Grid-Connected Solar Farms with Dynamic Reserve Power Point Tracking

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Keywords: Adaptable Power Regulation, Power System Assistance, Peak Power Output, Uneven Irradiance Distribution, Solar Energy Farm, Available Power Capacity, Sub-Optimal Power Point Management, Artificial Neural Network (ANN).

Abstract: The RPPT methodology permits dynamic Reserve of Power control for grid-connected Solar Farms, assuring the requisite Reserve of Power to sustain the grid and elevated PV power intrusion. Using a voltage controller based on a model and Model Predictive Control (MPC) to control PV voltage and inductor current, the algorithm switches the point of operation between two preset values within the PV curve. The RPPT methodology is tested in settings of partial shade, fluctuating power reference, and steady-state performance. It uses MPP information to control PV reserve power. The algorithm tracks MPP under partial shading, provides grid frequency support, reduces DC-link capacitor stress, and improves system reliability. It operates in MPPT, FPPT, or RPPT modes to maintain desired Power Reserve, offering advantages over traditional methods, enabling flexible power injection and grid frequency support.

1 INTRODUCTION

Reserve Power Point Tracking (RPPT) is introduced as a new algorithm for controlling power output from grid-connected PV systems. Unlike traditional MPPT, RPPT addresses modern grid requirements by providing ancillary services like frequency regulation and stable power injection. Key benefits of RPPT over existing Flexible Power Point Tracking (FPPT) methods:

No additional hardware needed: Avoids costs associated with measurement-based FPPT.

- **Robust without PV models**: Operates effectively without relying on potentially inaccurate models.
- **Handles partial shading**: Effectively tracks the global Maximum Power Point
- (MPP) even with multiple peaks due to shading.
- **Fast dynamic response**: Crucial for grid frequency support.
- **Easily implemented**: Requires no hardware modifications to existing PV inverters.

RPPT's "sweeping" action dynamically switches the PV system's operational point on the PV curve between two voltages, providing continuous MPP tracking, precise power control, and fast dynamic response.

The RPPT algorithm's use of an Artificial Neural Network (ANN) controller is not mentioned in the text. ANNs are not included in the RPPT method that has been explained, but they may be utilized in other areas of PV system control. The use of ANNs to improve RPPT performance may be investigated in future studies. The control diagram for the current RPPT for PV plants is displayed in Figure 1.

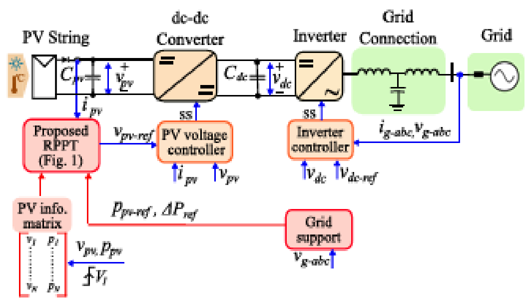

Figure 1: Control Schematic of the PV Plant's Current Rppt.

Ranganayakulu, J. S., Sreeya, Y., Vardhan, B. V., Sowmya, G. and Vinay, T.
Grid-Connected Solar Farms with Dynamic Reserve Power Point Tracking.
DOI: 10.5220/0013880100004919

In *Proceedings of the 1st International Conference on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25 2025) - Volume 2*, pages 202-207
ISBN: 978-989-758-777-1

2 PV SYSTEM CONNECTED TO THE GRID

A PV system connected to the grid with two stages uses the suggested RPPT algorithm. Two power converters are part of this setup:

- Photovoltaic-side DC-DC boost conversion.
- Grid-side three-phase DC-AC converter.
- A DC-link capacitor connecting the converters.

2.1 Grid Support

- The system has a "grid support block" that adjusts the power reference based on grid frequency changes.
- Grid support functions give a power reference to the RPPT algorithm.

2.2 RPPT Algorithm

It establishes the PV array's reference voltage. A voltage controller based on a model is used to regulate this voltage. By controlling the inductor current and DC-DC boost converter switching, Model Predictive Control (MPC) manages the PV output. While keeping the average DC-link voltage constant, the three-phase inverter sends the PV power to the grid. To summarize, the DC-DC boost converter controls the PV output based on the RPPT's voltage reference. In addition to managing the DC link, the inverter supplies electricity to the grid. In figure 2, it is depicted.

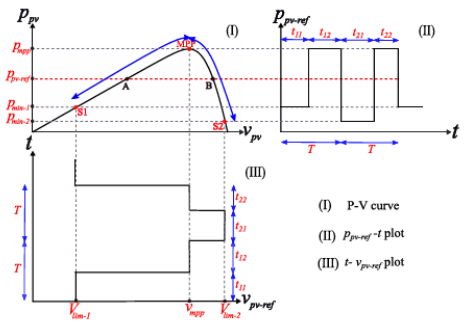

Figure 2: Operating Principle of RPPT.

3 EXISTING METHODOLOGY

Dynamic Reserve Power Point Tracking (DRPPT) is an algorithm that controls the power output of solar panel systems to maintain a desired power reserve. It operates by either following a power reference (Ppv-ref) or targeting a specific percentage of power reserve (%Pref).

3.1 Key Features of DRPPT

- **Regular scanning:** The algorithm scans the power-voltage curve between two voltage limits (Vlim-1 and Vlim-2) to find the Maximum Power Point (MPP), even under changing conditions.
- **Recording data:** During the scan, voltage and power are recorded. The algorithm spends calculated amounts of time at voltage limits and briefly at the MPP using energy balance equations to match the desired average power output.
- **Simplified process:** If the target power is within a specific range, the system only scans between two points, simplifying the process.
- **Handling delays:** The algorithm accounts for small system response delays.
- **Partial shading management:** By including the global MPP in the scanning range, RPPT effectively identifies the highest power point.
- **Grid support:** RPPT can actively control the output power to meet the grid frequency requirements according to the specific grid requirements (such as the South African standard), and thus can contribute to supporting and stabilizing grid frequency.

4 PROPOSED METHODOLOGY

4.1 Artificial Neural Networks (ANNs)

- **Structure**: Inspired by the human brain, consisting of interconnected neurons in layers (input, hidden, output).
- **Learning**: Connections between nodes have weights adjusted during learning, enabling adaptation to new data.

4.2 Algorithm of DRPPT

DRPPT is an advanced technique for controlling power reserves in grid-connected solar farms that also takes energy generation into account. DRPPT general algorithm:

1. **Initialization**
   - Set the desired power reserve level based on grid requirements.
   - Initialize the system parameters, including solar irradiance, temperature, and panel characteristics.
2. **Data Acquisition**
   - Keep an eye on the photovoltaic (PV) system's output voltage (V), current (I), and power (P) at all times.
   - Measure environmental conditions like solar irradiance and temperature.
3. **Maximum Power Point Estimation**
   - with the given conditions, implement an MPPT algorithm (like Perturb and Observe/Incremental Conductance) to determine the PV system's Maximum Power Point (MPP).
4. **Reserve Power Calculation**
   - Determine the reserve power by subtracting the intended power output from the MPP power.
   - Ensure the reserve power meets the grid's requirements for stability and frequency regulation.
5. **Dynamic Adjustment**
   - Maintain the intended power production while saving the calculated power by adjusting the PV system's operating point.
   - When operating below the MPP, employ a flexible power point tracking (FPPT) strategy.

1. **Grid Synchronization**
   - Make sure the power output's voltage, frequency, and phase are all in sync with the grid.
   - For grid compatibility, convert DC power to AC electricity using inverters.
2. **Feedback and Optimization**
   - Continuously monitor the system's performance and environmental conditions.
   - Update the algorithm parameters dynamically to adapt to changing conditions, such as partial shading or grid frequency deviations.
3. **Fault Handling**
   - Detect and isolate faults in the PV system to prevent disruptions.
   - Reconfigure the system to maintain optimal performance.

This algorithm ensures that the PV system can provide a stable power reserve while maximizing energy efficiency.

4.3 Benefits of ANN Controllers

1. **Adaptability**: Learn and adapt to changing conditions.
2. **Non-linearity**: Model complex, non-linear relationships.
3. **Fault Tolerance**: Handle noisy or incomplete data robustly.
4. **Parallel Processing**: Process multiple inputs concurrently for faster computations.
5. **Versatility**: Used in diverse fields like medical sciences, engineering, robotics, finance, and speech recognition.

4.4 Using ANNs in MATLAB

- **Neural Network Toolbox**: Comprehensive toolbox for creating, configuring, training, simulating, and visualizing ANNs.
- **Functions**: Define network parameters, use various training algorithms, predict outputs for new inputs, and evaluate performance.

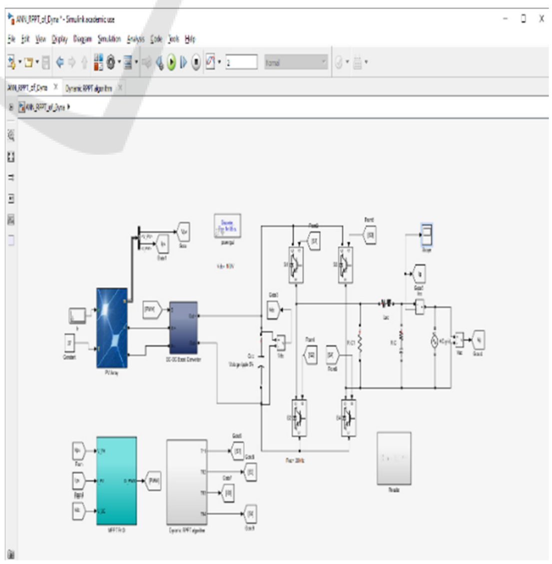

Figure 3: MATLAB Model of DRPPT Using ANN Controllers.

Table 1: Differences Between Existing and Proposed Methodology.

Feature	Existing Methodologies (Measurement/Estimation Based)	Proposed RPPT Methodology	Potential ANN Integration with RPPT
Hardware	Often requires additional sensors/hardware	No additional hardware required	Could potentially reduce sensor needs
Model Dependency	Relies on PV models, susceptible to inaccuracies	Model-free, robust to aging	Could improve model-based estimation if needed
Dynamic Response	Can be slow, especially with sensorless methods	Fast dynamic response	Could enhance prediction and control speed
Partial Shading	Challenges in identifying GMPP	Effectively handles partial shading	Could improve GMPP identification
Implementation	Can be complex	Simple, control-based	Could simplify control logic in complex scenarios

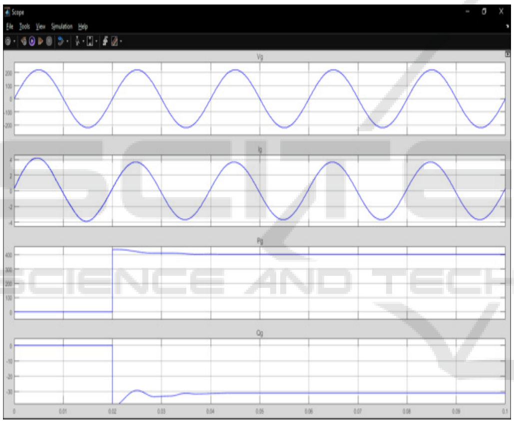

Figure 4: Output Voltage and Current Wave Forms of DRPPT Using ANN Controllers.

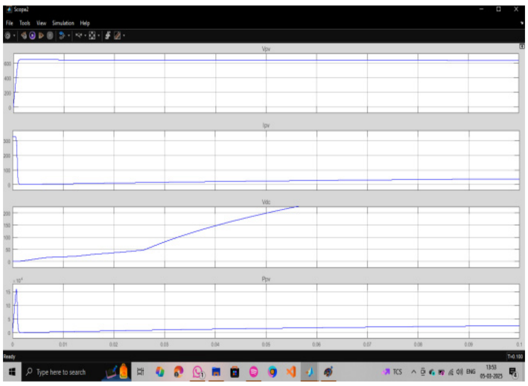

Figure 5: Output Power Wave Forms of DRPPT Using ANN Controllers.

5 OUTPUT WAVE FORM DESCRIPTION

When solar panels generate electricity, they produce direct current (DC), which is like water flowing steadily in one direction through a pipe. However, the electrical grids and most appliances use alternating current (AC), where the flow of electricity alternates direction. To make this transition, the system uses an apparatus known as an inverter. The inverter transforms the converting DC power to AC, creating a waveform that alternates back and forth, similar to the back-and-forth flow of water in a pipe. Table 1 shows the Differences Between Existing and Proposed Methodology.

Initially, the AC waveform created by the inverter might look a bit blocky or choppy, which isn't ideal for the grid. To smooth it out and make it more like the clean sinusoidal waves we want, the system uses special filters. These filters remove any unwanted noise or distortions, leaving behind a nice, smooth wave. This clean waveform can now be sent to the electrical grid or used by appliances. The peak values of output voltage (V_g) waveform are +2.200e+02 and -2. 200e+02.Simillarly the output waveforms current (I_g) are 3.666e+00 and -3.666e+00, active power (P_g) are 4.033e+02 and reactive power (Q_g) are -3.105e+01.

To ensure the generated AC power can merge seamlessly with the grid, the system fine-tunes the waveform. It aligns the wave's rhythm, including its voltage, frequency, and phase, with the grid's standards. This process ensures everything works together smoothly, like synchronized dancers moving in unison. The pv values of the output wave forms are V_{pv}=6.447e+02, Ipv=3.325e+01, Vdc=2.975e+01, Ppv=2.130e+04.

However, solar farms face challenges like sudden changes in sunlight or shifts in grid requirements. Dynamic algorithms like RPPT (Reserve Power Point Tracking) help adjust the waveforms quickly to meet these changing needs. This ensures that the system can maintain steady power output, even under varying conditions, and support the grid efficiently. It's a seamless blend of technology and adaptability to keep the power flowing.

6 SIMULATION RESULTS

Simulation results on a three-phase system also showed the RPPT algorithm's effectiveness at high power levels. The tests covered various conditions, including partial shading, MG predictive capabilities for enhanced Maximum Power Point (MPP) tracking, updated output to maintain grid stability under simulated grid frequency changes, and transient condition tests confirming seamless sequence to Utility Mode. Figure 3 shows the MATLAB model of DRPPT using ANN controllers.

The results presented in figures 4 and 5 suggest that RPPT is suitable for large-scale solar power stations. Artificial Neural Networks (ANNs) to improve the performance of the proposed algorithm, such as enhancing the precision of power tracking, the contribution to the grid, reliability, and optimizing the control.

But while adding ANNs seems like an attractive option, it would also add considerable complexity to the system, so the associated benefits need to be authenticated and weighed against the additional costs and effort required. However, the simulations indicated that ANNs have advantages for large-scale solar plants in particular.

7 CONCLUSIONS

RPPT is a novel design approach for solar power plants that maximizes the capacity it can output and incorporates flexible supply to the grid. It has three modes of operation: maximum power, fixed amount of power, or reserve for grid needs. When some panels are shaded, RPPT has demonstrated its ability to identify the ideal power point. Further integration on this version to include Artificial Neural Network (ANN) can prove beneficial in ensuring accuracy of power tracking, adaptation to changing conditions, noisy data handling and prediction of future power output. But the addition of ANNs to systems would also enhance complexity. RPPT, for now, works well without ANNs simple solutions at their best.

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