proceedings

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Proceeding Paper

Machine Learning - Gaussian Process Regression (ML-GPR) based Robust H-infinity Controller design for Solar PV System to achieve High Performance and Guarantee Stability †

Sureshraj S P *, Mohamed Badcha Y, Priya M, and Karthikeyan S

Department of Electrical and Electronics Engineering, J J College of Engineering and Technology, Tiruchirapalli, Tamil Nadu, India

* Correspondence: sureshraj2329@gmail.com

† Presented at the 1st International Electronic Conference on Processes: Processes System Innovation, 17–31 May 2022; Available online: https://ecp2022.sciforum.net/.

Abstract: The combined action of Machine Learning and Control System Algorithm is proposed in this Renewable Energy System. The reason for proposing the Renewable Energy System, which is the clean energy source from the nature and it's free of cost. Here the Renewable Energy system includes Solar PV System. Since this energy system has a higher scope of installation in most countries. For that, we propose a controller which achieves high performance and Guarantees Stability. In this proposed system the disturbance and Uncertain parameters are considered both internal and external parameters. To overcome this problem much Robust Control design is being already implemented in the Control Engineering Field to attain System Stability. Whereas this proposed method is a new approach to examining the System Stability by combining Machine Learning - Gaussian Process Regression (ML-GPR) with Robust H-infinity Controller. The major approach used in Machine Learning-GPR is to gather the data of the initial system and gradually decrease the Uncertainty, which results in improving the performance. Finally, ML-GPR learns a model with Uncertainty bounds. Now we combine a Control Framework (i.e., H-infinity Controller) that Guarantees Stability for this uncertain model. The design Environment used for the experimental verification is MATLAB/Simulink software. The Simulation Results confirmed the effectiveness of the newly proposed Control Strategy.

Keywords: Renewable Energy; Solar PV, Machine Learning, H-infinity, Stability, Uncertainty.

Citation: S P, Sureshraj; Y, Mohamed Badcha; M, Priya; S, Karthikeyan. Title. *Proceedings* **2022**, *69*, x. https://doi.org/10.3390/xxxxx

Academic Editor: Andrey Yaroslavtsev

Published: date

1. Introduction

As we Knew an alternating source for Non-renewable sources of energy is the Renewable energy which is eco-friendly. Even though the design of the Renewable Energy Resources has more effective but the Stability, Control and Efficiency need to be significant. Since the control and operation are challenging. The control methods for enhancing stability in Renewable energy system is a complex issue and major research efforts are increasing around the research community. Mainly Solar PV System is commonly being installed in most countries [1].

Robust control techniques are mainly proposed to address the control and stability problems. The major Robust Control methods include H-infinity, H2 norm, etc. The System Uncertainty and Disturbance are considered in designing H-infinity Controller [2].

The Robust Control Techniques combined with Machine Learning Algorithm can provide Robust Stability and Guarantees performance. The approach uses H-infinity Controller design and Gaussian Process Regression (GPR) for the design of Machine Learning-based Robust Control. This method combines a robust control framework with online learning to Guarantee Stability through gradually improving performance. Finally, the designed Gaussian Process (GP) based H-infinity Controller will Guarantee Stability for all Uncertainties learned by the GP model from the Nominal system with uncertainty signal [3].

This paper proposed the Machine Learning - Gaussian Process Regression (ML-GPR) based Robust Control Framework that Guarantees Stability through improving performance for all the Uncertainties in the Solar PV System.

2. Modelling of Solar PV System

The Photovoltaic cell is efficient in generating Electrical Energy from Solar Radiation (photon of Lights). This power generation is achieved through the PV modules that includes structured PV cells enclosed with laminated protection [4]. Solar PV system includes PV strings that get split into the number of strings connected in parallel and strings that has to be connected in series connections based on which the Power Generation is determined [4].

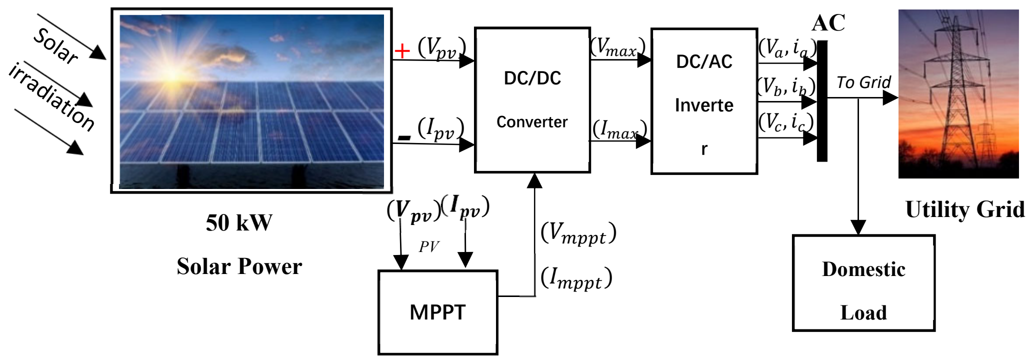


Figure 1. Configuration of Solar PV System.

The Solar Panel Connected Parallel will generate the amount of Current and connection in Series will be determining the Voltage of the solar farm [1]. One string connected in Parallel will generate a Current of 7.35 Amps similarly for Series connected string it has about 29 volts. In this model 17 strings are connected in Parallel which generates 124.95 Amps and 14 strings in Series that ranges about 406V of Voltage, total Power rating of this PV system is 50kW as illustrated in Figure 1 shows the Configuration of solar PV System. The MPPT and MPC for Solar PV System explain in the section 2.1.

2.1. MPPT and MPC for Solar PV System

The Maximum Power Point Tracking and Model Predictive Control algorithm this both methods are combined together to provide a Dynamic performance for the Boost converter. The Maximum Current tracked by the MPPT algorithm is given as the reference Current to MPC for the Current control purpose and also to eliminate the overshoot and undershoot present in the PV system that occurs due to the variation in the Radiation or Temperate change [5]. Mainly MPC algorithm acts by reducing the error value in the control parameter. The major two functionalities of MPC can be specified as Prediction and Reducing error value. For all the voltage the Current value is tracked by reducing the error value. This MPC in most cases uses tracking by comparing the reference with the measured value. Since it is quite different from other methods and it also provides a better dynamic capability. To extract the Maximum Power, the Perturb and Observe algorithm is implemented. In the MPPT model, the Current and Voltage values are calculated and the reference Current is given to the MPC algorithm. Initially its starts with measuring the Power parameters and reference values of Voltage and Current. After the MPPT, MPC action take place which initializes the parameters and minimizes the cost function to be smaller. This MPC performs as an effective method for current control based on MPPT reference [6].

2.2. Solar I-V and P-V Characteristics

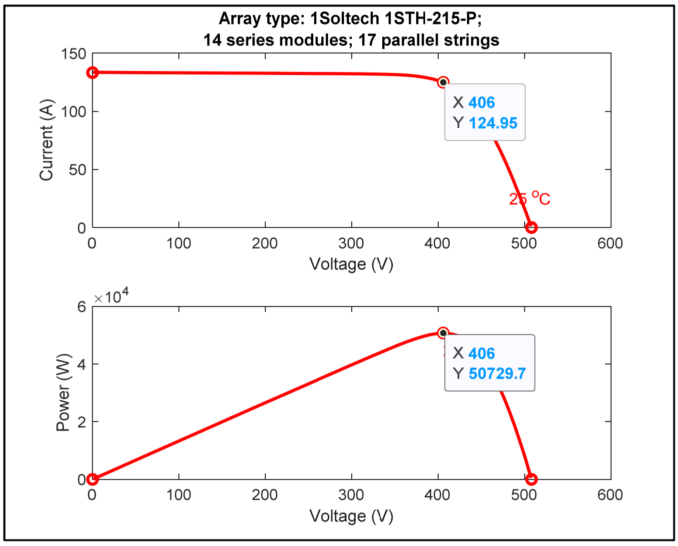


Figure 3. Characteristics of I-V and P-V of Solar Energy System.

The characteristics of Current and Voltage (V-I), Power and Voltage (P-I) in Figure 3, detail the Series modules and Parallel strings that are connected in the Solar PV farm as in the Section 2. The PV module used in the simulation is 1Soltech 1STH-215-P this term indicates the manufacturer and model name of the PV module. The I-V characteristics show the value of current concerning the Voltage value similarly in P-V characteristics total Power of 50000W generated by PV panel at the Voltage of 406 Volts. For PV panel the input Solar irradiation was given of about 1000 (W/m2) as the highest irradiation value at the time range of 2.2 minutes.

2. ML – GPR based Robust H-infinity Controller Design

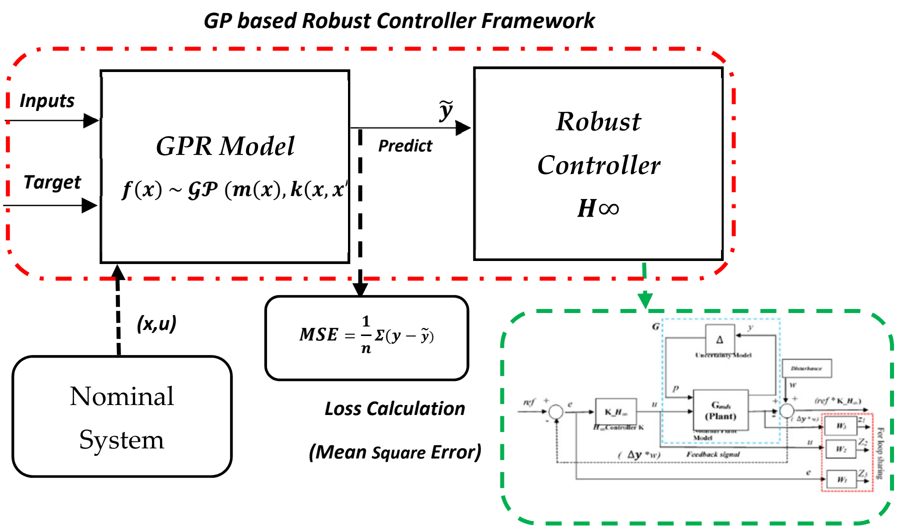


Figure 4. Configuration of ML – GPR based Robust H-infinity Controller.

The Machine Learning – Gaussian Process Regression-based Robust H-infinity Controller framework is illustrated in Figure 4. Initially the Inputs and Targets data for the GPR Model to Train the input data based on the target values. Here the nominal system considered is the Solar PV System as in Section 2. The PV DC Bus Voltage is considered to be the input data and the real value of the PV DC Bus voltage is the Target Value. The input and Target data are trained as explained in Section 3.1. The Specified Loss Function selected is the Mean square Error which is used to Calculate training losses in the data and finally, the model gets knowledge of the data. The predicted values will have fewer error values. These predicted values of the PV DC Bus Voltage are given to the Robust H-infinity Controller as detailed in section 3.2, which helps to attain robust stability.

3.1. Machine Learning – GPR Model

Machine Learning Algorithm – GPR comes under the specialization of Supervised Learning. This Supervised learning has been further categorized as Regression and Classification techniques. The Classification method is used to classify the input data with its discrete labels and Regression are mainly used to predict the continuous data values [7]. Here the Gaussian Process is considered with nonparametric regression which does not analyze prediction in a predetermined form, rather than it makes predictions based on the input data. For the GPR model, the training datasets are defined as follows $\{D = (x_i, y_i)\}$ where $i = (1,2,3\ldots,n)$ sequence of data values, x and y denote the input vector and scalar targets or ground truth correspondingly. All the input vectors of n values are collected in X and scalar targets value y as Y respectively. The Input Data X has the data values with noisy or mismatch values and target or ground truth Y has the real values of the system, which is further given to the GPR model for the training process.

In general Gaussian process is defined by mean function m(a) and covariance function k (a, a′) of real function $f(a)$ as in [7].

$$m(a) = \mathrm{E}[f(a)] \quad (1)$$

$$k(a,a') = E[f(a) - m(a))(f(a') - m(a'))] \quad (2)$$

Where $f(a')$ and $m(a')$is function and mean variance of input data a. The term E denotes expectation for example $\mathrm{E}_{q(a)}[z(a)]$ which means expectation z(a) when x ~ q(a). From the above two equations (1) and (2) the Gaussian Process ($\mathcal{GP}$) can be written as [7],

$$f(x) \sim \mathcal{GP}\ (m(a), k(a,a') \quad (3)$$

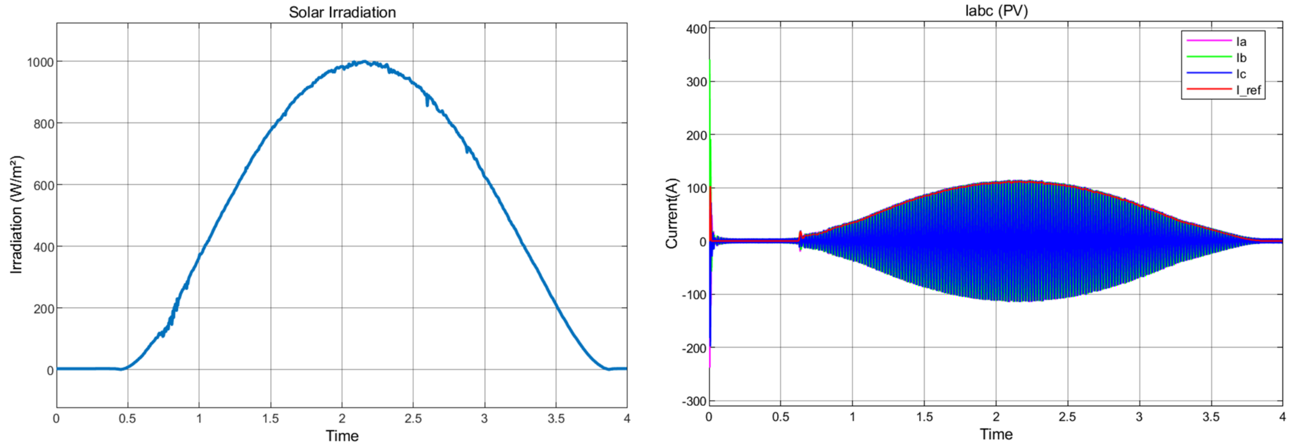
The Gaussian function includes the mean and covariance function as given in equation (3) of the input data. The Input data is given to the Gaussian field, then the function compares with observation data (target data) and reduce the variation in the input values by computing the mean and covariance which is further taken as kennel function by GP for their input data respectively.

3.2. Robust H-infinity Controller

The H-infinity Controller gives Robust Stability and improves good performance by rejecting high disturbance and Uncertainties signals. It has the controlling .1benefit over the traditional Control methods because the H-infinity controller is able to solve the problems involved in multivariate systems [3].

For H-infinity Controller design is carried out by obtaining the State Space model for Solar PV System. Where the state space model is used to define the Controller Plant G. Here the controller Guarantee Stability for the signal from the ML-GPR model predicted values by reducing the possible uncertainty signals as detailed in Section 4. The Parametric uncertainty signal considered in this solar PV system is the Solar Irradiation.

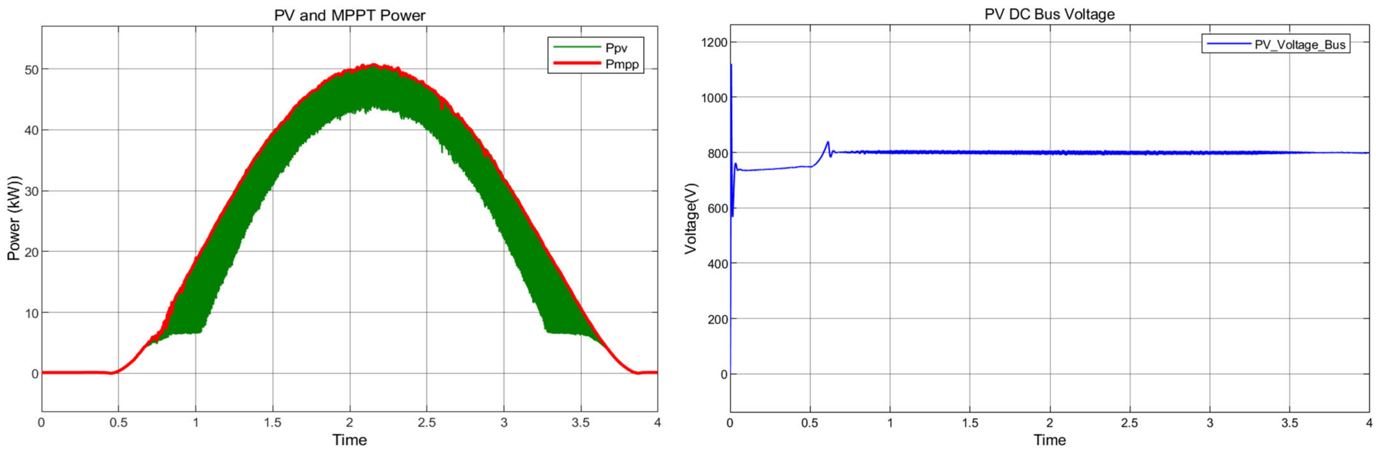
4. Simulation Results



(**a**) (**b**)

Figure 5. (**a**) Solar Irradiation in Watts per unit area (W/m2); (**b**) PV Current (I*abc* and Ref Current).

Figure 5 (a) shows the Solar Irradiation input signal to the Solar PV panel is given of range 1000 Watts per meter square for which the panel generates the Power of 50 kW. The Irradiation signal as shown in Figure 26, includes the variation in the signal for a smaller range. Figure 5 (b) represents the PV Current I*abc* is obtained with the reference current value. This maximum current is obtained for the input solar irradiation signal to the PV panel. It reaches a maximum current value of 120 A at the time period of 2 to 2.5 seconds with similar to the reference current (I_*ref*).



(**a**) (**b**)

Figure 6. (**a**) Solar PV and Maximum Power Point Tracking Power comparison; (**b**) Solar PV DC bus voltage.

The PV Power (P_{pv}) and Maximum Power Point tracking comparison plot are given in which the P_{pv} has the more variation of power but even though it can attain maximum power as shown in Figure 6 (a), the red color line represents the MPPT algorithm and the green line is the PV Power value. In Figure 6 (b) the DC Bus Voltage of the Solar Energy Source is of the range 800 Volts. It could include some undershoot and overshoot at the initial of the DC bus voltage and voltage reach the 800V at the time seconds of 0.8. This signal is also found with some fluctuations which are reduced by the proposed method as shown in Figure 7.

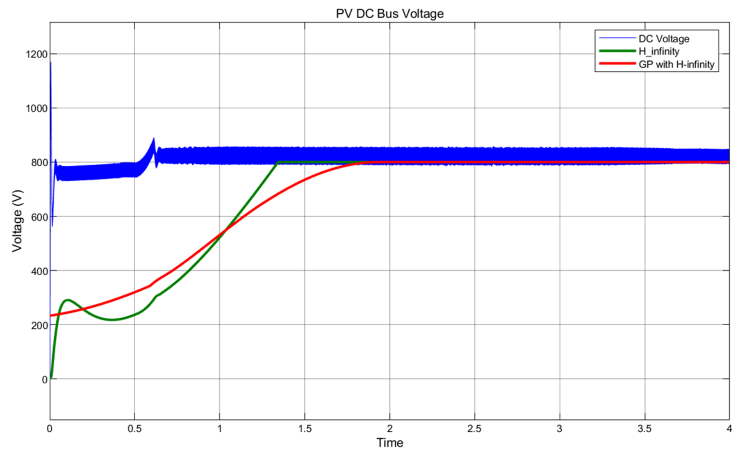


Figure 7. Proposed ML – GPR based Robust H-infinity Controller response.

Figure 7 shows PV DC Bus Voltage and the plot includes the response of H-infinity and GP with H-infinity Controller response. The Initial PV DC Voltage Signal with higher range of Overshoot at the initial stage and the variation in the signal occurs due to the Uncertainty signal given to it. For this Uncertainty Signal H-infinity Controller can able to Control the Uncertainty but it found with the overshoot in the signal at 0.04 time seconds and it also has undershoot at 0.5 seconds, further it attains a stable performance by giving the voltage of 800V at 1.48 seconds. The proposed GP with H-infinity Controller can reduce the undershoot and overshoot which is present in H-infinity Controller response. This Proposed Controller can give Robust stability and improves performance by smoothly converging to the Voltage range of 800V.

5. Conclusions

In this proposed method, a Machine Learning based Robust control algorithm is designed to achieve high performance and Guarantee Stability. The results were verified by using MatLab R19a/Simulink Software. From the results, it is clear that Gaussian Process Regression-based H-infinity Controller can guarantee Robust Stability and improve performance than ideal H-infinity Controller.

Conflicts of Interest: The authors declare no conflict of interest.

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