Memorial University of Newfoundland

Dynamic Maximum Power Point Tracking and Robust Voltage Regulation for Photovoltaic Systems

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MEMORIAL UNIVERSITY

In This Study…

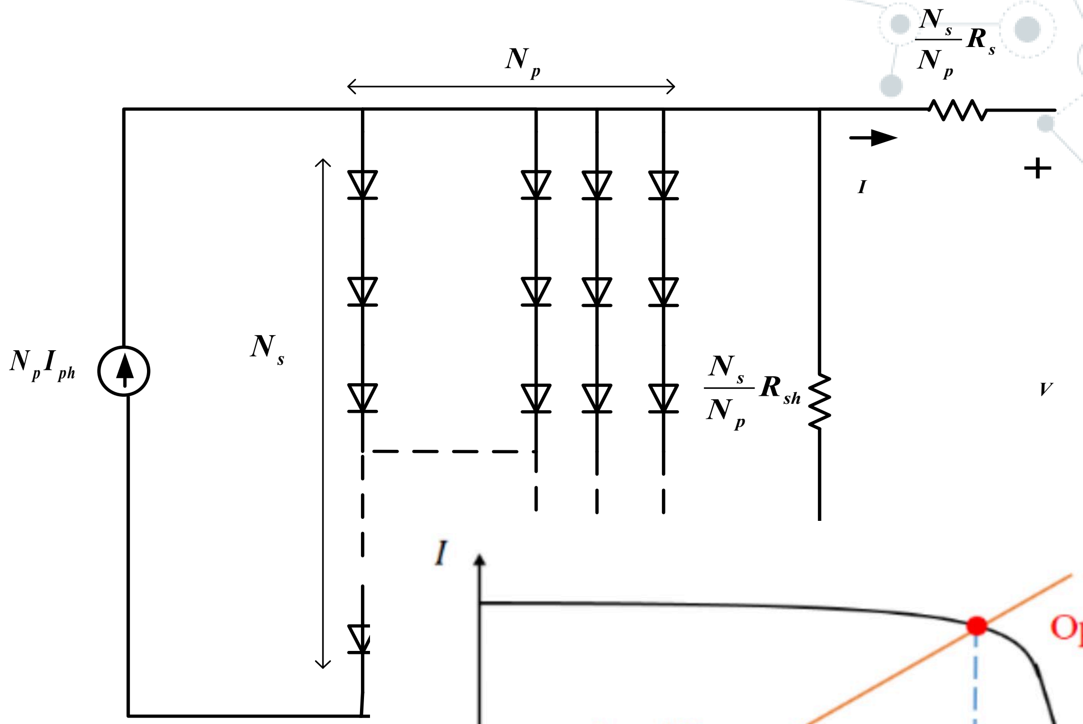
- The conventional MPPT algorithms are benchmarked in this study under varying environmental conditions .
- A modified P&O algorithm is presented, and the results for the conventional algorithms and modified P&O have been compared in different environmental conditions.
- An adaptive controller is designed to regulate the output voltage of the DC–DC converters in a PV system.
- A super-fast sliding mode controller is designed to control the output voltage and inductor current of the DC–DC converters.
- The proposed controller’s effectiveness and robustness are validated when subjected to load variations, input voltage changes, and reference voltage changes.

Introduction:

- Solar plays a significant role as a source of clean power electricity, which addresses environmental problems in meeting future energy demands.
- Photovoltaic (PV) power generation systems are used to convert solar energy to electricity due to:
  - ✓ Availability,
  - ✓ Ease of installation,
  - ✓ Near-zero maintenance.
- Designing an effective control algorithm plays a vital role in developing an efficient solar PV system.

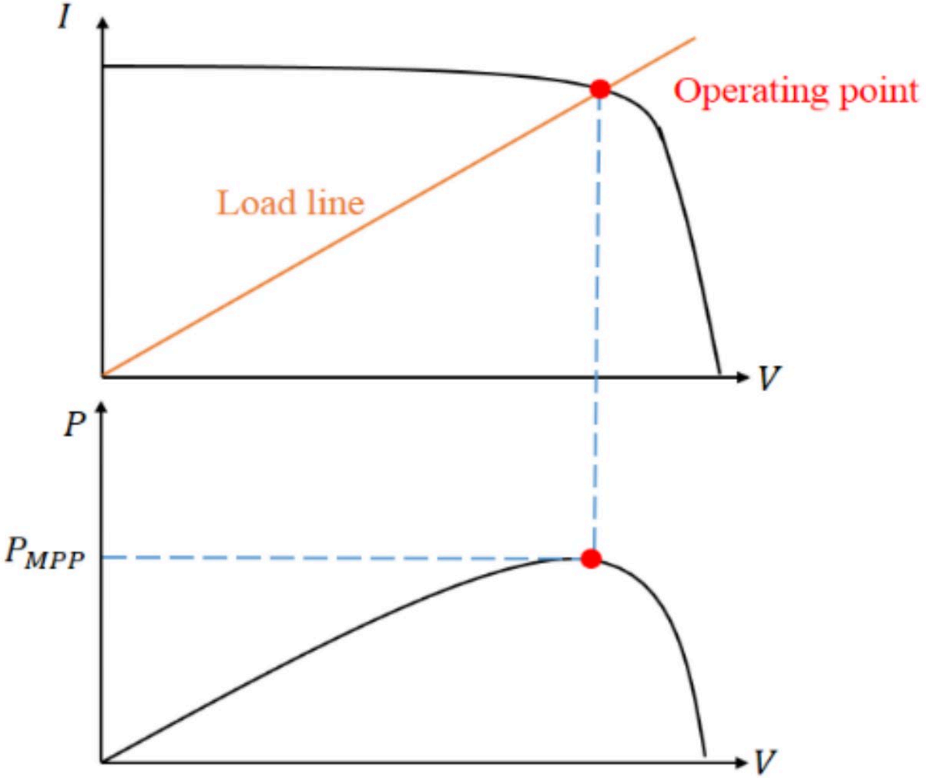
PV Model:

- For the simulations of the behavior of PV systems we need to know the Modeling of PV Modules.
- The series-parallel connectivity is used to keep things simple.
- The comparable circuit is given for a PV system with N_s series and N_p parallel modules.



Maximum Power Point:

- In PV systems, one of the main solutions to increase efficiency is of Maximum Power Point Tracking (MPPT) techniques.
- MPPT ensures that the operating voltage and current remain at the maximum power point (MPP) on the p-v characteristic curve.



Conventional MPPT Algorithms:

- There are many works with a variety of control techniques for PV MPPT systems
  - ✓ Conventional
    - Perturb and observer (P&O)
    - Incremental conductance (InC) algorithm
    - Hill- climbing (HC) algorithm
  - ✓ Soft computing approaches
    - Particle swarm optimization (PSO)
    - Genetic algorithm (GA)
    - Artificial intelligence (AI) based algorithms
    - Fuzzy logic-based controllers (FLBCs)
    - Artificial neural network (ANN)-based MPPT

- Soft computing approaches show less settling time, less overshoot, and better performance about MPPT, but they require data set in the beginning to train the input-output relation.
- The implementation remains an issue with the modern algorithms.

Overview of the conventional P&O algorithm:

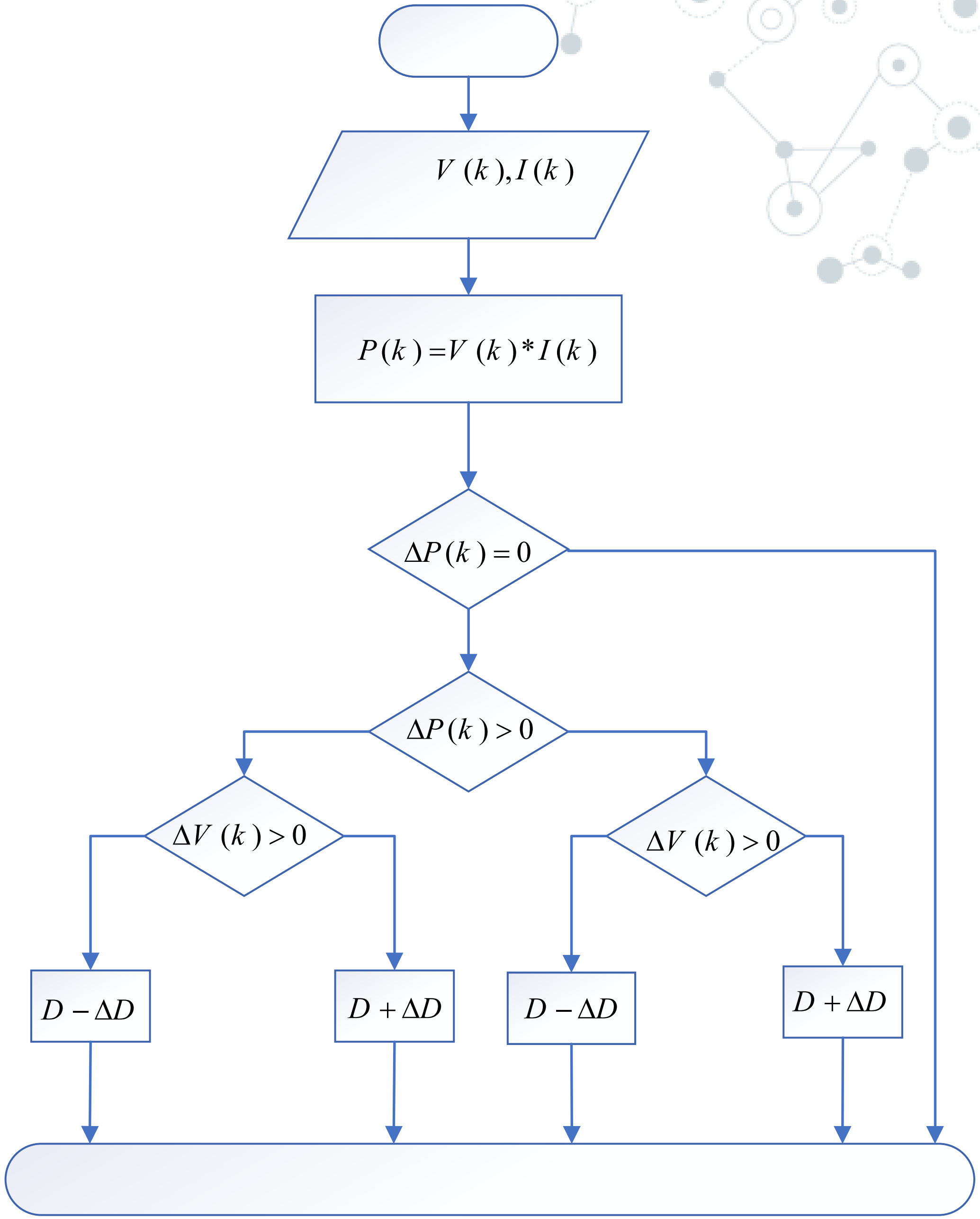
- The P&O algorithm is the most often used conventional MPPT method
  - ✓ It is based on perturbing the PV array output voltage by tuning the duty cycle of a power converter.
  - ✓ Check the changes of the output power of the array.

- The perturbation step-size plays an undeniable role in reaching the MPP
  - ✓ Large step-size may lead to a fast-tracking response, but the amplitude of the steady-state oscillations will be high.
  - ✓ If the step-size has a small value, the tracking is slower, and, small oscillation will be seen.

- This method has indubitable merits such as the high efficiency, being cheap for the implementation.

Overview of the conventional P&O algorithm:

- If ΔP is positive,
  it means we are approaching the maximum of panel power, and the perturbation must be made along the same direction.
- In opposite, if the output power is decreasing, the perturbation must be made in the reverse order.
- $\Delta P = 0$ shows that the MPP is reached.



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Overview of the conventional InC algorithm:

- The InC method relies on the observation that the first derivative of the PV function, $\Delta P/\Delta V$ becomes zero.
- We know PV current's dependence on voltage,

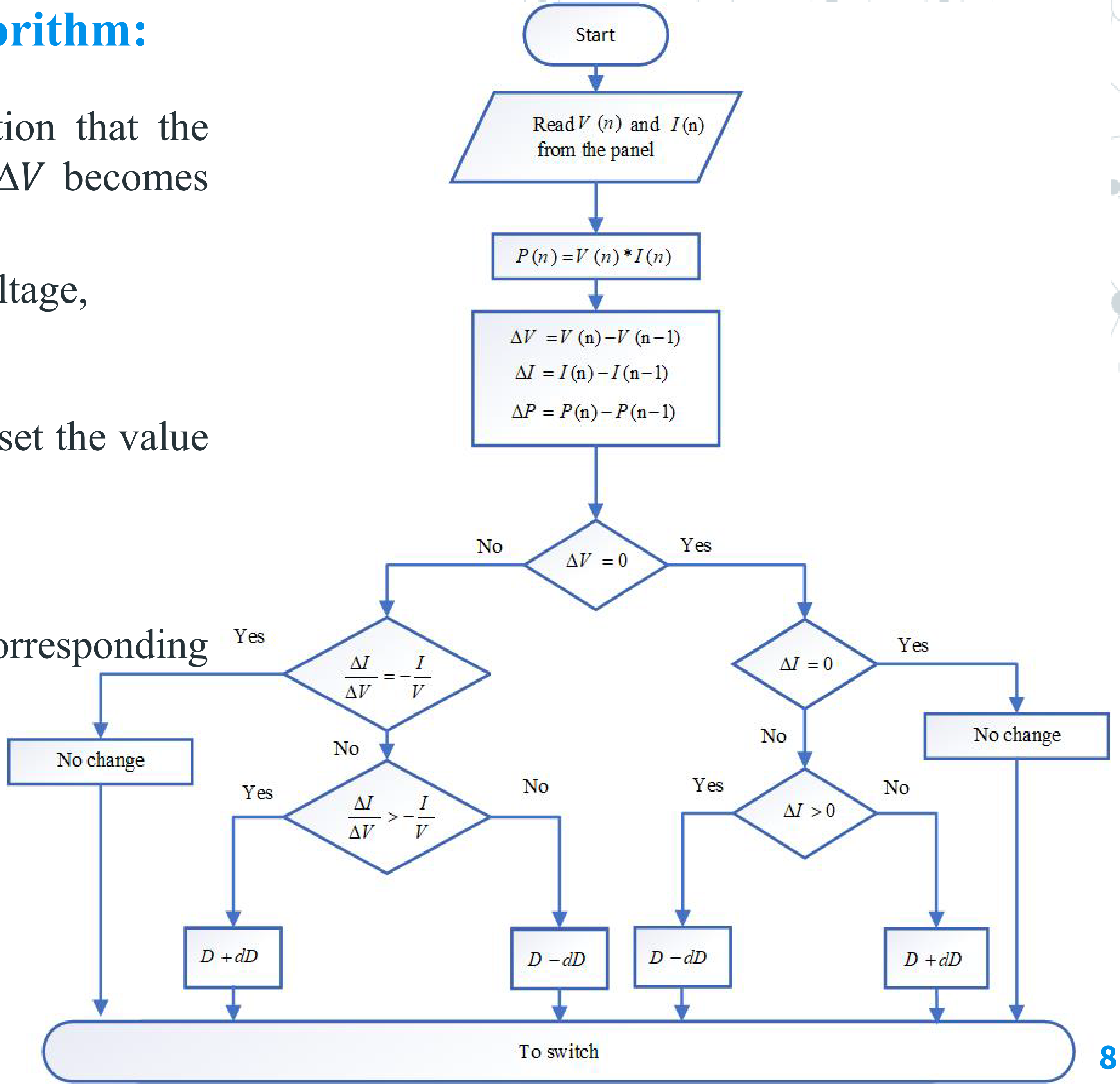
Thus, $$\frac{\Delta P}{\Delta V} = V \times \left(\frac{\Delta I}{\Delta V}\right) + I(V)$$

- We get the following equation when we set the value of the variable equal to zero:

$$\frac{\Delta I}{\Delta V} = -\frac{I(V)}{V}$$

- So, the MPP is defined as the voltage corresponding to the point where:

$$\frac{\Delta I}{\Delta V} = -\frac{I(V)}{V}$$



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Modified P&O Algorithms:

- Conventional algorithms are the most used methods due to:
  - ✓ Their ease of implementation
  - ✓ More suitable for low-cost applications
- Despite their ease of use, traditional methods have demonstrated a sluggish response to changes in ambient conditions.
- So, many MPPT algorithms focus on improving the conventional algorithm's efficiency and response time.

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Modified P&O Algorithms:

Algorithm	Error	Response Time (s)	Application			
			Slow irradiance changes	Fast irradiance changes	Drift	PSC
Conventional P&O	4.1%	0.4	✓	-	-	-
[15] MP&O	1.36%	<0.02	✓	-	-	✓
[16] Drift-free P&O	4.1%	<0.05	✓	✓	✓	-
[17] P&O based on the Pythagorean theorem	3.9%	<0.5	✓	✓	✓	-
[18] Zero voltage switching	3.7%	0.4	✓	✓	-	-
[19] Adaptive P&O	2.05%	<0.001	✓	✓	-	-
[23] PSC P&O	0.3%	<0.01	✓	✓	-	✓
[24] Adjustable step size and inspection algorithm	0.16%	<0.03	✓	✓	-	✓
[25]GA P&O	3.33%	<0.06	✓	✓	-	-
[44] LT P&O	0.25%	<0.05	✓	-	-	-
[45] DPGM	2.05%	<0.6	✓	✓	✓	-
[21] MVSS P&O	2.1%	<0.03	✓	✓	-	✓
[22] adaptive step size P&O	1.33%	<0.13	✓	✓	-	✓

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Modified InC Algorithms:

Algorithm	Error	Response Time (s)	Application			
			Slow irradiance changes	Fast irradiance changes	Drift	PSC
InC	5.85%	0.5	✓	-	-	-
[46] VSS InC	0.16%	<0.013	✓	✓	✓	-
[47] Variable step lengths InC	1.65%	<0.03	✓	✓	✓	-
[48] Modified VSS InC	0.82%	<0.02	✓	✓	✓	-
[49] Direct control VSS InC	1.8%	<0.013	✓	✓	✓	-
[50] Dual-scaled adaptive step-size InC	4.29%	<0.02	✓	✓	-	-
[51] Filter variable modified InC	1.188 %	<0.01	✓	-	-	-
[52] Integral regulator InC	5%	<0.5	✓	✓	-	-
[53] InC-PID	0.4%	0.055	✓	✓	-	-
[54] Fast InC	0.6%	<0.04	✓	✓	-	-
[55] PSC InC	1.18%	<0.4	✓	✓	-	✓
[56] SA and MINC	2.95%	<3	✓	✓	-	✓
[57] Fuzzy logic based InC	4.77%	<0.013	✓	✓	-	-

Proposed MPPT Algorithm:

- The new modified algorithm focuses on the steady-state response of PV array power output.
- In conventional algorithm, only case that the original P&O algorithm stop oscillation is $\Delta P = 0$. For the other cases, fluctuation is inevitable.
- As the $\Delta P = 0$ rarely happens during perturbation, we need to increase the chance of stopping the oscillation.
- For the proposed algorithm, one parameter is added to the MPPT flowchart, which is $\Delta P(k-1)$ to recognize when the algorithm is crossing the MPP of the power curve.

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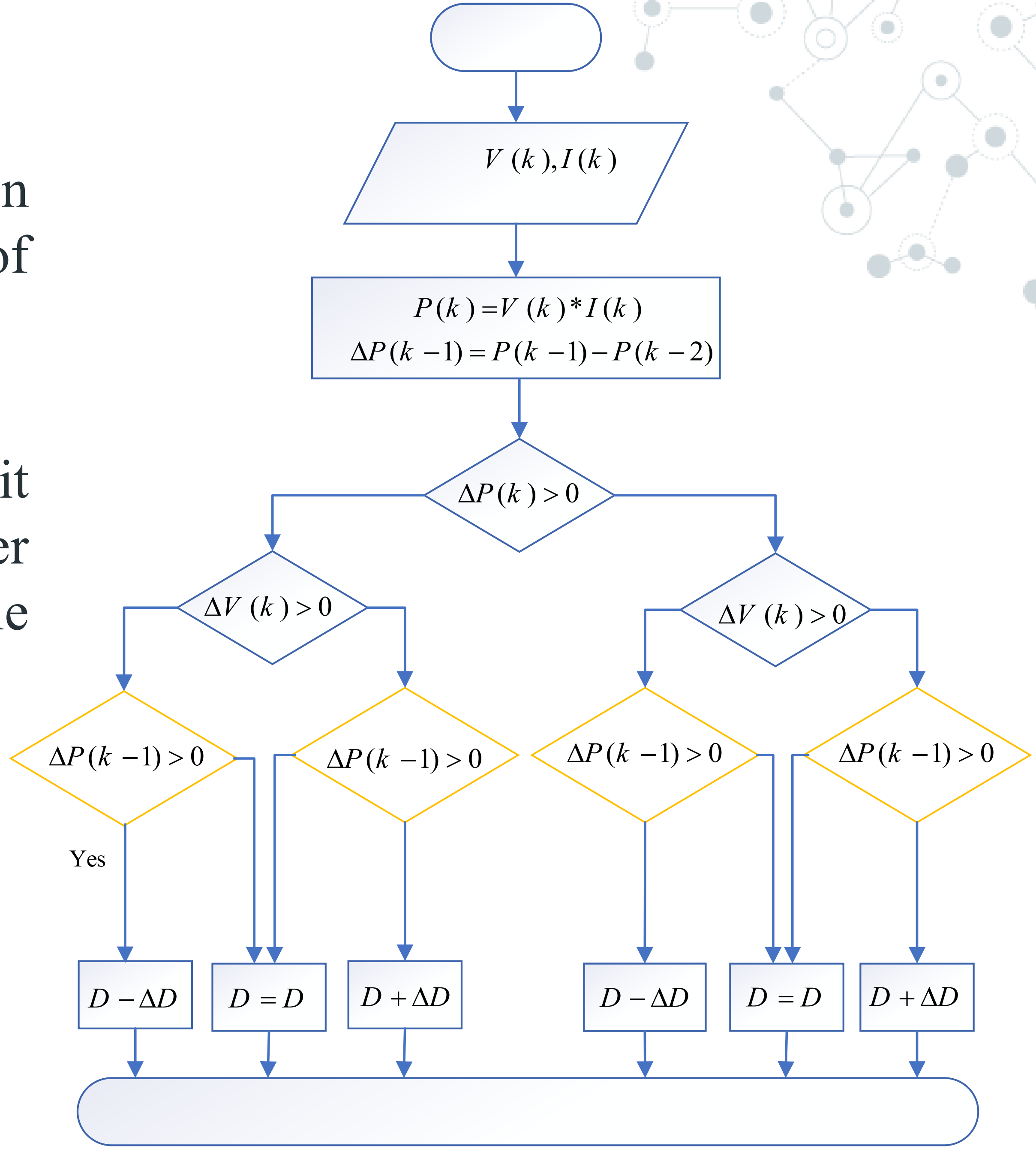
Proposed MPPT Algorithm:

- In this algorithm, the sign of $\Delta P(k)$ in each cycle is compared to the sign of $\Delta P(k-1)$.

- If these two signs are different, it means the PV array output power crosses the peak, and the duty cycle should not be changed.



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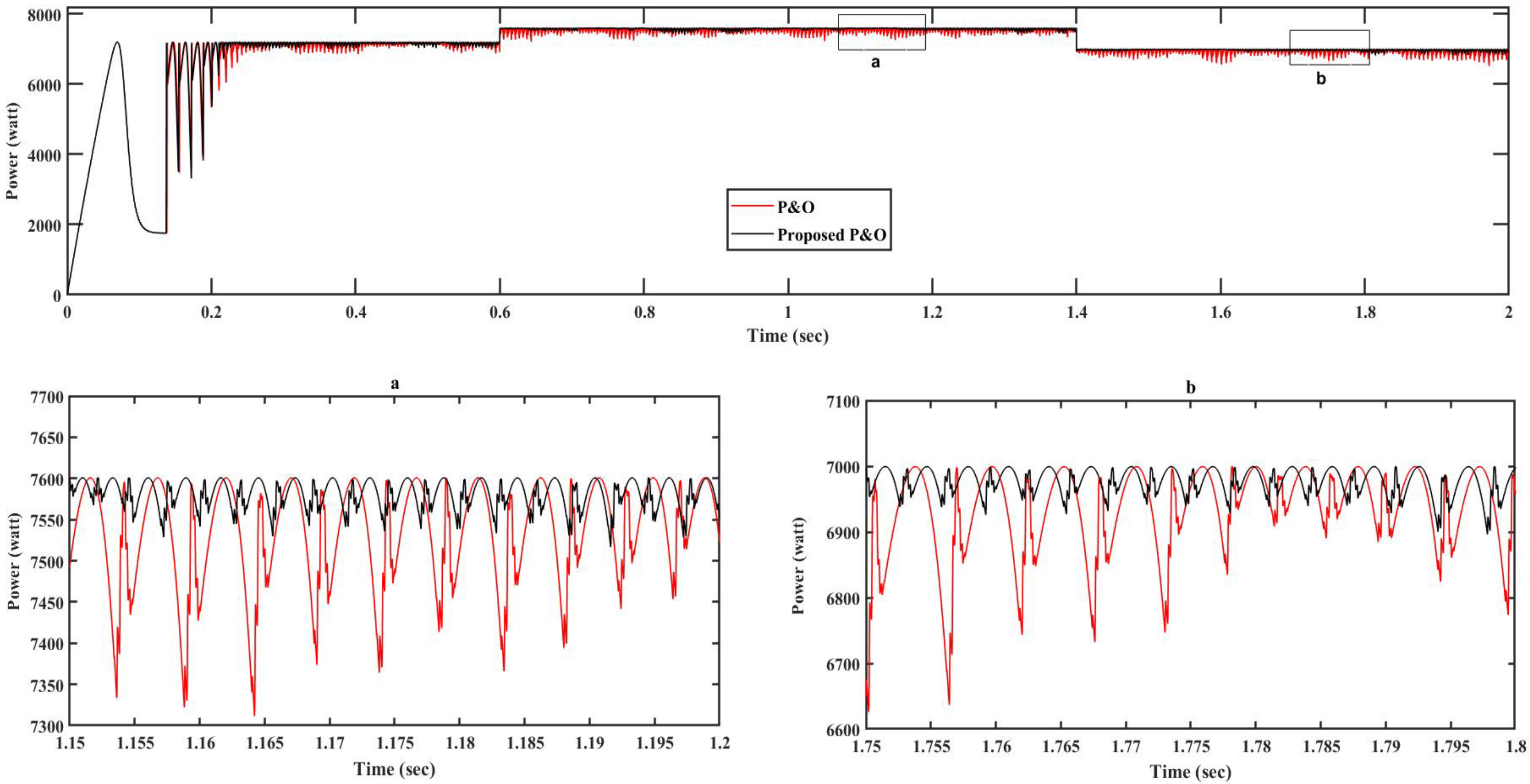
Sudden Irradiance Changes
Proposed P&O



Comparison of tracking performances of proposed P&O and conventional P&O under sudden irradiance changes

Accepted in the Journal of Modern Power Systems and Clean Energy (MPCE), September 2022.

Sudden Irradiance Changes
Proposed P&O

Type of MPPT	Evaluated parameters	
	Nature of tracking waveforms	Tracking efficiency (%)
Modified P&O	Less oscillatory and stable	95.27
P&O	Oscillatory	93.52
InC	Oscillatory	93.67

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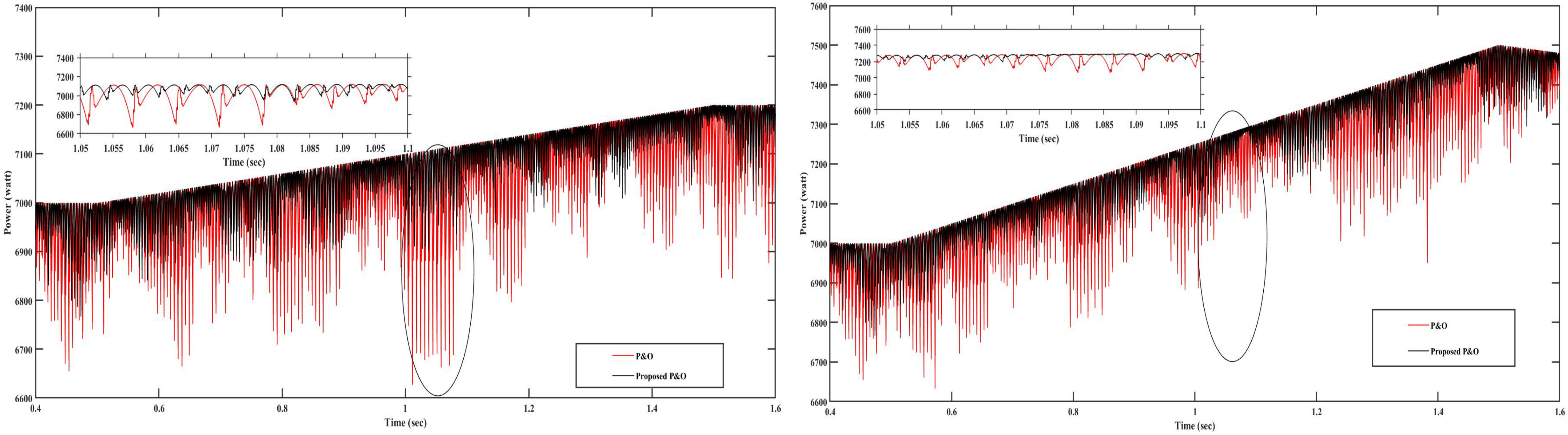
Slow and Fast Irradiance Changes
Proposed P&O



Comparison of tracking performances of proposed P&O and conventional P&O under slow and fast irradiance change

Accepted in the Journal of Modern Power Systems and Clean Energy (MPCE), September 2022.

Slow and Fast Irradiance Changes
Proposed P&O

Type of MPPT	Evaluated parameters	
	Slow irradiances change tracking efficiency (%)	Fast irradiances change tracking efficiency (%)
Modified P&O	96.68	96.72
P&O	96.19	96.23

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The Proposed P&O Algorithm With Optimized Duty Cycle:

- The step size of the algorithm should be flexible by getting close to the MPP.
- It means that each the algorithm is closer to the MPP, the step size should be smaller.
- In this way, the presented algorithm has the chance to stop as close as possible to the maximum power curve.
- When the algorithm approaching the MPP to the right, the rate of approaching is optimized by multiplying the duty cycle by (V/I).
- When the algorithm approaching the MPP to the left, the duty cycle should be multiplied by (I/V).
- As the step size reduces as it gets closer to the MPP, it helps the algorithm track the MPP more precisely.

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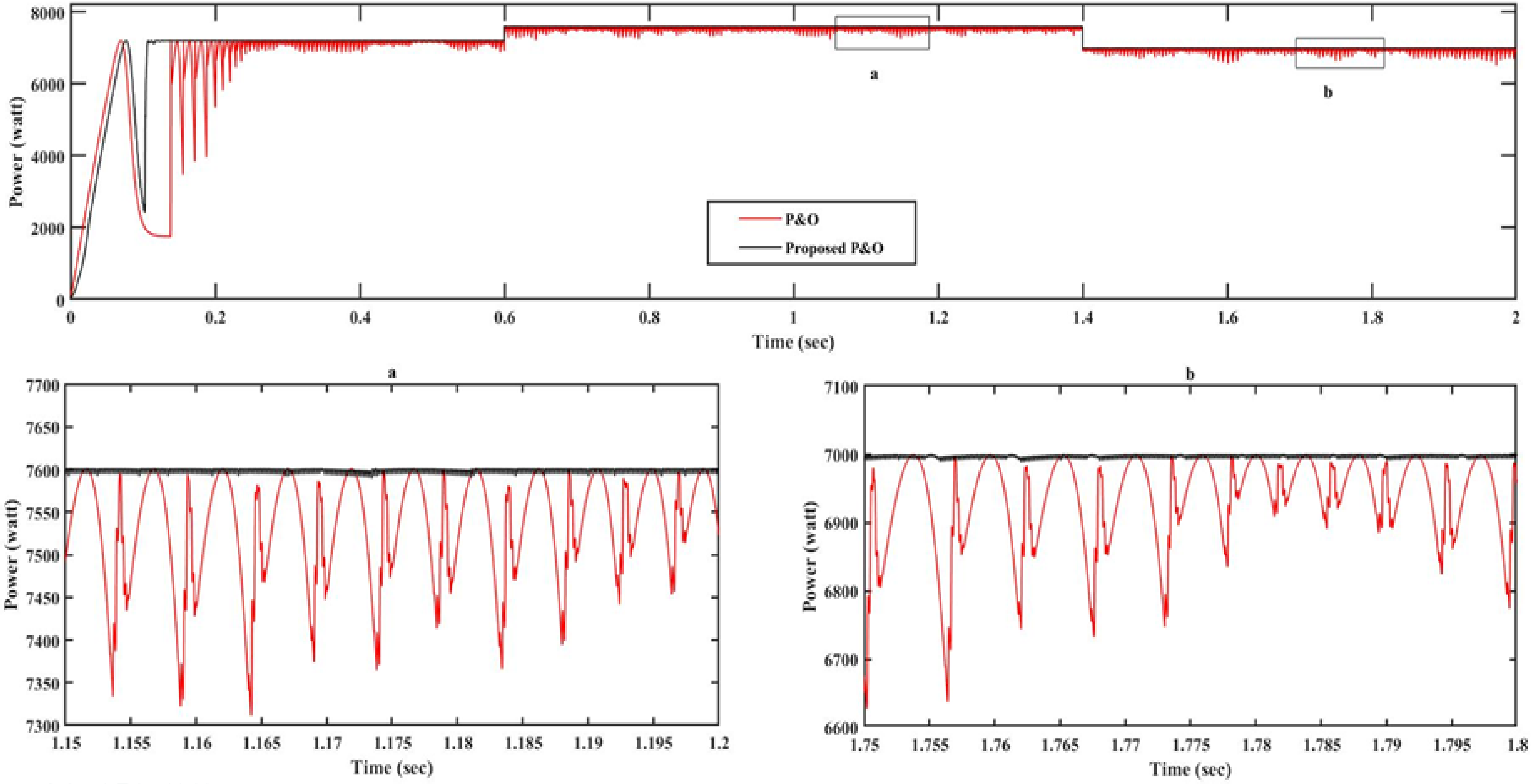
Sudden Irradiance Changes
Proposed P&O with Optimized Duty Cycle



Comparison of tracking performances of proposed optimized duty cycle P&O and conventional P&O under sudden irradiance changes

Accepted in the Journal of Modern Power Systems and Clean Energy (MPCE), September 2022.

Sudden Irradiance Changes
The Proposed P&O Algorithm With Optimized Duty Cycle

Type of MPPT	Evaluated parameters	
	Nature of tracking waveforms	Tracking efficiency (%)
Modified P&O	Less oscillatory and stable	98.21
P&O	Oscillatory	95.07
InC	Oscillatory	95.08

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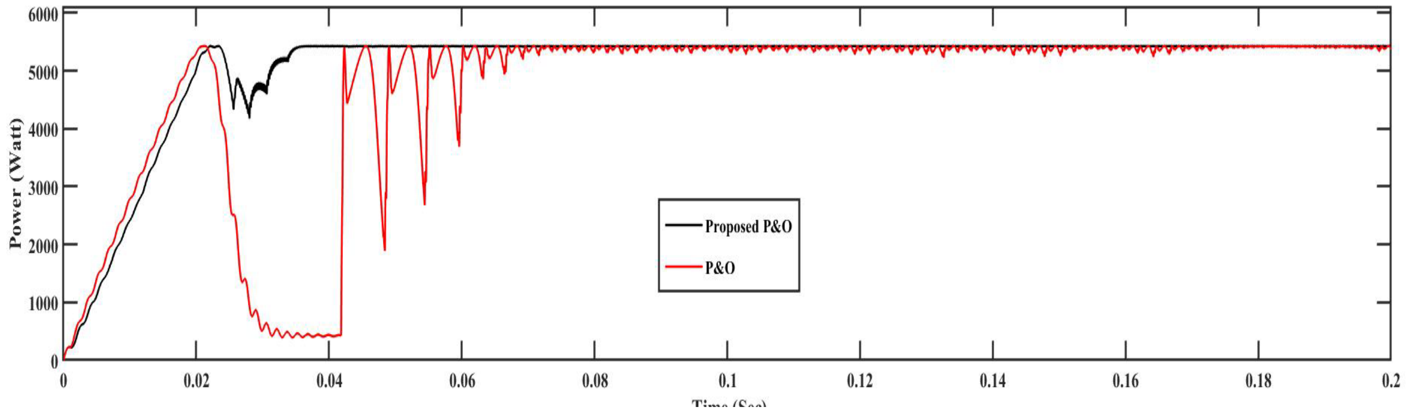
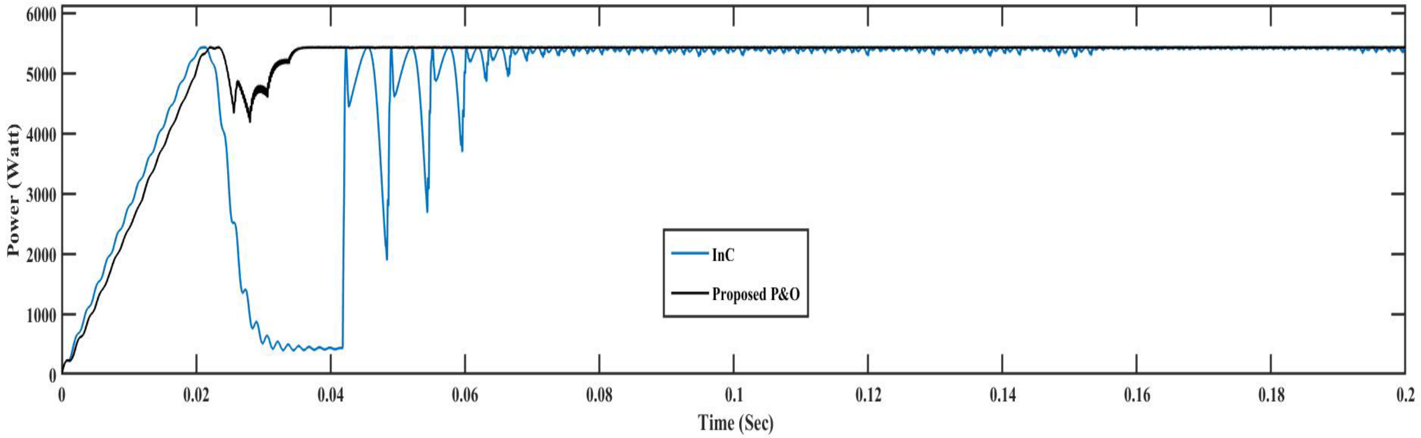
Partial Shading Condition
The Proposed P&O Algorithm With Optimized Duty Cycle

Five PV modules that are not shaded receive 700 W/m^2 uniform irradiance, five partially shaded modules receive 300 W/m^2, and the five remaining modules receive 100 W/m^2. (Moderate pattern)





Type of MPPT	Evaluated parameters	
	Nature of tracking waveforms	Tracking efficiency (%)
Modified P&O	Less oscillatory and stable	98.22
P&O	Oscillatory	95.11
InC	Oscillatory	95.11

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Partial Shading Condition
The Proposed P&O Algorithm With Optimized Duty Cycle

Five PV modules that are not shaded receive 750 W/m^2 uniform irradiance, five partially shaded modules receive 150 W/m^2, and the five remaining modules receive 100 W/m^2. (Strong pattern)

Type of MPPT	Evaluated parameters	
	Nature of tracking waveforms	Tracking efficiency (%)
Modified P&O	Less oscillatory and stable	91.85
P&O	Oscillatory	82.79
InC	Oscillatory	82.87

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Drift Analysis
The Proposed P&O Algorithm With Optimized Duty Cycle

Tests of the proposed MPPT algorithm have been conducted for an insolation level step shift from 300 to 700 W/m^2 in 0.1 s.

Type of MPPT	Evaluated parameters	
	Nature of tracking waveforms	Tracking efficiency (%)
Modified P&O	Less oscillatory and stable	93.83
P&O	Oscillatory	85.43
InC	Oscillatory	85.50

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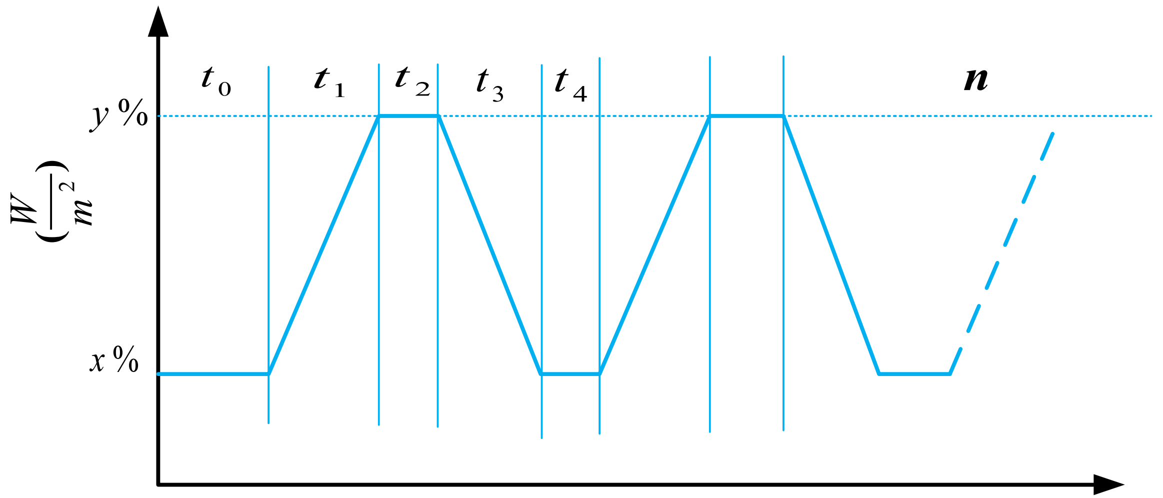
Efficiency Test According to EN 50530 Standard
The Proposed P&O Algorithm With Optimized Duty Cycle



Type of ramps	Step times (s)				Tracking efficiency (%)		
	t_1	t_2	t_3	t_4	Modified P&O	P&O	InC
10%-50%	0.1	0.4	0.1	0.4	77.67	52.97	52.97
	0.2	0.3	0.2	0.3	81.06	52.32	52.32
30%-100%	0.1	0.4	0.1	0.4	95.29	89.21	89.44
	0.2	0.3	0.2	0.3	96.23	89.57	89.74

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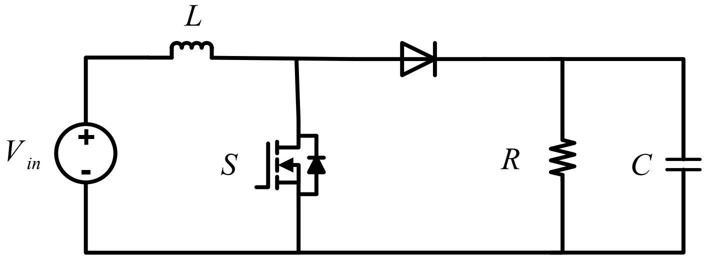
Voltage Regulation of PV Systems:

- Besides, the power maximizing issue for the PV systems, there is voltage regulation problem when they are getting connected to the grid.
- Due to the low system inertia and fast changes in the output power of solar power sources, voltage can vary from nominal operating conditions.
- When we have a DC grid, the DC–DC converters are the most significant part of the system.



- Due to the nonlinear dynamics of boost converters and non-minimum phase (NMP) behavior, controller design for boost converters is challenging.

Published in Energies, July 2022.

Voltage Regulation of PV Systems Using DMRAC:

- A direct model reference adaptive controller (DMRAC) is designed to regulate the output voltage of the DC–DC converters.
- The proposed DMRAC controller essentially contains two loops of voltage control.
  - ✓ A PID controller in real-time to ensure that the actual system is following the desired reference model (Inner loop)
  - ✓ The MIT rule for a model reference adaptive control (Outer loop)
- The proposed controller does not require any current sensor, and the control scheme is only obtained using the voltage feedback. So, the proposed design is cost-effective.

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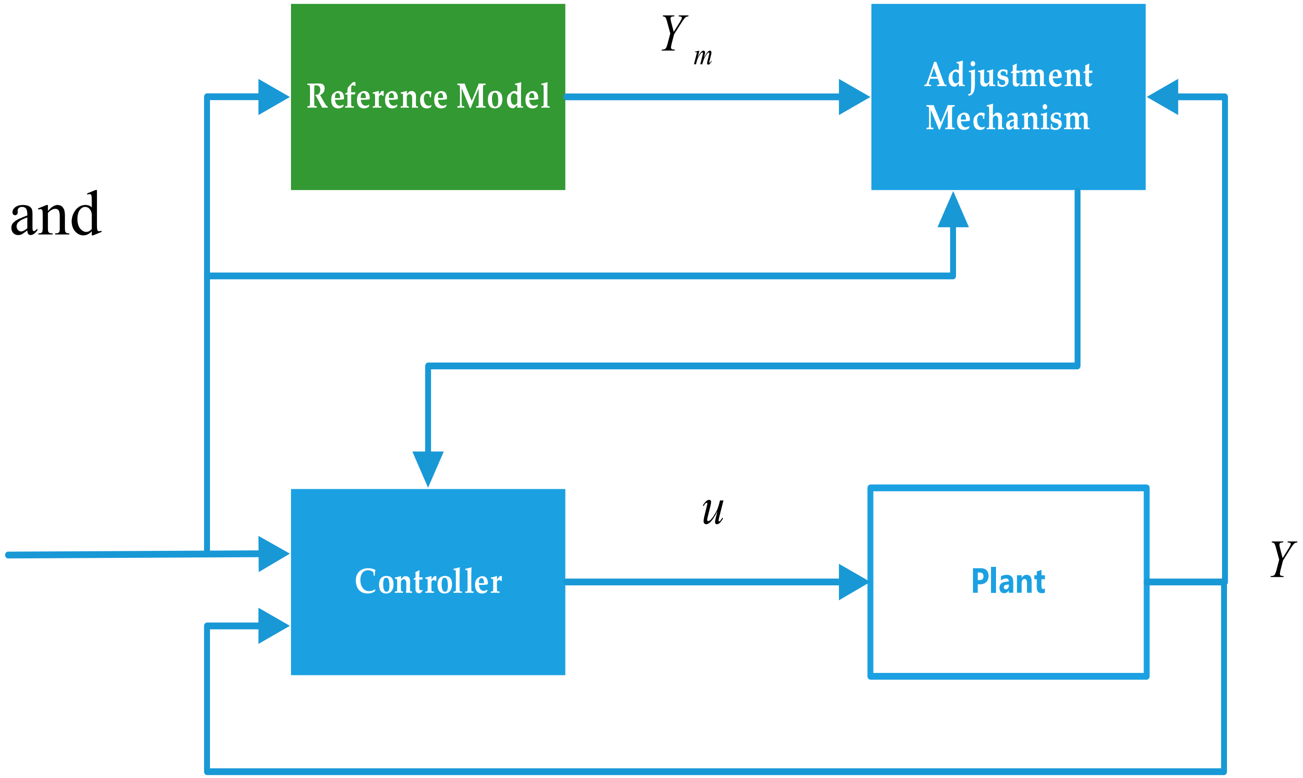
Voltage Regulation of PV Systems Using DMRAC:

Y_m represents the output of the reference model,

Y is the output of the real plant,

ε denoting the difference between Y_m and Y.

$$\varepsilon(t) = y(t) - y_m(t)$$



DMRAC system diagram

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Voltage Regulation of PV Systems Using DMRAC:

- A cost function is defined as follows in this rule:

$$J(\theta) = \varepsilon^2/2$$

θ is the variable parameter.

- The θ must be changed in a way that the cost function be reduced to zero. As a result, the change in the θ parameter is maintained in the direction of J's negative gradient, i.e.:

$$\frac{d\theta}{dt} = -\gamma \frac{\partial J}{\partial \theta} = -\gamma \varepsilon \frac{\partial \varepsilon}{\partial \theta}$$

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Voltage Regulation of PV Systems Using DMRAC:

- Assume the process transfer function is $KG(s)$, where K is an unknown parameter and $G(s)$ is a known second-order transfer function.
- Also, the reference model using this transfer function

$$G_m(s) = K_o G(s)$$

where K_o is a known parameter.

- The transfer function based on average modeling technique

$$\widetilde{v_o}(s) = R\frac{(1-D)V_o - (LI_l)s}{(RLC)s^2 + Ls - R(1-D)^2}\tilde{d}(s)$$

where R can be considered as K and $\tilde{d}(s)$ is the $U(s)$. Moreover, R can be considered a system uncertainty.

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Voltage Regulation of PV Systems Using DMRAC:

Defining a PID control law, $\theta = k_p, k_i, k_d$. Therefore u(t) is as follows:

$$u(t) = k_p e(t) + k_i \int e(t)dt + k_d \dot{e(t)}$$

where: k_p is the proportional gain; k_i is the integral gain; k_d is the derivative gain; y is the plant output; and $e(t) = r(t) - y(t)$, with $r(t)$ as the input of the reference model.

Therefore, the Laplace domain of the system output will be as follows

$$Y(s) = G(s)U(s) = G(s)[k_p E(s) + \frac{1}{s} k_i E(s) + s k_d E(s)]$$

By substituting $e(t) = r(t) - y(t)$, in above equation

$$Y(s) = G(s)[R(s) - Y(s)][k_p + \frac{1}{s} k_i + s k_d]$$

$$Y(s) = \frac{G(s)R(s)[k_p + \frac{1}{s} k_i + s k_d]}{[1 + G(s)[k_p + \frac{1}{s} k_i + s k_d]]}$$

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Voltage Regulation of PV Systems Using DMRAC:

Now the time domain of the system output can be written as:

$$y(t) = \frac{g(t)r(t)[pk_p + k_i + p^2 k_d]}{[1 + g(t)[pk_p + k_i + p^2 k_d]]}$$

According to Equation $\varepsilon(t) = y(t) - y_m(t)$

$$\varepsilon(t) = \frac{g(t)r(t)\left[pk_p + k_i + p^2 k_d\right]}{\left[1 + g(t)\left[pk_p + k_i + p^2 k_d\right]\right]} - \frac{{\omega_n}^2}{p^2 + 2\xi\omega_n p + {\omega_n}^2} r(t)$$

The derivative of $\varepsilon(t)$ with respect to the PID parameters, is as follows

$$\frac{\partial \varepsilon}{\partial \theta}$$

$$\frac{\partial \varepsilon(t)}{\partial k_p} = \frac{g(t)ep}{\left[1+g(t)\left[pk_p+k_i+p^2 k_d\right]\right]}$$

$$\frac{\partial \varepsilon(t)}{\partial k_i} = \frac{g(t)e}{\left[1+g(t)\left[pk_p+k_i+p^2 k_d\right]\right]}$$

$$\frac{\partial \varepsilon(t)}{\partial k_d} = \frac{g(t)ep^2}{\left[1+g(t)\left[pk_p+k_i+p^2 k_d\right]\right]}$$

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Voltage Regulation of PV Systems Using DMRAC:

$$\frac{\partial \varepsilon}{\partial \theta}$$

$$\frac{\partial \varepsilon(t)}{\partial k_p} = \frac{g(t)ep}{\left[1+g(t)\left[pk_p+k_i+p^2k_d\right]\right]}$$

$$\frac{\partial \varepsilon(t)}{\partial k_i} = \frac{g(t)e}{\left[1+g(t)\left[pk_p+k_i+p^2k_d\right]\right]}$$

$$\frac{\partial \varepsilon(t)}{\partial k_d} = \frac{g(t)ep^2}{\left[1+g(t)\left[pk_p+k_i+p^2k_d\right]\right]}$$

For ensuring that the tracking error is perfect, we assume the time behavior of this close loop process is equal to the time behavior of the close loop reference model, as follows:

$$\frac{g(t)}{\left[1+g(t)\left[pk_p+k_i+p^2k_d\right]\right]} = \frac{{\omega_n}^2}{p^2+2\xi\omega_n p+{\omega_n}^2}$$

Now we can find the expressions of the control parameters:

$$\frac{dk_p}{dt} = -\gamma_p \varepsilon(t) \frac{p{\omega_n}^2}{p^2+2\xi\omega_n p+{\omega_n}^2} e(t)$$

$$\frac{dk_i}{dt} = -\gamma_i \varepsilon(t) \frac{{\omega_n}^2}{p^2+2\xi\omega_n p+{\omega_n}^2} e(t)$$

$$\frac{dk_d}{dt} = -\gamma_d \varepsilon(t) \frac{p^2{\omega_n}^2}{p^2+2\xi\omega_n p+{\omega_n}^2} e(t)$$

$$\frac{d\theta}{dt} = -\gamma \varepsilon \frac{\partial \varepsilon}{\partial \theta}$$

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Voltage Regulation of PV Systems Using DMRAC:

- In the simulations, the inductor is $L = 1.3 \times 10^{-3}$ H , the capacitor is$C = 6.5 \times 10^{-3}$ F, the resistor is $R = 100\ \Omega$,, and the input voltage source is considered to be $V_{in} = 5$ V.

- Therefore, the transfer function of the boost converter, which gives the output voltages in terms of duty ratio, is:

$$\frac{\widetilde{v_o}(s)}{\tilde{d}(s)} = \frac{(1-0.5)15-(1.3\times10^{-3})(45)s}{(1.3\times10^{-3})(6.5\times10^{-3})s^2+\frac{1.3\times10^{-3}}{100}s-(0.5)^2}$$

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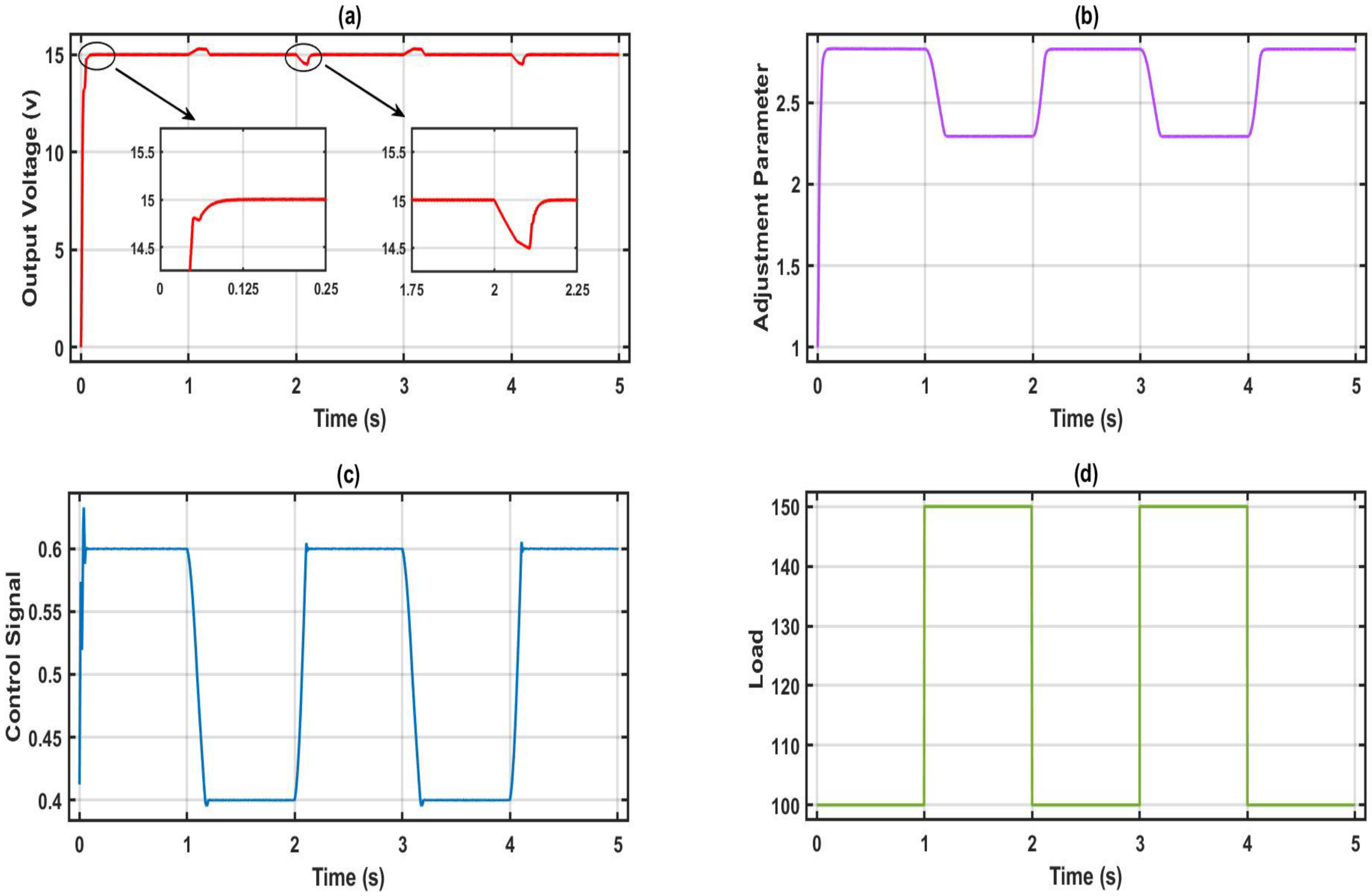
Voltage Regulation of PV Systems Using DMRAC:



The DC–DC converter transient output voltage and the responses to the load changes from 100 Ω to 150 Ω (and vice-versa),

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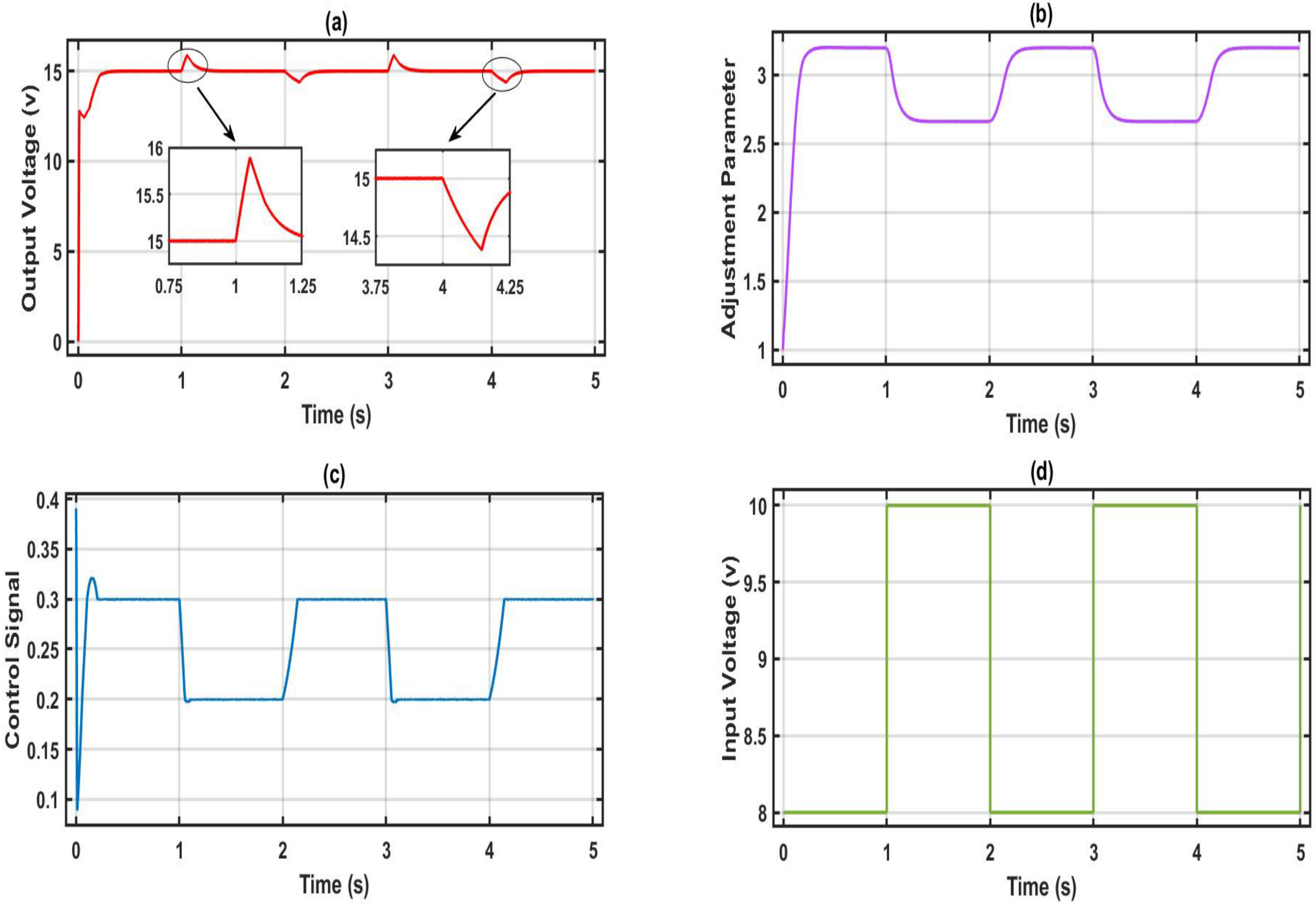
Voltage Regulation of PV Systems Using DMRAC:



The DC–DC converter transient output voltage and the responses to the input voltage changes from 8 V to 10 V (and vice-versa),

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Voltage Regulation of PV Systems Using DMRAC:

- The worst-case settling time is 0.2 s and worst overshoot response is less than ~1 V. It means that the maximum overshoot in the effect of input voltage changing is less than ~6.6%.

- The lowest overshoot, among three different PID tuning methods, namely the Ziegler–Nichol's frequency-domain method, damped oscillation method, and Good Gain method, is 34%.

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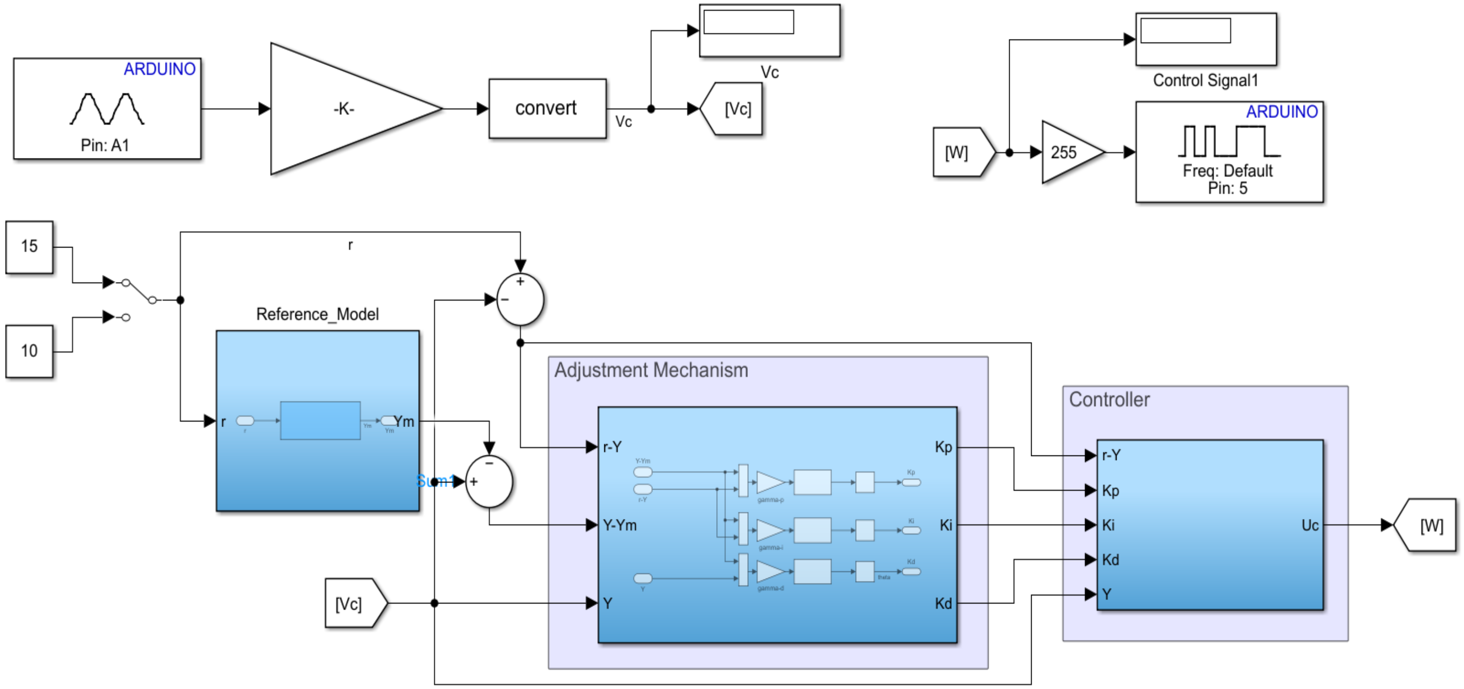
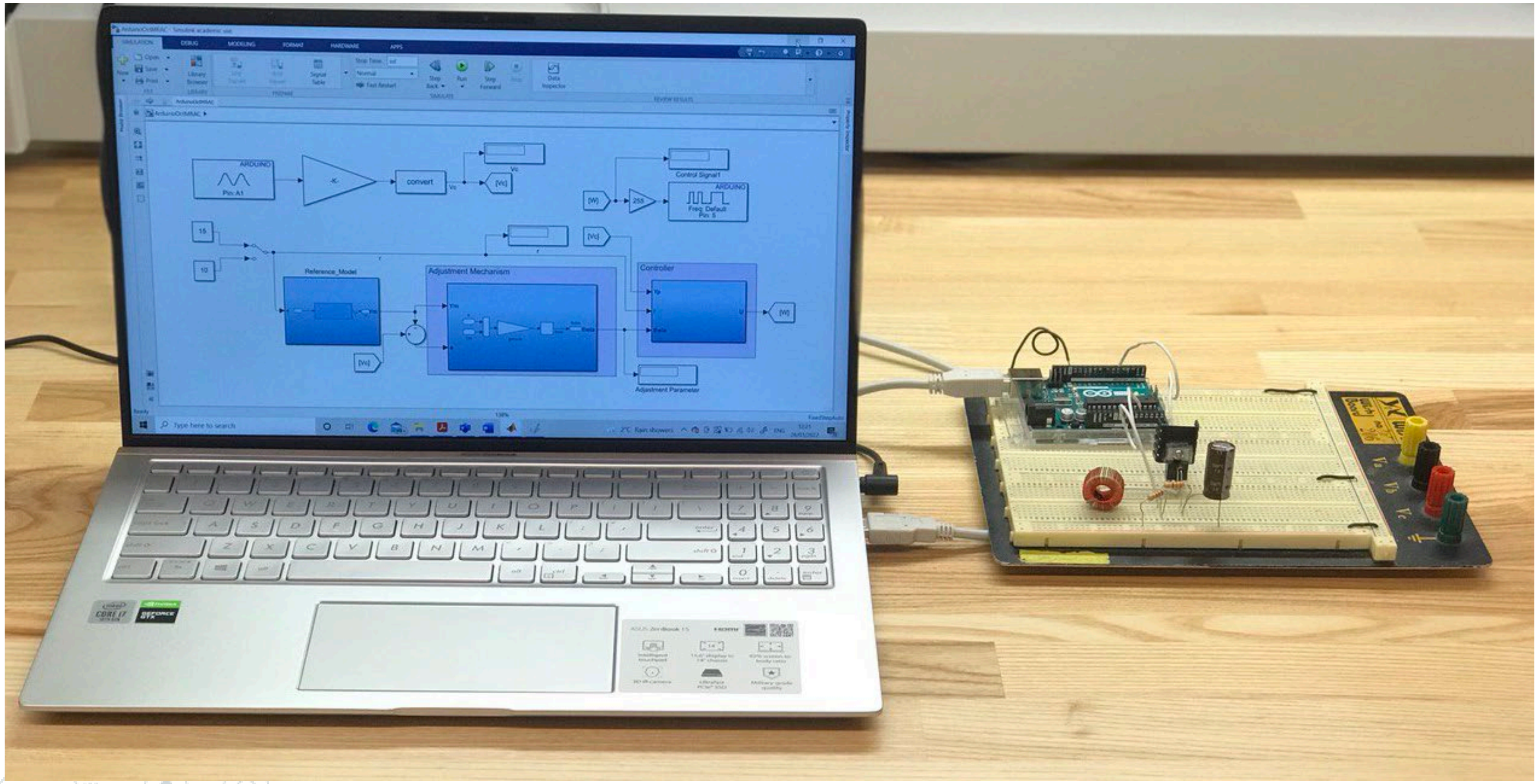
Hardware Implementation of Voltage Regulation of PV Systems Using DMRAC:

- A hardware implementation is conducted to evaluate the controller's performance in the real world.
- The Arduino Uno is used to interface Simulink's DMRAC controller and the DC–DC boost converter circuit.
- Following figure shows the designed Simulink to create an embedded system on Arduino Uno.



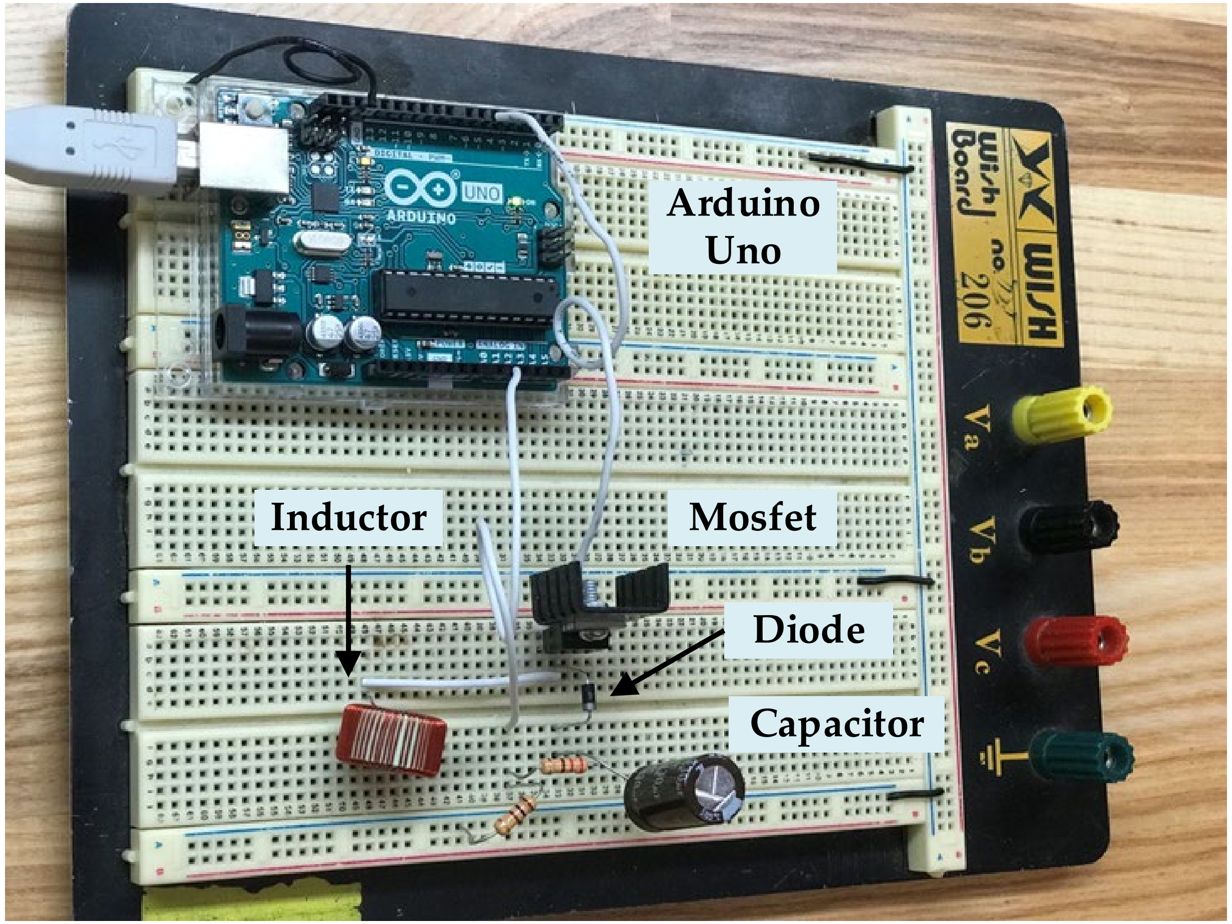
Hardware Implementation of Voltage Regulation of PV Systems Using DMRAC:

- Figure illustrates the setup connectivity between Simulink and the DC–DC boost converter.

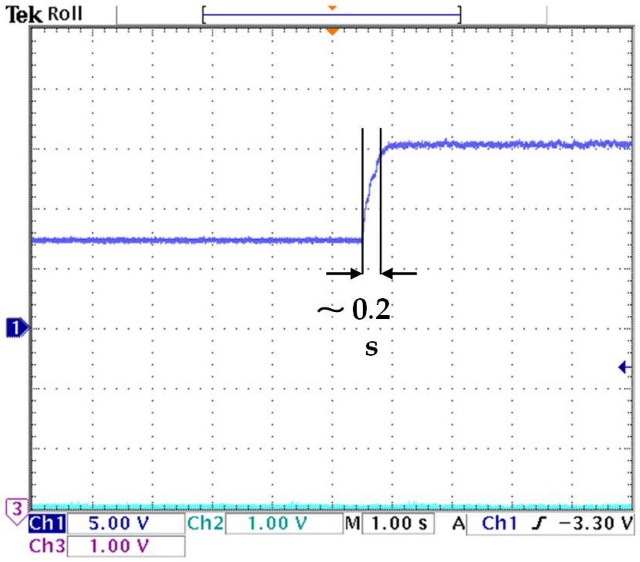


Hardware Implementation of Voltage Regulation of PV Systems Using DMRAC:

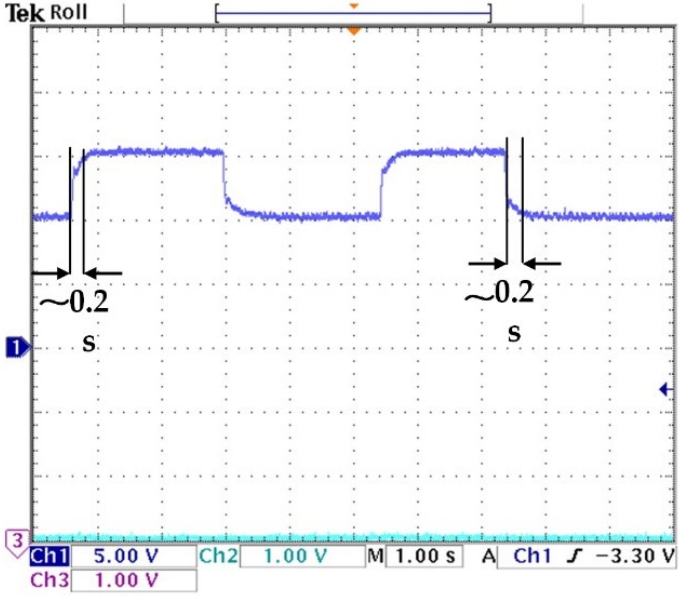
- The components used to implement the experimental test are shown here.



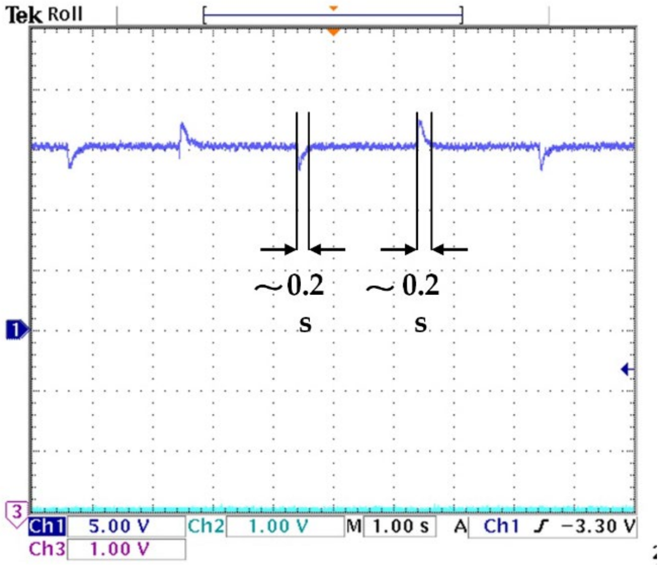
Hardware Implementation of Voltage Regulation of PV Systems Using DMRAC:



Transient output response of the boost converter for the reference voltage of 15 V.



output response waveform of input voltage changes from 8 V to 10 V (and vice-versa).



The output voltage changes with the presence of a change in voltage reference from 15 V to 10 V (and vice-versa) implementation.

Voltage Regulation of PV Systems Using SFSM:

- Another issue with output voltage regulation of DC-DC converter is having a slow dynamical response.
- We proposed super fast sliding mode (SFSM) control, which both the output voltage error and the inductor-current error are controlled.
- The switching function u = 1/2(1 + sign(S)), where u represents the logic state of the switch.
- A linear combination of three state variables is used as the sliding surface of the proposed controller, i.e., $S = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3$

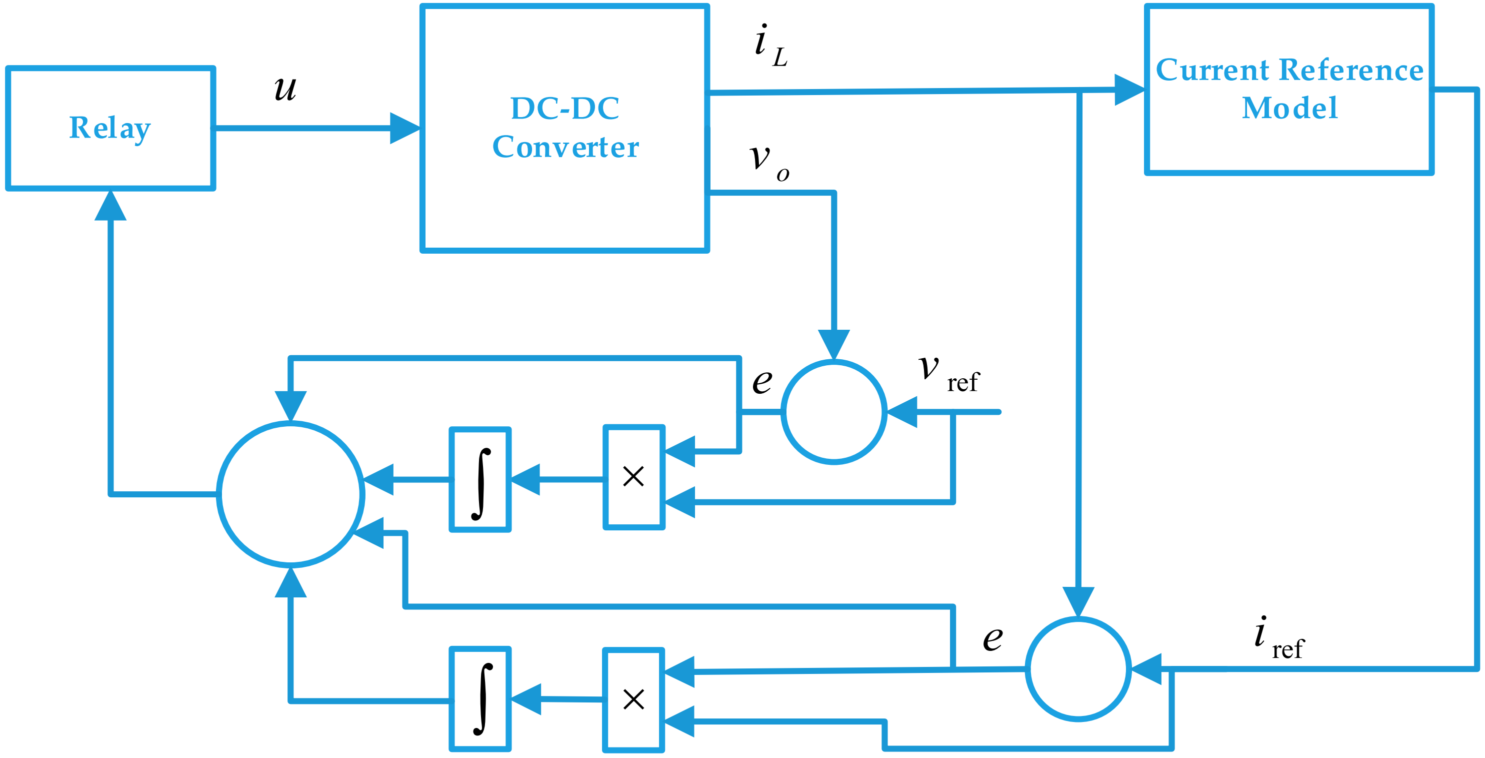
where α_1, α_2, and α_3 represents the sliding coefficients.

- we are using the current errorx_1, the voltage error x_2, and the integral of the current and voltage errors x_3, which is expressed as follows:

$$\begin{cases} x_1 = i_{\mathrm{ref}} - i_L \\ x_2 = V_{\mathrm{ref}} - v_o \\ x_3 = \int [i_{\mathrm{ref}} x_1 + V_{\mathrm{ref}} x_2] dt \end{cases}$$

Submitted to Energies, 2022.

Voltage Regulation of PV Systems Using SFSM:



SFSM Control System

Submitted to Energies, 2022.

Voltage Regulation of PV Systems Using SFSM:

In the simulations, the inductor is $L = 0.16 \times 10^{-3}\ H$, the capacitor is $C = 0.1 \times 10^{-3}\ F$, the resistor is $R = 100\ \Omega$,, and the input voltage source is considered to be $V_{in} = 100$ V.

Therefore, the transfer function of the boost converter, which gives the output voltages in terms of duty ratio, is:

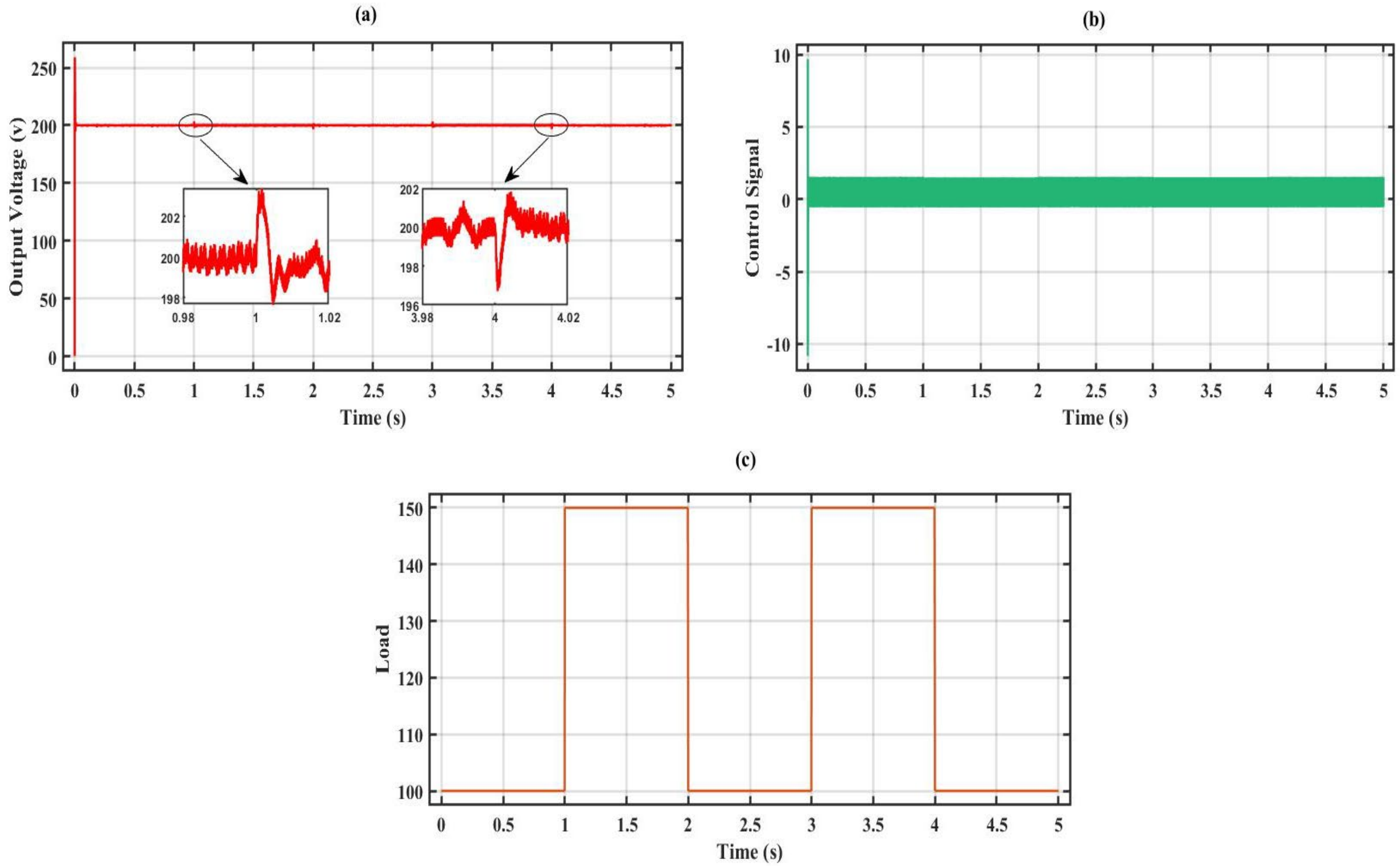
$$\frac{\widetilde{v_o}(s)}{\tilde{d}(s)} = \frac{(1-0.5)100 - (0.16 \times 10^{-3})(10)s}{(0.16 \times 10^{-3})(0.1 \times 10^{-3})s^2 + \frac{0.166 \times 10^{-3}}{100}s - (0.5)^2}$$

the model reference block of the inductor current is a 1st order transfer function with a pole far enough from the origin.

$$\frac{i_{ref}}{I_L} = \frac{1}{0.001s + 1}$$

Submitted to Energies, 2022.

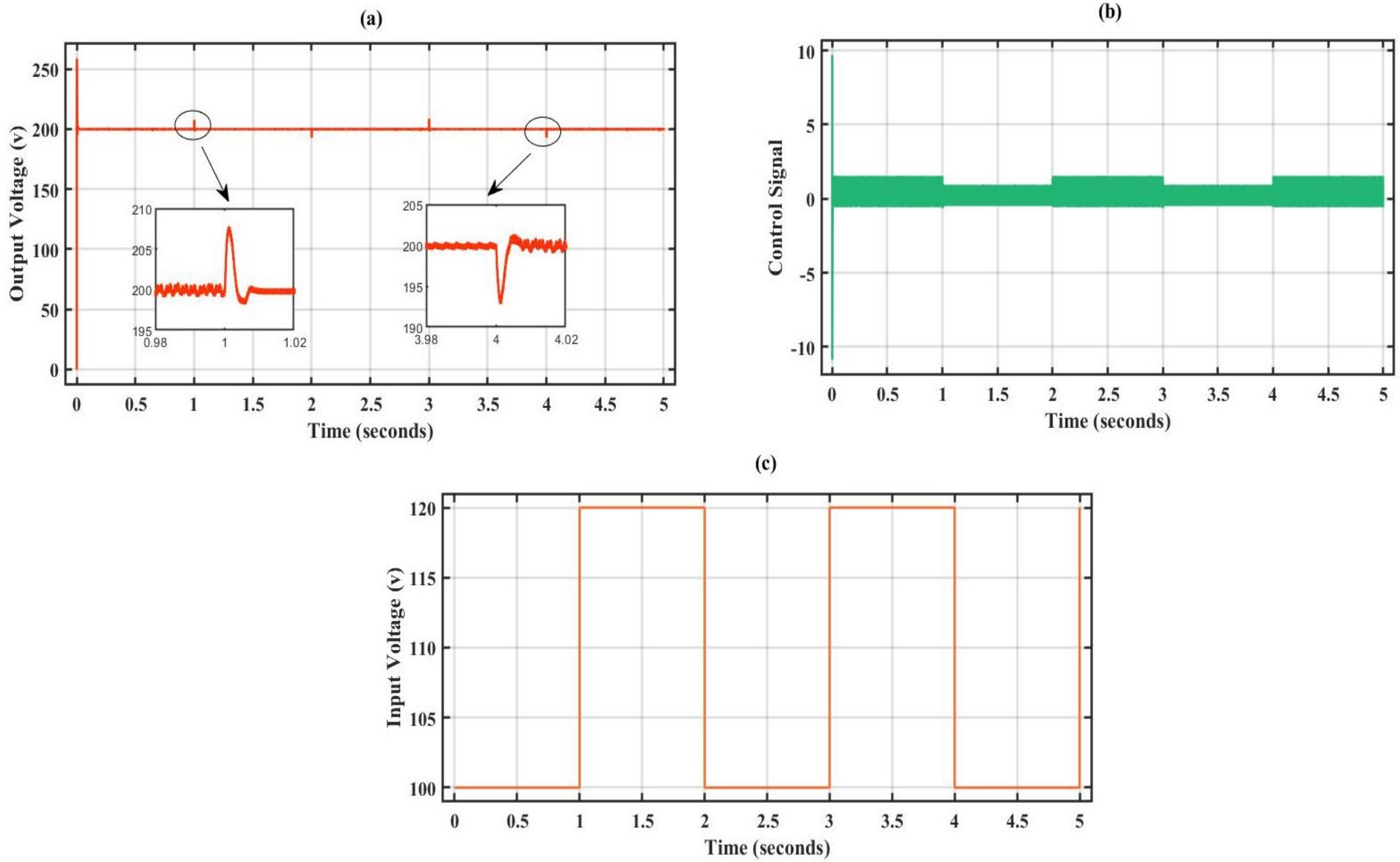
Voltage Regulation of PV Systems Using SFSM:



The DC-DC converter transient output voltage and the responses to the load changes from 100Ω to 150Ω (and vice-versa)

Submitted to Energies, 2022.

Voltage Regulation of PV Systems Using SFSM:



The DC-DC converter transient output voltage and the responses to the input voltage changes from 100V to 120V (and vice-versa)

Submitted to Energies, 2022.

Voltage Regulation of PV Systems Using SFSM:

- The worst overshoot response is less than ~8V.
- It means that the maximum overshoot in the effect of input voltage changing is less than ~4%.
- Also, worst-case settling time is 0.01 s.

Submitted to Energies, 2022.

Conclusion:

- The modified MPPT method results in an improvement over the conventional P&O algorithm and incremental conductance (InC) algorithm of roughly 3.1 percent for sudden irradiance fluctuations.
- Under strong partial shading (PSC) circumstances and drift avoidance tests, the new technique performed better than the conventional algorithms on average by 9% and 8%, respectively.
- We offer an adaptive controller (DMRAC) to adjust the output voltage of the DC-DC converters of PV systems.
- The DMRAC using only an output voltage feedback sensor and adjusting the PID controller parameters in real-time to make sure the system tracks the desired reference model.
- Finally, the super fast sliding mode (SFSM) controller proposed for DC-DC output voltage tracking with fast dynamical responses.

Thank You!

Appendix: List of Publications

Articles in Refereed Publications

- **R. Kahani**, M. Jamil, MT. Iqbal, "A Novel Dynamic MPPT Algorithm for Photovoltaic Power Systems" Journal of Modern Power Systems and Clean Energy (MPCE), September 2022.
- **R. Kahani**, M. Jamil, MT. Iqbal, "Direct Model Reference Adaptive Control of a Boost Converter for Voltage Regulation in Microgrids". Energies, 12;15(14):5080, July 2022.
- **R. Kahani**, M. Jamil, MT. Iqbal, " Super-Fast Sliding Mode Control of a Boost Converter for Voltage Tracking in Microgrids". Submitted in Energies, October 2022.
- **R. Kahani**, M. Jamil, MT. Iqbal, "Maximum Power Point Tracking (MPPT) Modified Algorithms Survey". Submitted in the Journal of Renewable and Sustainable Energy Reviews, October 2022.

Regional Conference Publications

- **R. Kahani** and M. Jamil, "Designing a Model Reference Adaptive Controller for a DC-DC Boost Converter" *the 30th Annual Newfoundland Electrical and Computer Engineering Conference (NECEC), 2021.*