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Robust Nonlinear control of Maximum Power Point Tracking in PV solar energy system under real environmental conditions

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Ambe Harrison [a], Jean de Dieu Nguimfack Ndongmo [b], Njimboh Henry Alombah [c], Claude Vidal Aloyem Kaze [d], René Kuate-Fochiee [e], Derek Ajesam Asoh[b,f], Eustace Mbaka Nfah[f]

[a] Department of Electrical and Electronics Engineering, College of Technology (COT), University of Buea, P.O.Box 63, Buea, South-West, Cameroonn

[b] Department of Electrical and Power Engineering, Higher Technical Teacher Training College (HTTTC), University of Bamenda, Bambili, P.O. Box 39, Bamenda, North-West, Cameroon, [c]

Department of Electrical and Electronics Engineering, College of Technology, University of Bamenda, P.O. Box 39, Bambili, Cameroon

[d] Department of Renewable Energy, HTTTC- Kumba, P.O. Box 249 Buea Road, University of Buea, Cameroon,

[e]Unité de Recherche d'Automatique et d'Informatique Appliquée (UR-AIA), Département de Génie Électrique, IUT FOTSO Victor Bandjoun, Université de Dschang, B.P. 134 Bandjoun, Cameroun

[f]Department of Electrical and Electronic Engineering, National Higher Polytechnic Institute (NAHPI), University of Bamenda, Bambili, P.O. Box 39, Bamenda, North-West, Cameroon

Corresponding author: ambe.harrison@ubea.cm

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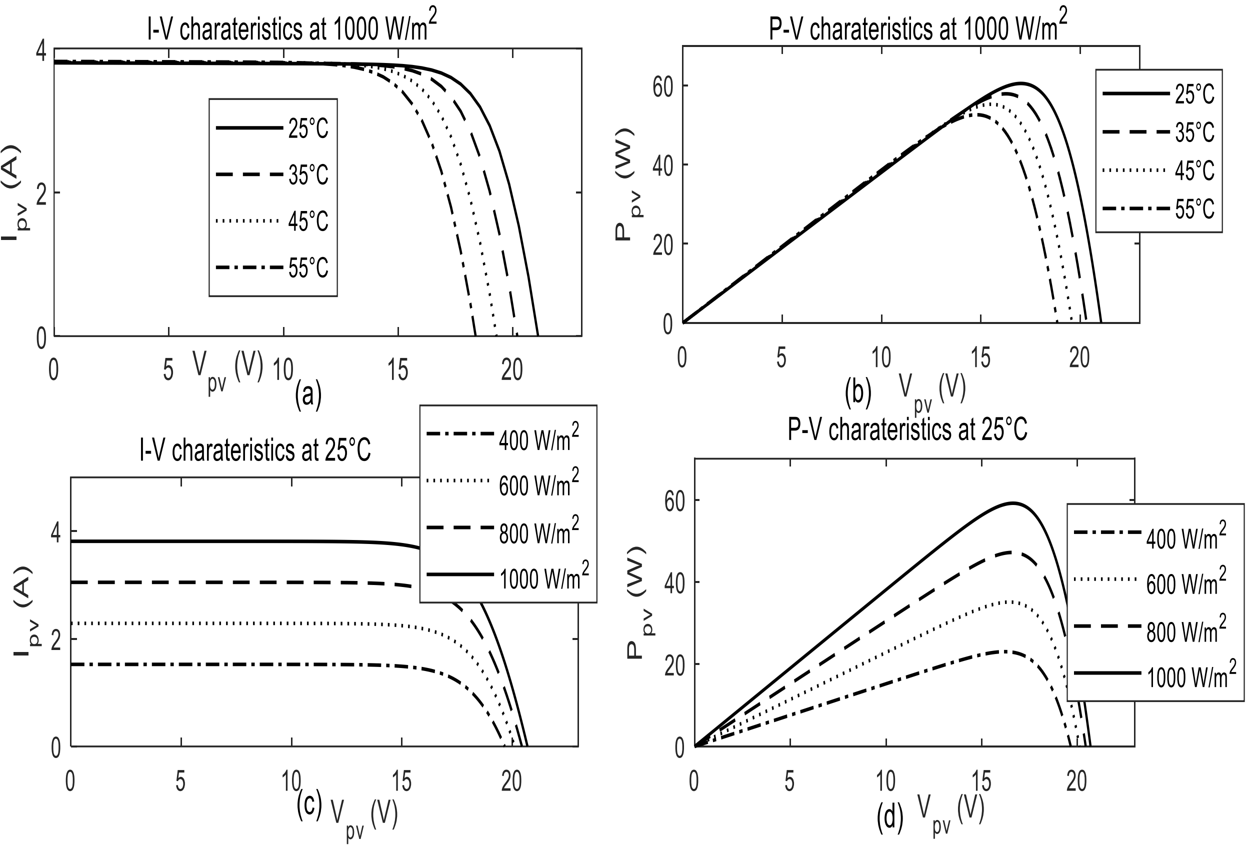
Presentation outline

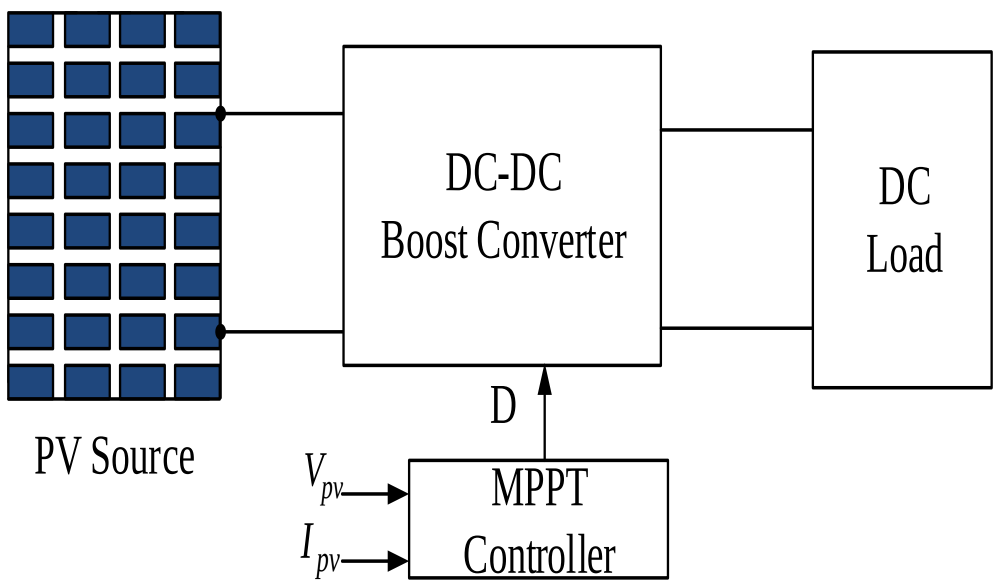
- ❑ Introduction
- ❑ Proposed System
- ❑ Nonlinear Control design
    1. Integral Backstepping Controller
    2. Formulated tuning approach for the controller
    3. Choice of Switching frequency
- ❑ Results and Discussions
- ❑ Conclusion

Introduction

Nonlinear characteristic of the PV module

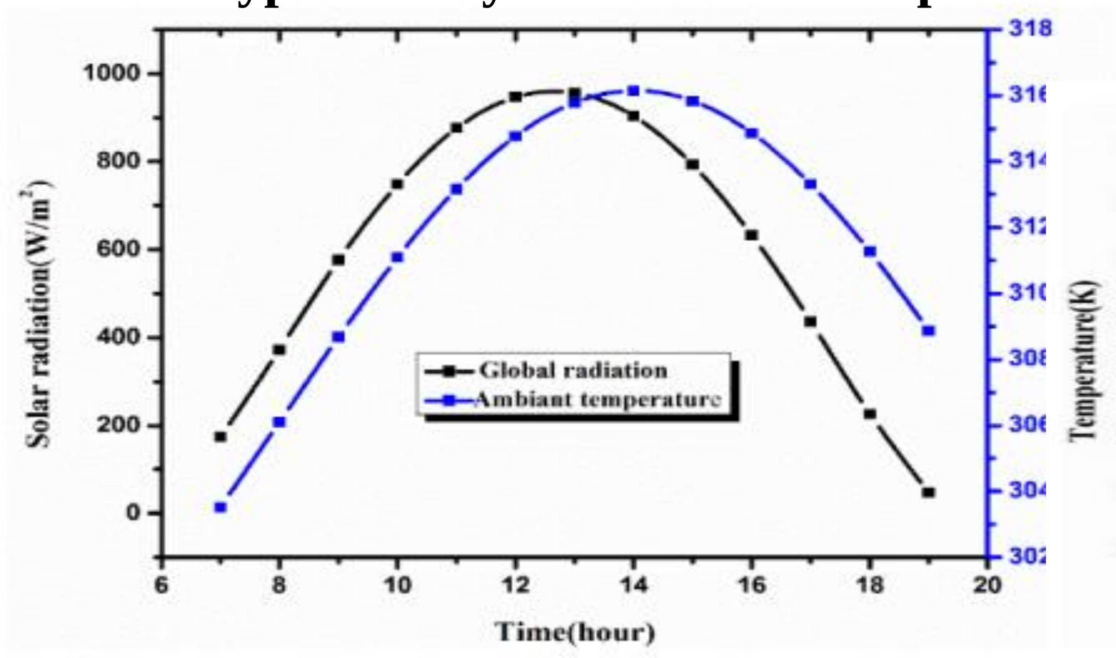


PV system with MPPT control

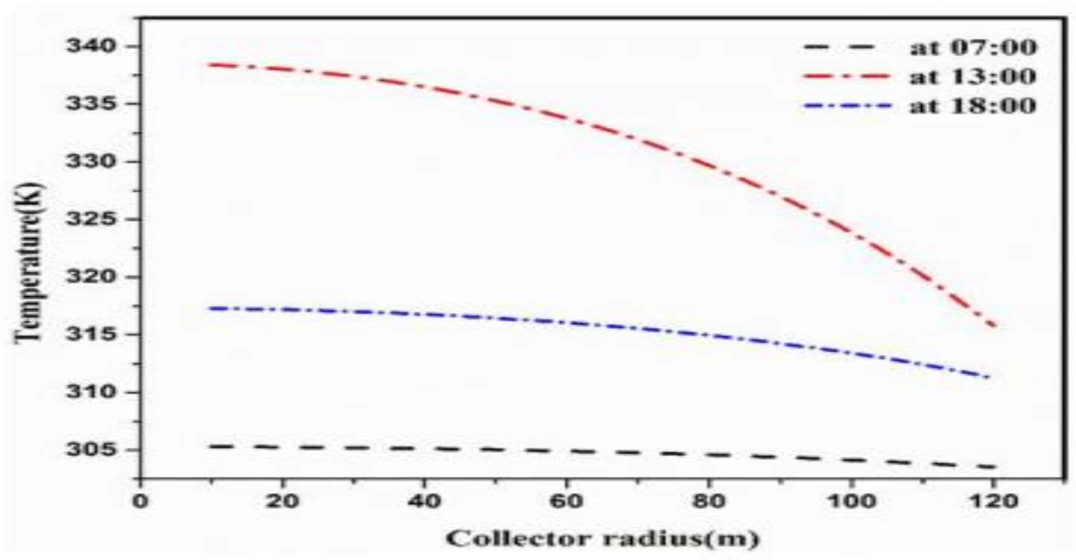


- The need for fast energy transition.
- Solar energy at the center of this transition.
- The low conversion efficiency of the PV module.
- The variability of the operational efficiency of the PV module.
- The need for Maximum Power Point tracking (MPPT) in PV systems.
- The limitation of most MPPT algorithms in the literature.

Typical Daily Solar irradiation profile

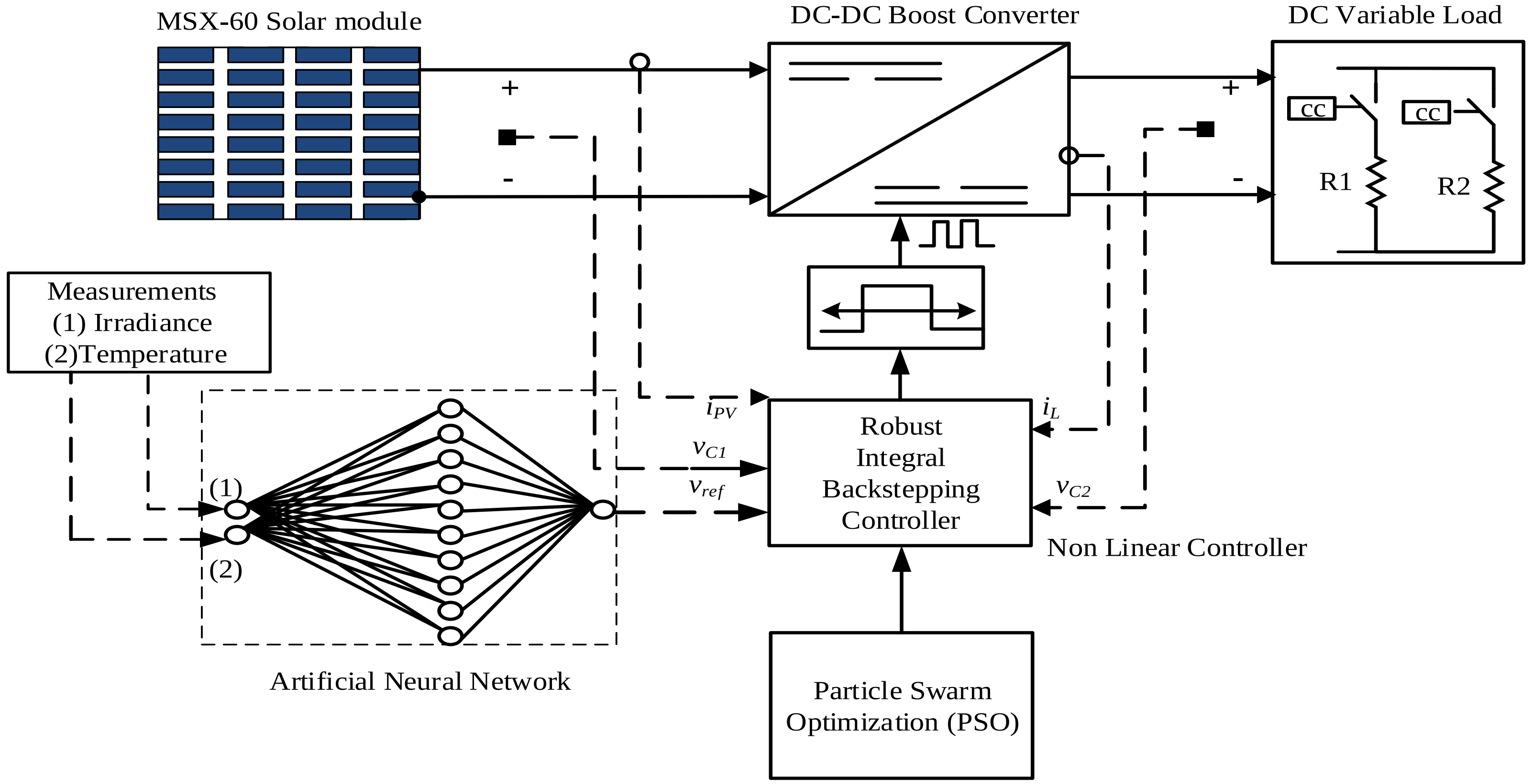


Typical Daily Solar temperature profile

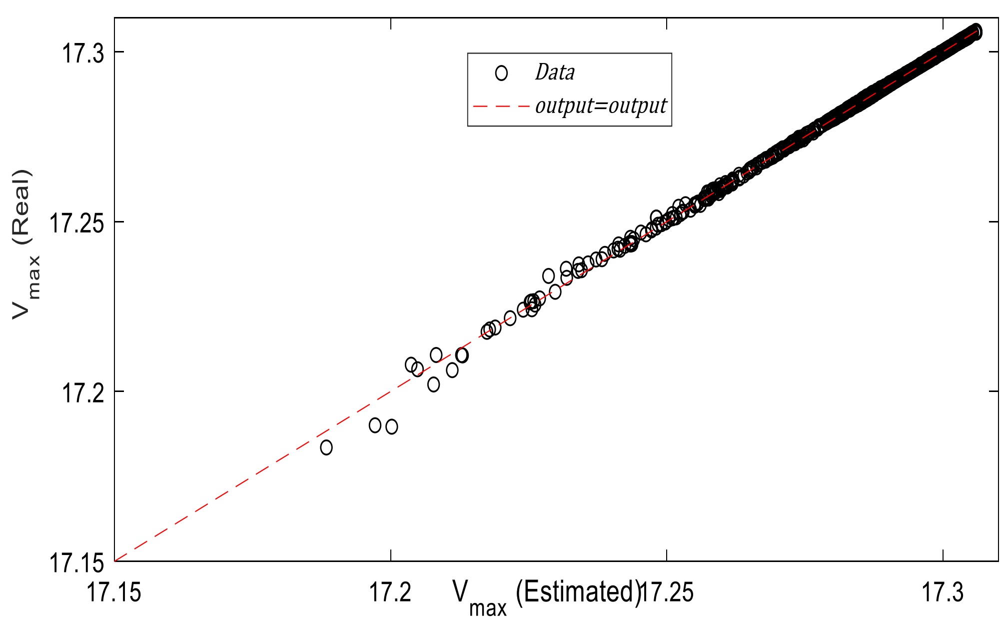


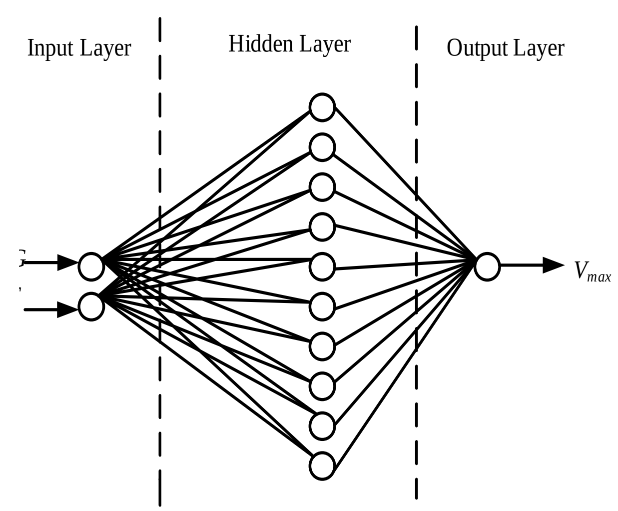
Proposed MPPT controller system

Block Diagram of the Proposed MPPT system



Artificial Neural Networks (ANN)





Description of the Proposed system

- System composed of PV module, Boost converter, Load, ANN, proposed controller, and PSO block for parameters tuning.
- The Boost ensures impedance matching between the PV source and the Load (principle of MPPT)
- The controller via a nonlinear control law, controls the Boost converter using a PWM signal
- The ANN, predicts maximum voltage based on environmental conditions
- Controller optimization is ensured via PSO

Nonlinear control design

The Nonlinear controller proposed in this work is a Robust Integral Backstepping controller (RIBS) based on recursive and virtual Lyapunov design.

$$u = 1 - \frac{L}{x_3}\left(K_2 e_2 + \frac{x_1}{L} + K_1^2 C_1 e_1 + K_1 e_2 + kK_1 C_1 p - \dot{i}_{PV} + C_1 \ddot{x}_{1ref} - C_1 k e_1 - \frac{e_1}{C_1}\right) \quad (1)$$

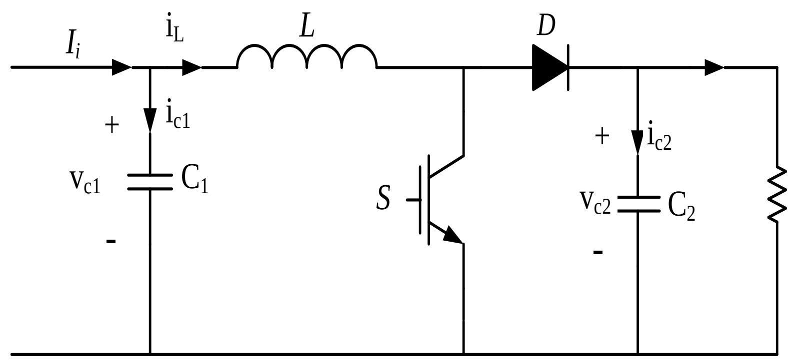
The controller is obtained from the dynamics of the boost converter, considering that the objective of the controller is to zero the error e_1 between the reference voltage from the ANN and the actual PV voltage. As was stated, the controller is based on recursive design, hence e_2 is the virtual control input, which in principal is the difference between the reference an the actual inductor current from the boost converter. In the control law (u), p is an integral action that has been added in the design to improve the steady-state performance of the controller. To controller as seen from the control law has three parameters i.e. $K_1, K_2, and\ K_3$.

Tuning the proposed controller

Tuning of the proposed controller is a milestone to ensure robust and optimal operation of the PV system. As was mentioned, the controller has three parameters contained in a vector $V,$ as seen in $Eq.(5)$. We have developed mathematical equations to optimally tune the controller. This equations have been developed from optimal assumptions in the control law. The control parameters must therefore be obtained interims of desired control goals. From the mathematical equation of the control parameters developed (see Equation (k) and Equation (K_2) , one needs to set a value of K_1, the goal e_1 to obtain K_2. The value of K_2 along with control goal e_2 and $p,$ are used to compute k.

$$k = \frac{\left(k_2 e_2 + K_1^2 C_1 e_1 + K_1 e_2 - \frac{e_1}{C_1}\right)}{(C_1 e_1 - K_1 C_1 p)} \qquad K_2 = -\frac{x_1}{L} - K_1^2 C_1 e_1 - K_1 e_1 + \frac{e_1}{C_1}$$

Boost converter with mathematical dynamics Equation



$$\begin{cases} \dfrac{dv_{c1}}{dt} = \dfrac{I_i}{C_1} - \dfrac{i_L}{C_1} \\ \dfrac{di_L}{dt} = \dfrac{v_{c1}}{L} - \dfrac{v_{c2}}{L}(1 - u'') \\ \dfrac{dv_{c2}}{dt} = \dfrac{i_L}{C_2}(1 - u') - \dfrac{v_{c2}}{C_2 R} \end{cases} \quad (3)$$

$$p = \int_o^t e_1(\tau)d\tau = \int_o^t (x_1 - x_{1ref})d\tau \quad (2)$$

$$V = [K_1\ K_2\ k] \quad (5)$$

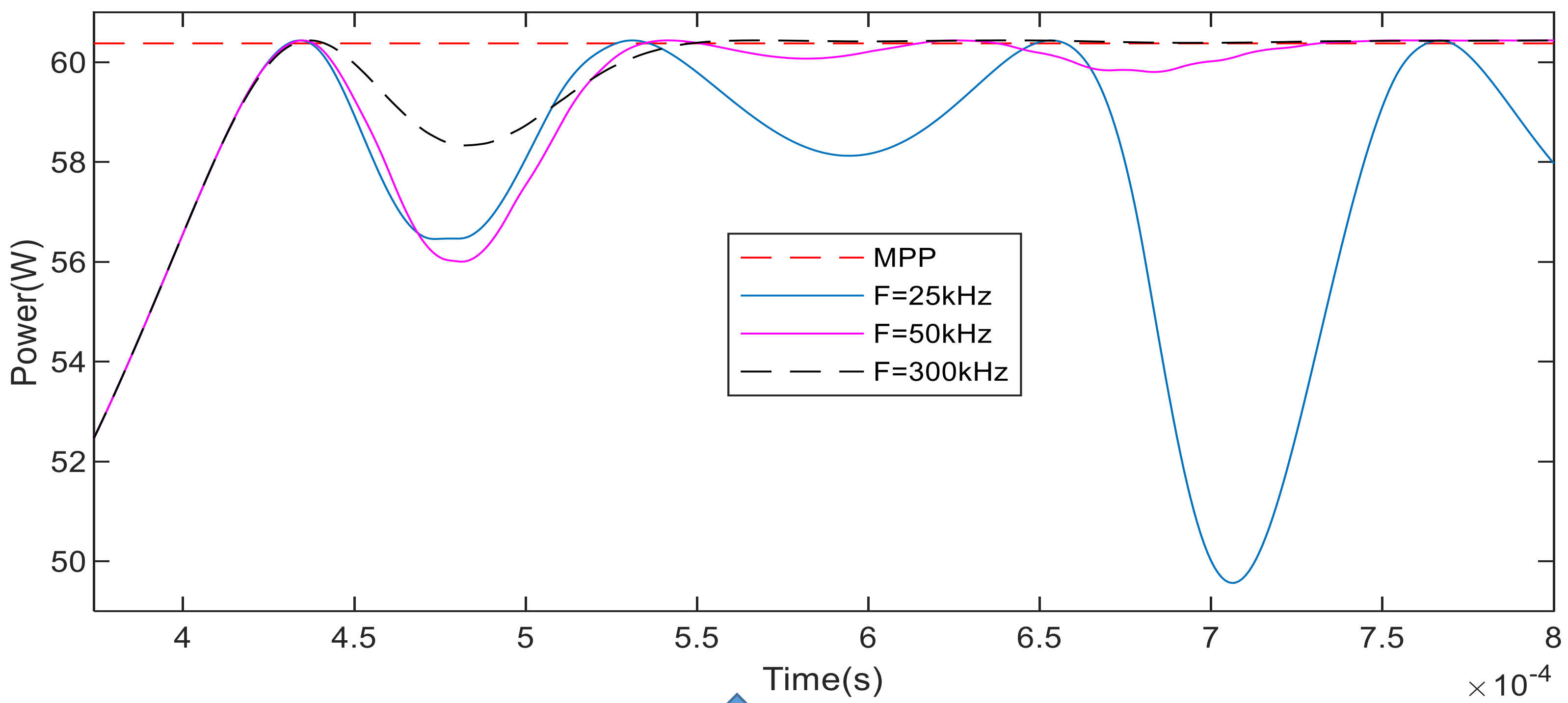
$$\begin{cases} \dot{x_1} = \dfrac{I_i}{C_1} - \dfrac{x_2}{C_1} \\ \dot{x_2} = \dfrac{x_1}{L} - \dfrac{x_3}{L}(1 - u) \\ \dot{x_3} = \dfrac{x_2}{C_2}(1 - u) - \dfrac{x_3}{C_2 R} \end{cases} \quad (4)$$

Choice of the Switching Frequency

Just like any switch mode power electronics converter, that requires a defined switching frequency, the choice of the switching frequency is eve more critical for the proposed control system. A poor frequency will negatively impact the transient regime of operation of the controller, if care not taken the controller might deteriorate. In this work, though we don't make precision on the choice of the frequency, we show that a high frequency can guarantee good transient response

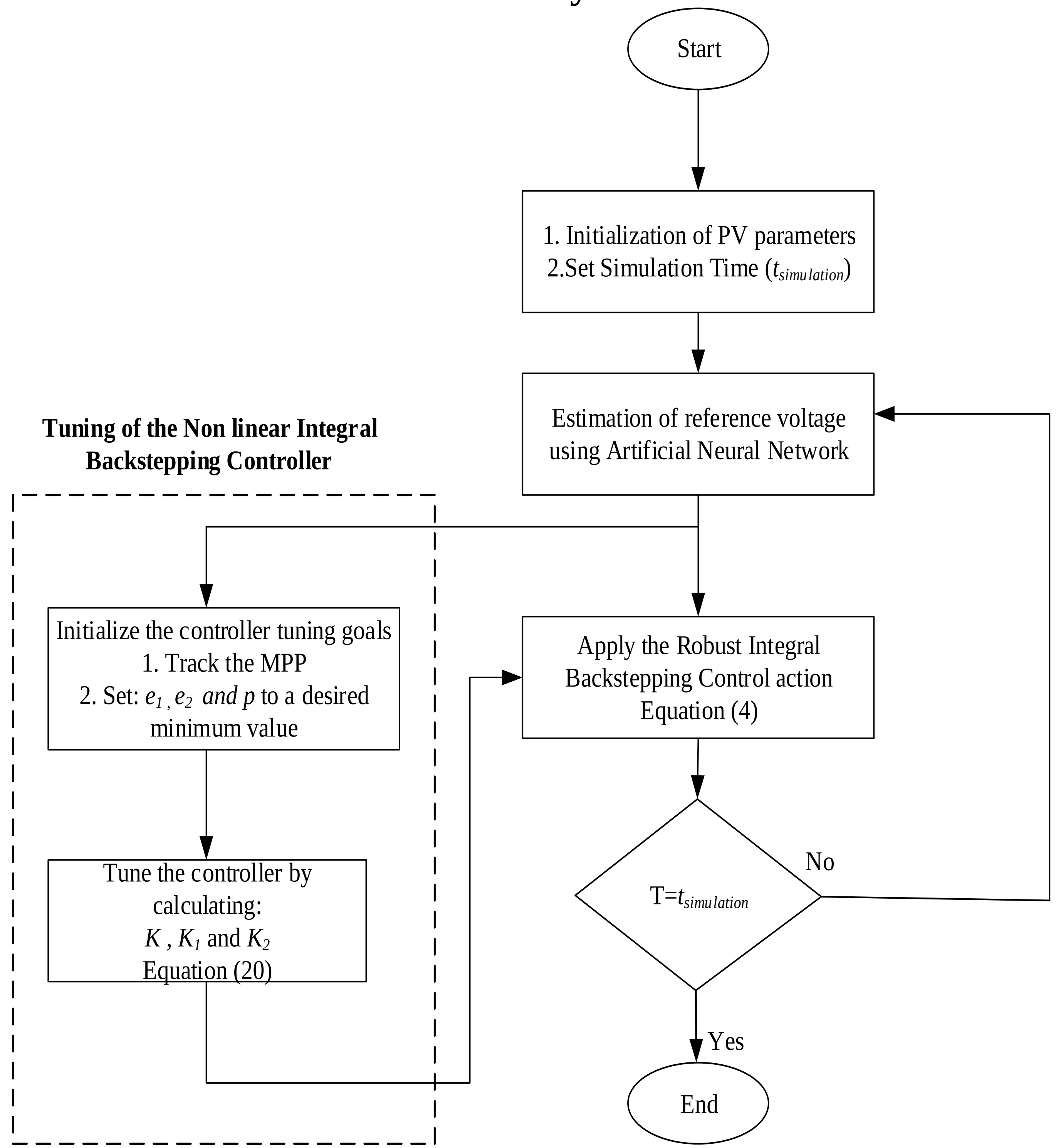
Nonlinear control design

Choice of the Switching Frequency



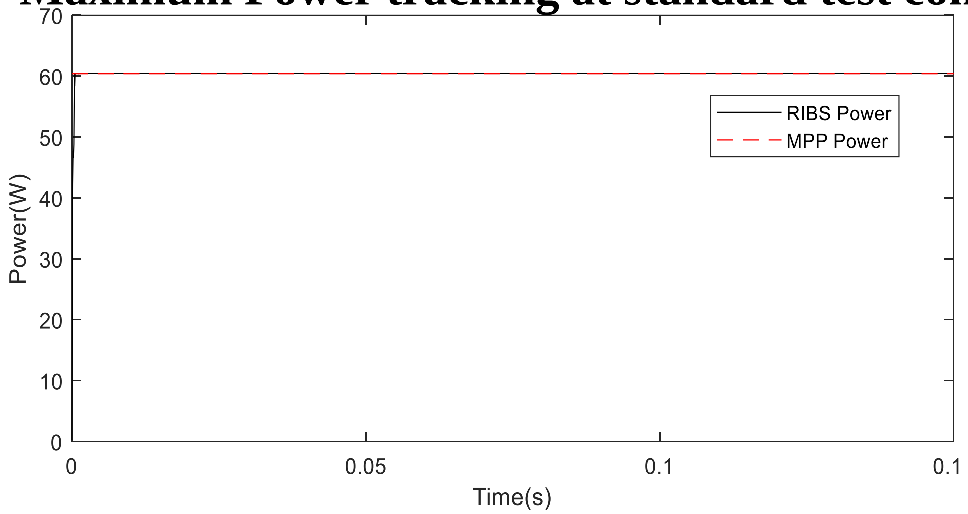
It can be seen from the graph that high frequency improves the dynamic of the controller. Though we are still working on a precise approach of obtaining this frequency, we recommend that a high frequency should be considered. For this system the switching frequency of 300kHz ensured satisfactory desired response

Flowchart for the implementation of the proposed controlled system

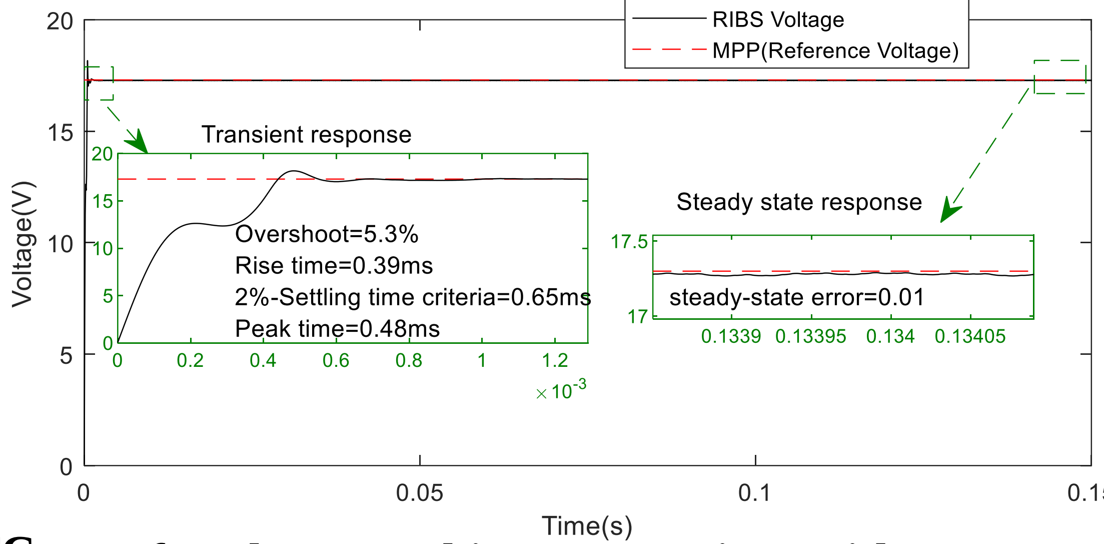


Results and Discussion

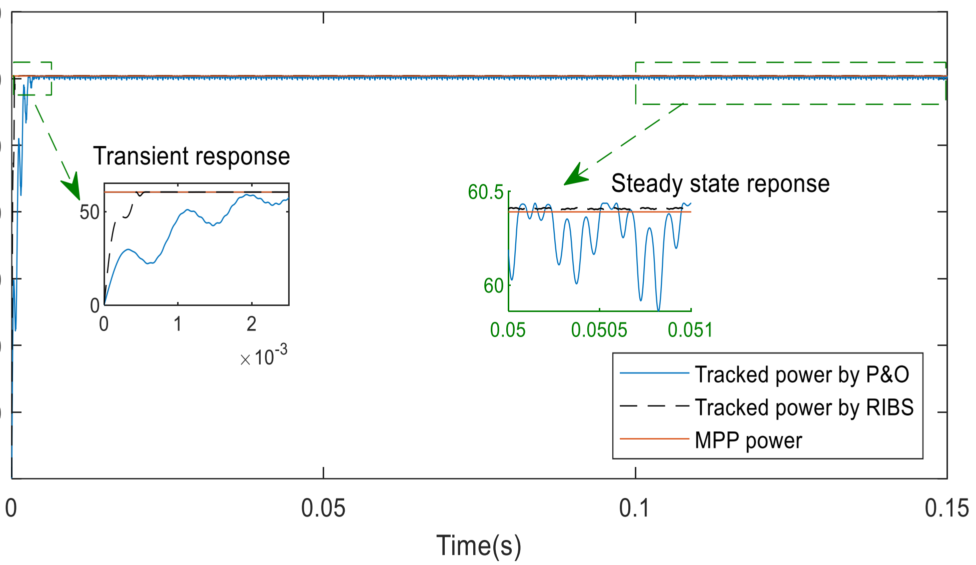
Maximum Power tracking at standard test condition



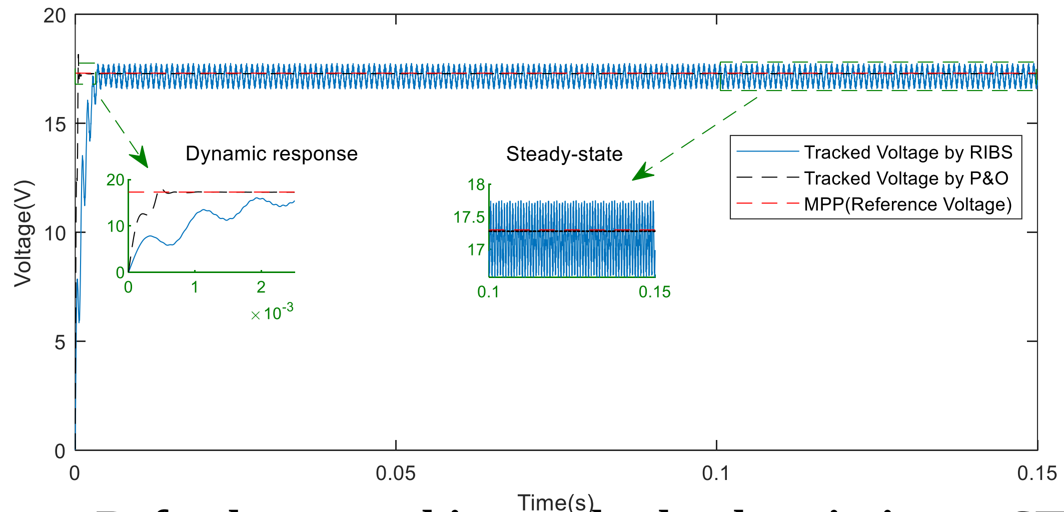
Reference voltage tracking at STC



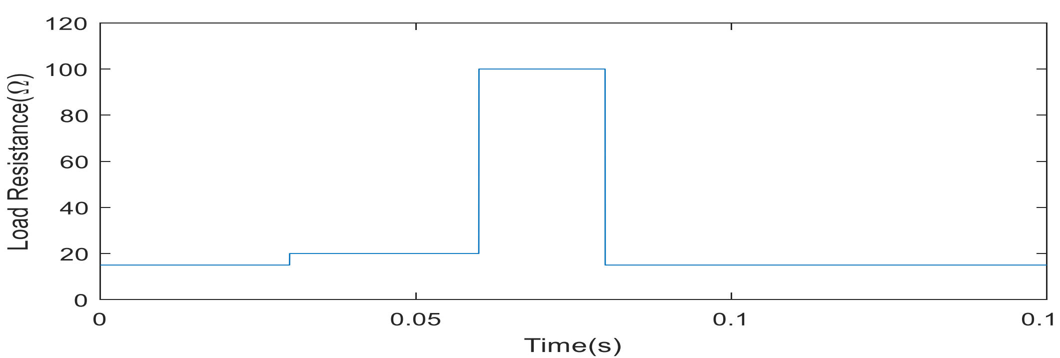
Max Power tracking Comparison with P&O at STC



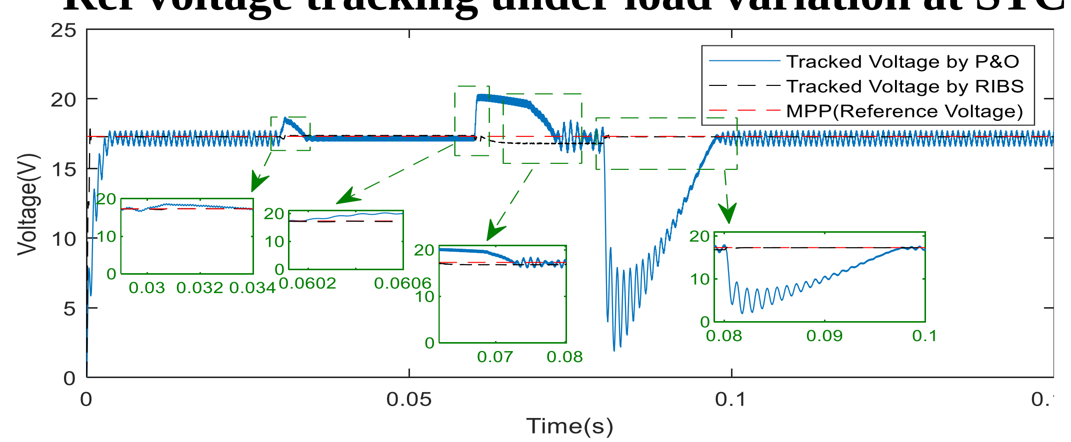
Ref vooltage tracking Comparison with P&O at STC



Voltage variation profile



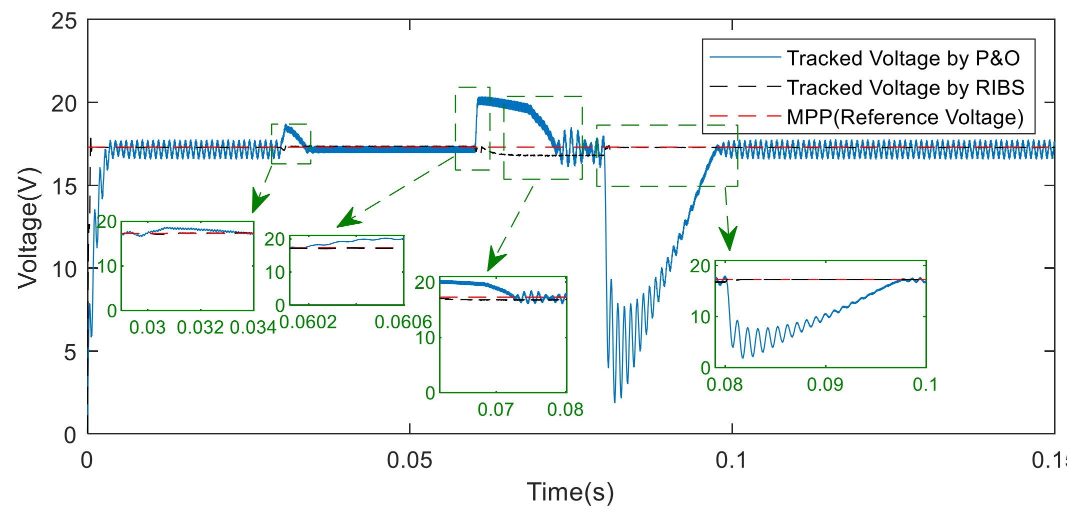
Ref voltage tracking under load variation at STC



Key remarks

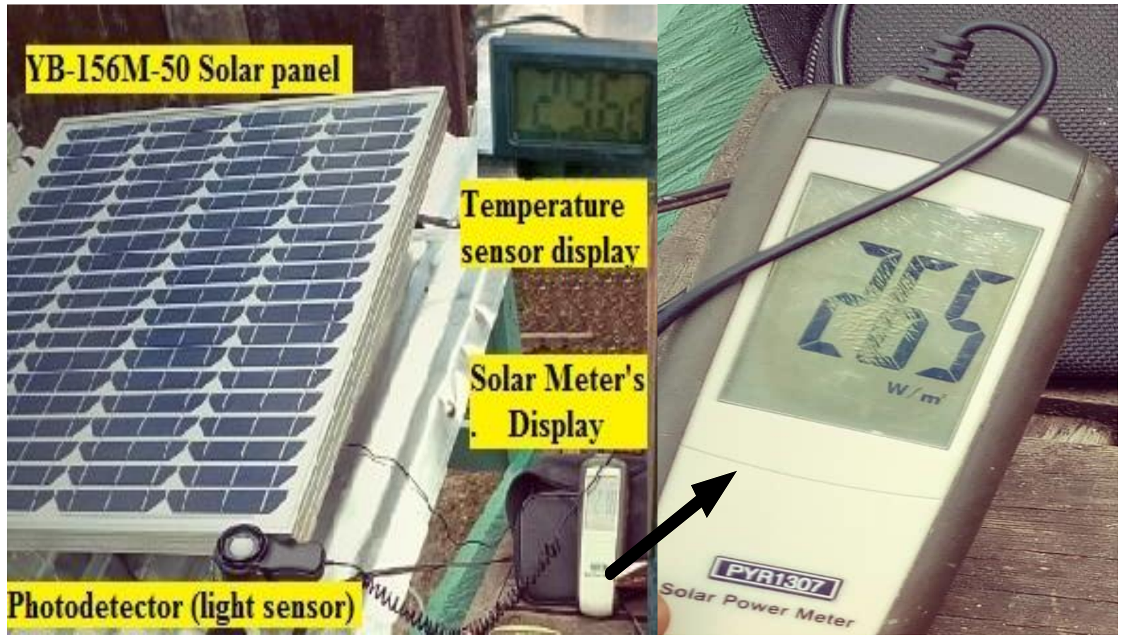
- The proposed Robust Integral Backstepping Controller (RIBS) shows exceptional performance in terms of accurate tracking the reference voltage, stabilization of the PV around the maximum power point, rejection of uncertainties due to load changes.
- The RIBS is largely better than the convectional P&O MPPT algorithm under all conditions.
- The Robustness of the RIBS is appreciated under load variations.

Max Power tracking under load variation at STC

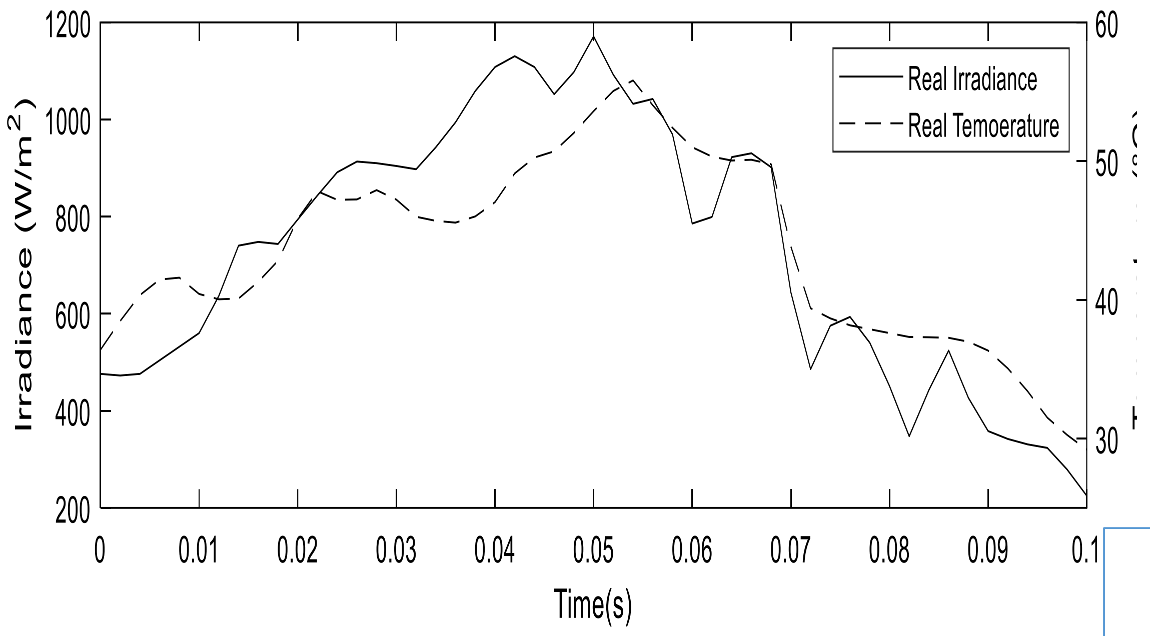


Real environmental conditions validation

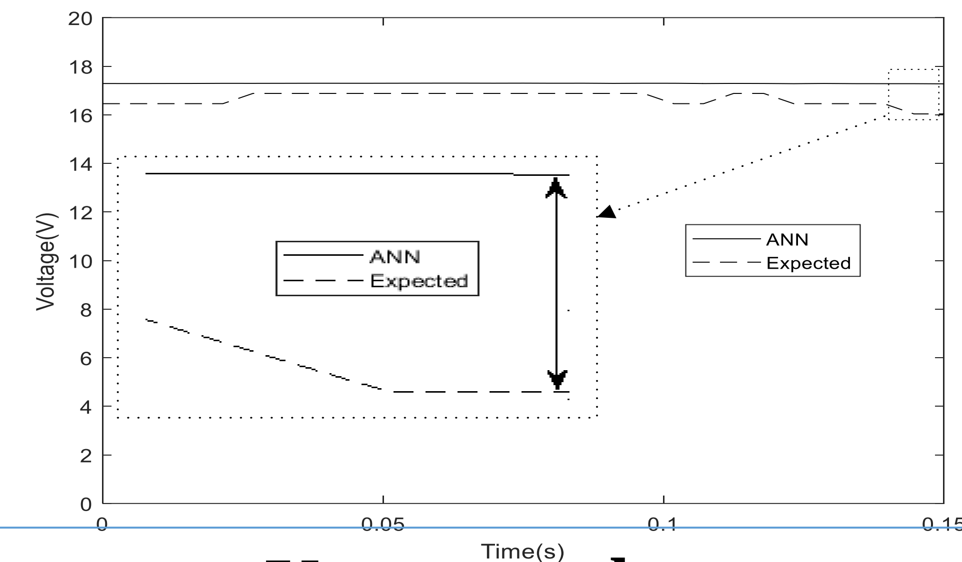
Experimental set-up



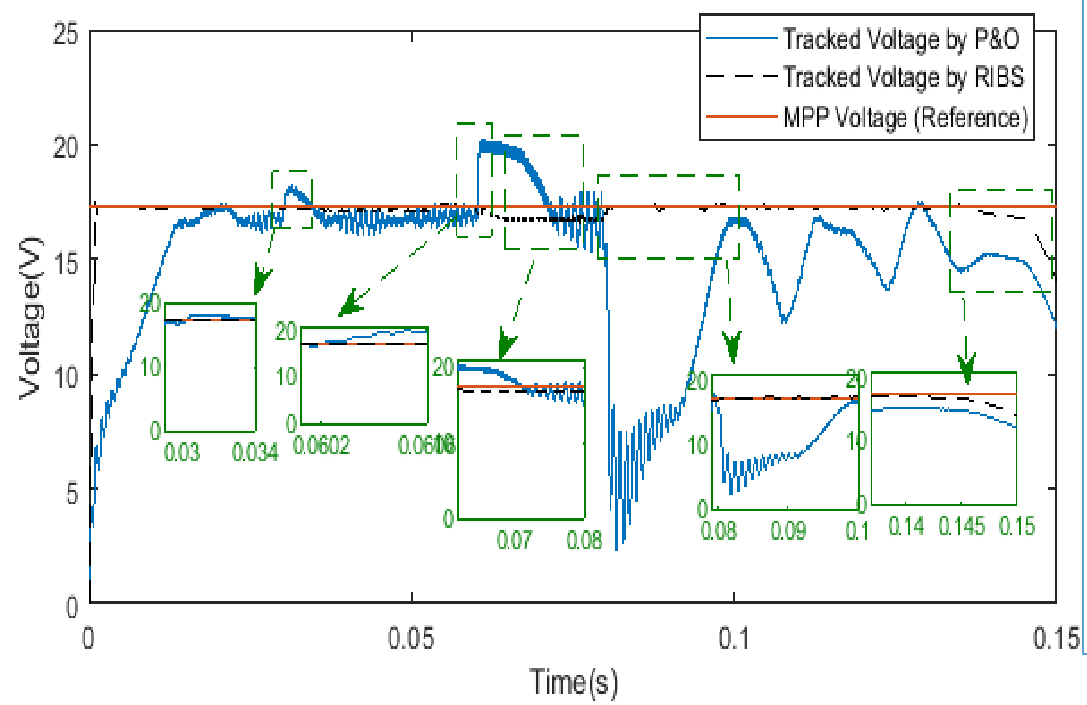
Real time parameters



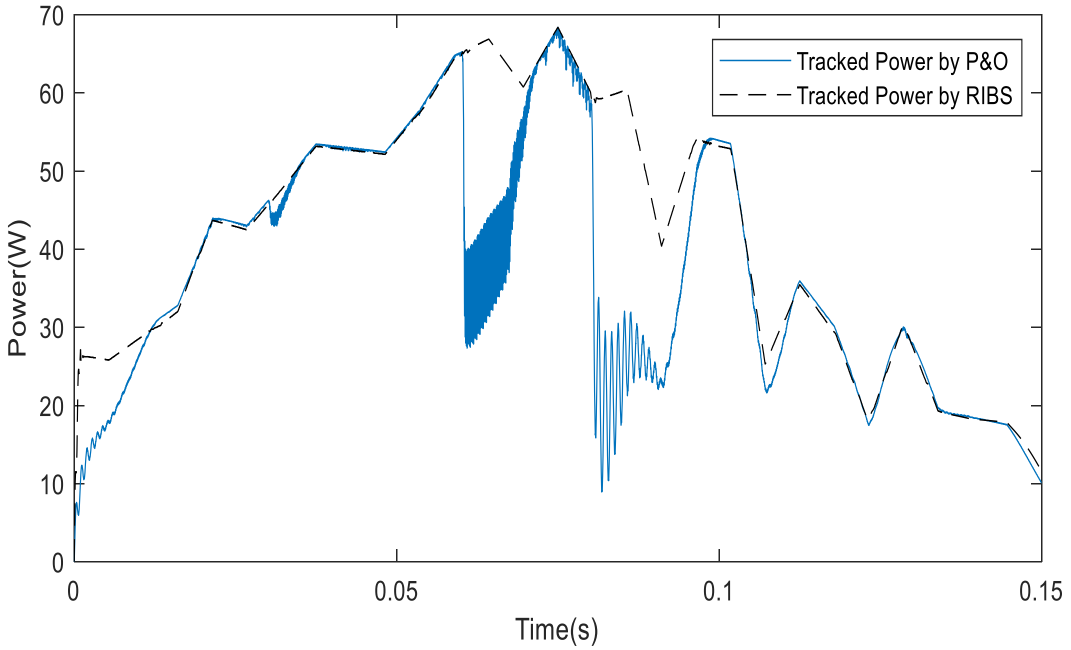
Performance validation of the ANN under real time conditions



PV voltage under real conditions with load variation



Power delivered under real conditions with load variations



Key remarks

- Under real environmental conditions, the proposed RIBS confirmed its exceptional performance and superiority over the P&O
- Under real environmental conditions, in the presence of load variations, the RIBS maintains accurate tracking of the reference voltage.
- Averagely, the proposed control system ensure the affective and efficient operational performance of the PV system above 99.6%

Conclusion

A robust integral backstepping controller (RIBS) for MPPT application using a Boost converter has been presented. A trained Artificial Neural Network model has been used to generate the reference maximum voltage. In addition to the proved Lyapunov stability guarantees of the closed loop system, mathematical equations derived from the tuning law have been used to tune the controller. From comparisons, the controller performed better than the P&O. Furthermore, the controller has been validated under real environmental conditions and heavy load variations considered as external disturbances in the system. Averagely the controller proved to be extremely robust and satisfactory for optimizing the performance of PV systems.

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Thank you for your kind attention!!

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