response to changes of irradiance. A new method, named the Estimate-Perturb-Perturb (EPP) algorithm was previously published by the authors, which was shown to have good performance [4]. The EPP algorithm uses one estimate for every two perturbs that results in a fast response to irradiance changes, leading to significantly higher PV system power output. This paper describes the three algorithms that were implemented and tested under different weather and irradiance conditions. The performance of the proposed EPP algorithm for the MPPT control versus typical MPPT algorithms for different conditions is discussed and compared.

## MPPT ALGORITHMS

The three main versions of the hill climbing algorithm, P&O, MP&O and EPP, are described below.

### **Perturb and Observe**

The P&O method is the most popular MPPT algorithm due to its simplicity. Figure 1 shows the flow chart of P&O method. After one perturb operation the current power is calculated and compared with previous value to determine the change of power  $\Delta P$ . If  $\Delta P > 0$ , then the operation continues in the same direction of perturbation. Otherwise the operation reverses the perturbation direction.

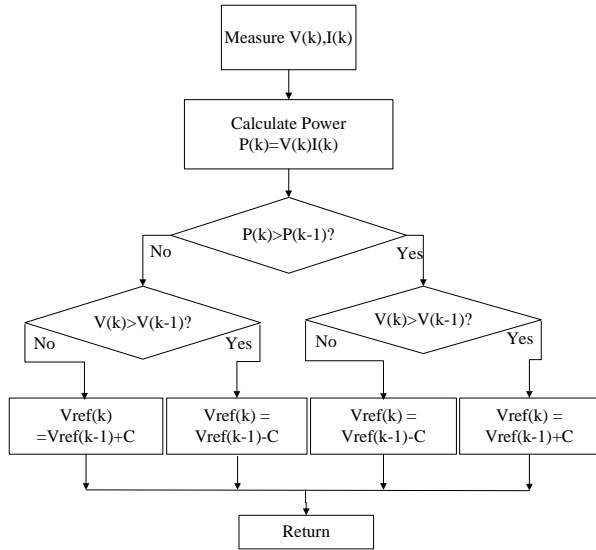


Figure 1 Flow chart of P&O algorithm.

**Modified Perturb and Observe**

The P&O method implements a hill climbing technique, which works well in slow changing environment but has some limitations under rapidly changing atmospheric conditions [1]-[8]. The methods may lead to incorrect or slow maximum power point tracking.

To overcome such problems the MP&O method shown in Figure 2, isolates the fluctuations caused by the perturbation process from those caused by the irradiance or weather change.

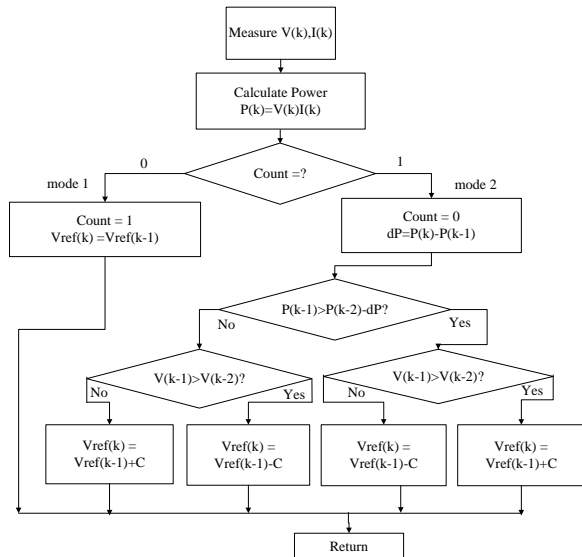


Figure 2 Flow chart of MP&O algorithm.

This method adds an irradiance-changing estimate process in every perturb process to measure the amount of power change caused by the change of atmospheric condition.

Because the estimate process stops tracking maximum power point by keeping the PV voltage constant, the tracking speed of MP&O method is only half of the conventional P&O method.

**Estimate, Perturb and Perturb**

The EPP algorithm was introduced in previous work by the authors in order to improve the speed of the MP&O algorithm while keeping its main features. When compared with the MP&O algorithm, the EPP algorithm that uses one estimate mode for every two perturb modes increases significantly the tracking speed of the MPPT control, without reduction of the tracking accuracy.

Comparing with the MP&O algorithm, the EPP algorithm has a tracking speed of 1.5 times faster but has the same delay time between the estimate process and the perturb process. Therefore the EPP algorithm has obvious advantages over the MP&O algorithm.

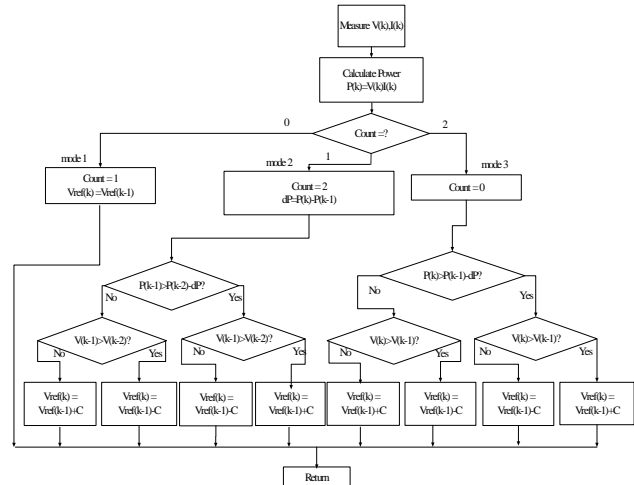


Figure 3 Flow chart of EPP algorithm.

**IMPLEMENTATION**

To test the performance of these MPPT algorithms, the setup shown in Figure 4 was implemented. The setup consists of 1) a DC/DC converter, 2) a solar array simulator, 3) a DSP control board, and 4) digital real time oscilloscope and a PC.

**DC/DC Converter**

The DC/DC converter is a 1KW boost converter working at a switching frequency of 100 KHz. The parameters of the converter are given in Table 1.

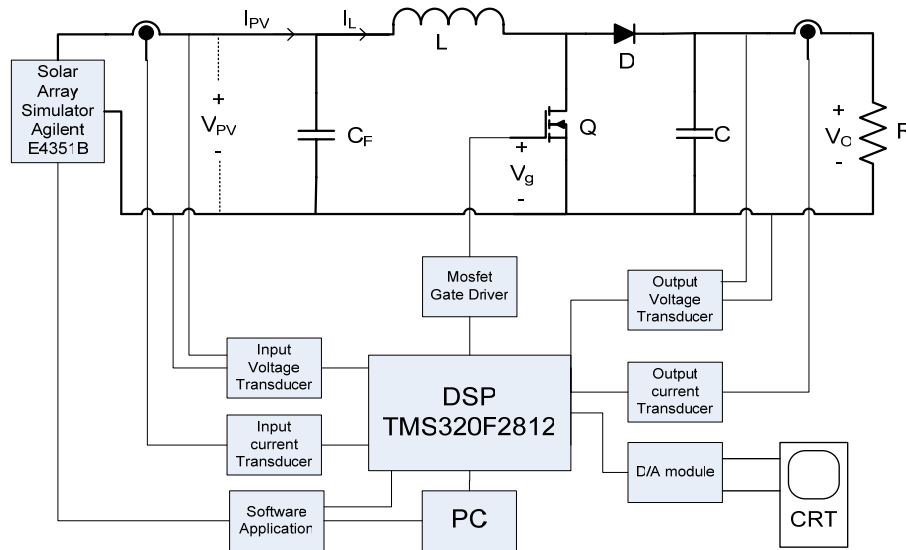


Figure 4 Block diagram of the proposed PV system with MPPT control.

Table 1  
 DC/DC converter parameters.

PARAMETER	VALUE
Inductance L	265 $\mu$ H
Capacitor C	1.36mF
Mosfet switch	36A 500V
Diode	60A 600V
Switching freq.	100 KHz
MPPT Update rate	25msec

### Solar Array Simulator

The varying irradiance conditions were simulated using the solar array simulator E4351B (Agilent). The current and voltage characteristics, of five BPSX60 multi-crystalline photovoltaic modules connected in series, were fed to the simulator. And a Visual Basic software application was implemented, to facilitate the change of the output power as a sine function of the irradiance and temperature. The simulator was connected to the PC using USB/GPIB interface. The power settings generated by the software application was also fed to the DSP module through UART port.

### DSP control Board

The MPPT algorithm and the control of the DC/DC converter were implemented of TI TMS320F2812 DSP. The DSP measured the input current and input voltage through the A/D module and calculated the power obtained from the SAS. The duty cycle is used as the control variable in order to simplify the control structure of the system [6]. The calculated power together with the power values fed from the software application was provided to the D/A module to be able

to compare and analyze the MPPT algorithms. The D/A module was implemented as pulse-width-modulated (PWM) signal and a two-stage low-pass filter. The update rate of the MPPT algorithms was set to 25msec. This value was found experimentally by setting it as fast as possible without causing instability to the system, too fast update rate may cause the system to become unstable due to the relatively long time constant of the power stage [3]. The setup used in the experiment is shown in Figure 5.

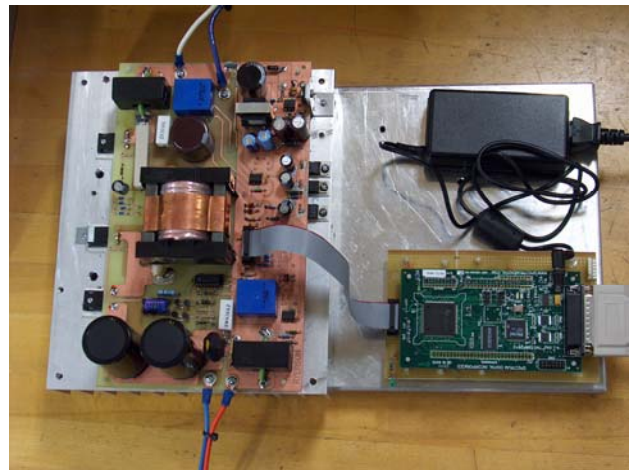


Figure 5 1KW experiment prototype.

## EXPERIMENT RESULTS

The above-described setup was used to test the MPPT algorithms. Figure 6 shows the output voltage waveform of the boost converter, the inductor current and the gate pulses. Figures 7 and 8 show the change PV current-voltage characteristics due to change of

irradiance and temperature. Figures 9, 10 and 11 shows the voltage and current waveforms of the PV array, under constant power condition, with P&O, MP&O, and EPP algorithms, respectively.

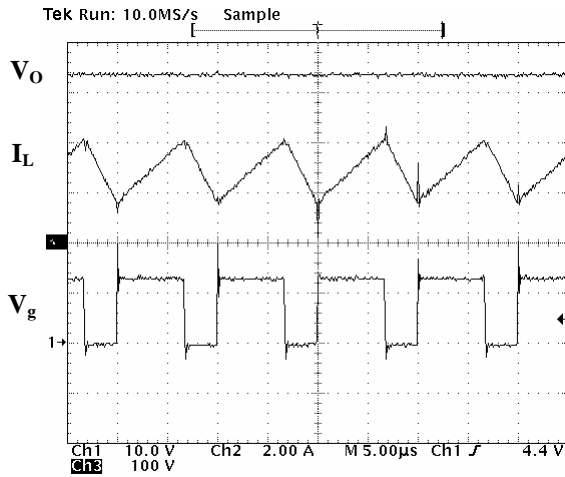


Figure 6 Converter output voltage, inductor current and gate pulse.

The oscillations of the P&O algorithm around the maximum power point can easily be seen from the oscillation of the current waveform in Figure 9. The MP&O and EPP algorithms have much less oscillation and this is obvious from Figures 10 and 11, respectively.

### Irradiance Change

The change of irradiance results in vertical shifting of the IV curve of the PV array as shown in Figure 7. This change can be implemented as the shifting of the maximum operating current and the short-circuited current values. In this experiment the irradiance was changed from 1KW/m<sup>2</sup> to 600W/m<sup>2</sup> following a sine function with period of 5sec.

Figures 12, 13 and 14 show the responses of the P&O, MP&O and EPP algorithms respectively where  $P_{max}$  is the reference maximum power set by the software application,  $P_{pv}$  is the power obtained from the solar array and  $P_{max} - P_{pv}$  is the difference between them.

The erratic behavior of the P&O algorithm under fast changing irradiance is obvious from waveforms of Figure 12. The enhancement that MP&O and EPP algorithms exert on the performance under fast changing irradiance condition is confirmed in Figures 13 and 14.

### Temperature Change

Although the change in temperature of the PV array is a slow process in residential type application, it might

be much faster and wider in other PV array application. For an inclusive evaluation of the algorithms the change in temperature from -25°C to 75°C is considered. The change result in shifting the IV curve horizontally, as in Figure 8 and is implemented as a function of sine with period of 6 sec.

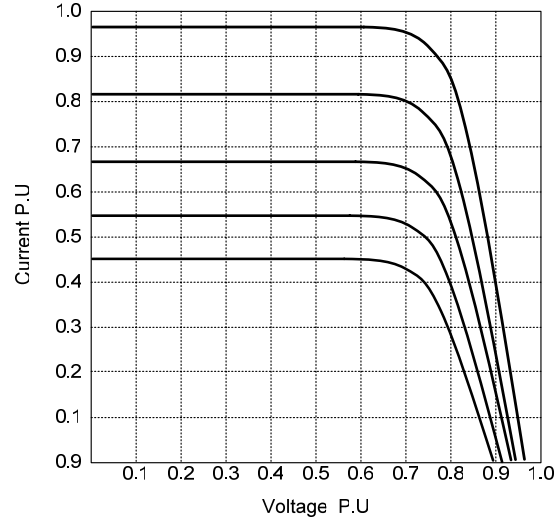


Figure 7 Change in IV characteristics due to change of irradiance.

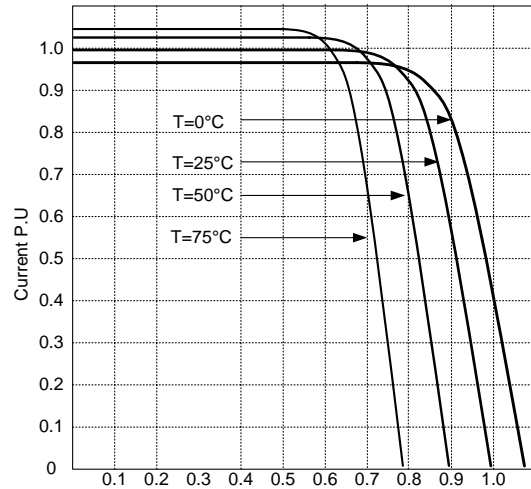


Figure 8 Change in IV characteristics due to change of temperature.

Figures 15, 16 and 17 show the performance of the PV system under P&O, MP&O and EPP algorithms. The erratic performance of the P&O algorithm due to fast change in irradiance is also experienced with the fast change in temperature as shown in Figure 15. On the other hand, Figures 16 and 17 show the performance of the MP&O and EPP algorithms, which is more consistent and stable than the P&O algorithm.

### Step Change

Step change response is one of the most important parameters of MPPT algorithms it is a measure of the speed of the algorithms. Figures 18, 19 and 20 show the response of the P&O, MP&O and EPP algorithms under a step change of irradiance from 700W/m<sup>2</sup> to 1KW/m<sup>2</sup>. As can be seen from the three graphs there is a 100msec delay in the response this is mainly due to the delay in the response of the solar array simulator and the delay in the software Application. As expected the P&O algorithm has the fastest response with 300msec rise-time, and then comes the EPP algorithm with 400ms rise-time and the slowest being the MP&O with 600ms rise-time.

### CONCLUSION

This paper discussed the implementation of a DSP photovoltaic system that is used to evaluate the performance of the MPPT algorithms. The EPP algorithm is tested versus the most popular P&O algorithm and its modified version the MP&O. The algorithms were tested against fast change in irradiance, fast change in temperature and step change in irradiance. The EPP algorithm achieved the same accuracy as the MP&O with a speed comparable to the P&O speed.

### ACKNOWLEDGMENT

We would like to acknowledge the contribution of the NSERC Solar Buildings Research Network.

### REFERENCES

[1] Al-Atrash, H.; Batarseh, I.; and Rustom, K.; "Statistical modeling of DSP-based Hill-climbing MPPT algorithms in noisy environments." IEEE Applied Power Electronics Conference and Exposition (APEC), 2005, pp1773 – 1777.

[2] Hua C., Lin J., and Shen C., Implementation of a DSP-controlled photovoltaic system with peak power tracking, IEEE Transactions on Industrial Electronics, Vol: 45, 1998, pp99-107.

[3] Hohm P. and Ropp M. E., "Comparative Study of Maximum Power Point Tracking Algorithms," Progress in Photovoltaics: Research and Applications, Vol. 11, 2003, pp 47-c62.

[4] Liu C., Wu B., and Cheung R., "Advanced Algorithm for MPPT Control of Photovoltaic Systems," 1<sup>st</sup> Canadian Solar Buildings Research Network Conference, Aug. 2006.

[5] Sera D., Kerekes T., Teodorescu R. and Blaabjerg F., "Improved MPPT algorithms for rapidly changing environmental conditions," 12th International Power Electronics and Motion Control Conference, 2006, pp1614-1616.

[6] Xiao W. and Dunford W.G.: "A modified adaptive hill climbing MPPT method for photovoltaic power systems," IEEE Power Electronics Specialists Conference (PESC), 2004, pp1957–1963.

[7] Liu X., and Lopes L.A.C.: "An improved perturbation and observation maximum power point tracking algorithm for PV arrays" IEEE Power Electronics Specialists Conference (PESC), 2004, pp2005-2010.

[8] Jung Y., So J., Yu G., and Choi J., "Improved perturbation and observation method (IP&O) of MPPT control for photovoltaic power systems." 31<sup>st</sup> IEEE Photovoltaic Specialists Conference, 2005, pp1788–1791.

### EXPERIMENTAL DATA

#### Constant power operation

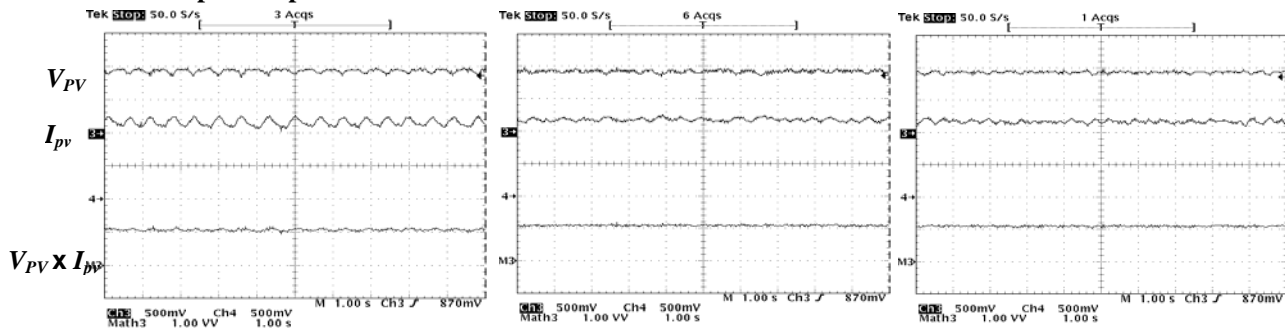


Figure 9 P&O voltage & current

Figure 10 MP&O voltage & current

Figure 11 EPP voltage & current

### Irradiance Change Response

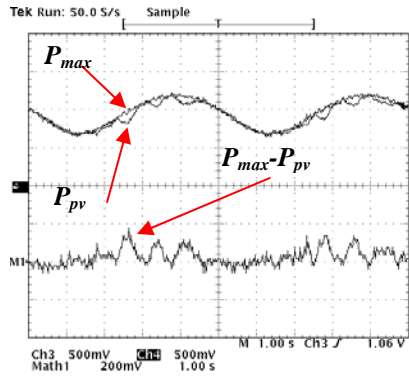


Figure 12 P&O performance

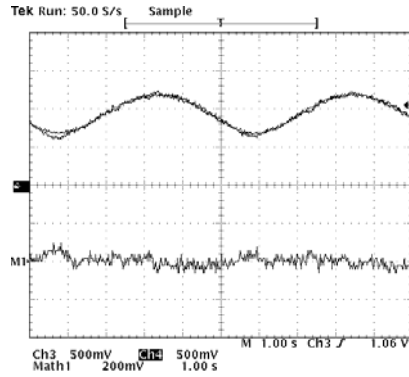


Figure 13 MP&O performance

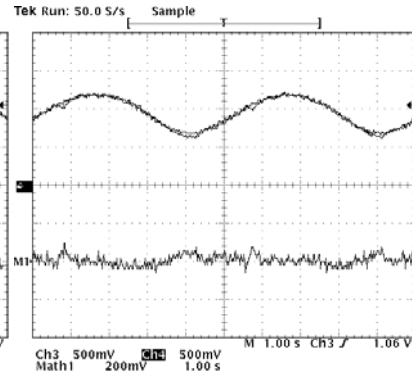


Figure 14 EPP performance

### Temperature Change Response

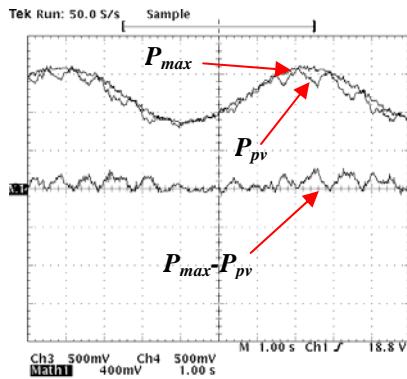


Figure 15 P&O performance

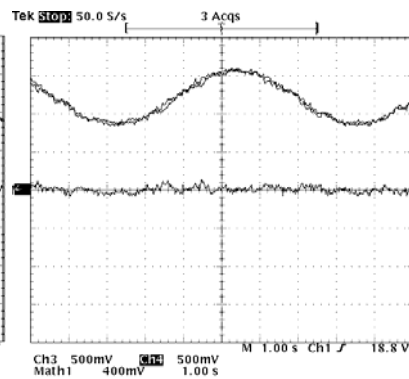


Figure 16 MP&O performance

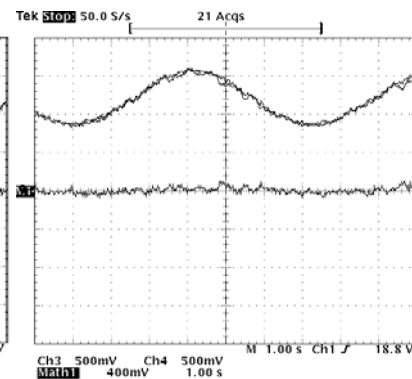


Figure 17 EPP performance

### Step Change Response

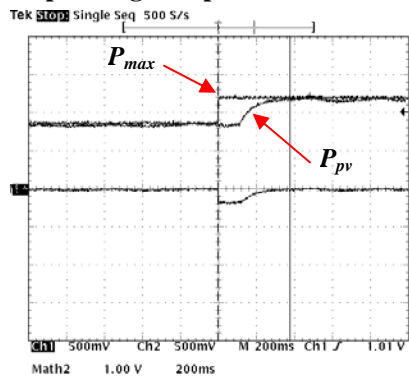


Figure 18 P&O performance

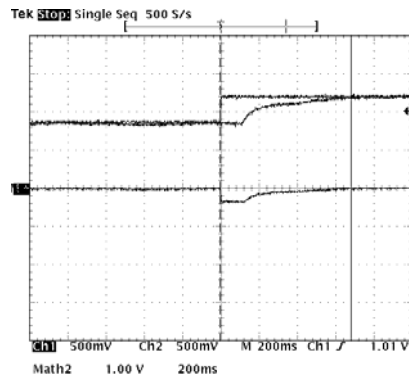


Figure 19 MP&O performance

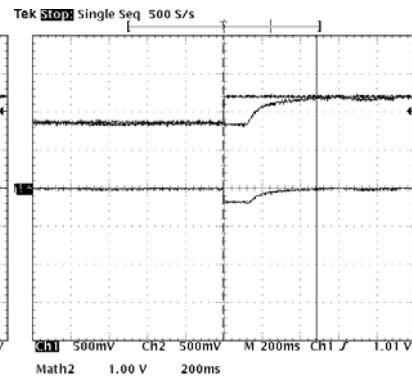


Figure 20 EPP performance