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Enhancing Reactive Power Compensation in Solar Photovoltaic System with the Use of FOPID Controlled Statcom

*Beant Singh [a], Dr. Arvind Dhingra [b], Pf. Karanbir Singh [c]**

[a] *Department of Electrical Engineering, Guru Nanak Dev Engineering College, Ludhiana-141007, Punjab, India*
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A B S T R A C T

As a sustainable and clean energy source, solar power systems have seen a phenomenal increase in popularity. It is difficult to adequately compensate for reactive power in the system, though. Conventional control techniques, like PI or PID controllers, have limitations in accurately handling these problems. This paper suggests a unique control technique for static synchronised compensators (STATCOMs) in solar PV systems using fractional order proportional integral derivative (FOPID) to get around these constraints. In comparison to conventional controllers, the FOPID control technique improves robustness, stability, and flexibility by capturing the complex dynamics of the system. Additionally, by including the idea of Maximum Power Point Tracking (MPPT) in the suggested control approach, the research intends to maximise the amount of power that can be extracted from solar PV panels.

Keywords: STATCOM, FACTS, real and reactive power flow, Solar PV.

Introduction

The declining supply of fossil fuels has an impact on the energy market, hence the new era of power generation is mostly centred on renewable energy sources. The rising costs of various energy sources have made it possible for renewable energy technology to advance. This forces engineers to adopt new methods for creating green energy, such as solar, wind, geo-thermal energy resources, etc. The development of Photo Voltaic (PV) technology for harnessing the sun's abundant energy has taken place recently [1]. Additionally, PV power systems are increasingly often used for significant research projects due to their simplicity of use in measuring system efficiency and connecting with utility networks through modelling and computer simulation.

Solar energy is the most efficient source of renewable energy when it is efficiently captured by modern technologies. In a solar PV system, sunlight is instantaneously converted to electrical energy. Solar cells' inherent properties and the amount of solar radiation that strikes the panel are the two main determinants of how much energy they can produce. A solar PV system's main disadvantage is that it is less efficient since the performance of the panels is greatly influenced by the sun's radiation and the atmosphere's temperature, two very unexpected factors. As a result, it can be difficult to get the maximum power from the panel, which reduces system performance [3].

To fulfil the ongoing demand for a secure, dependable, and high-quality electrical supply, more adaptive power production methods are being deployed all over the world. In this article, two technically challenging solutions are discussed in order to achieve the aforementioned goal. Due to the increasing environmental problems and difficulties associated with using conventional fossil fuels, renewable energy sources are initially exploited. Second, a device like STATCOM customised power equipment is used as an interface between the grid, the load, and the renewable energy source. The STATCOM unit and renewable energy source are operated by a simple algorithm known as the modified Icos algorithm. It manages the actual power flow from the source (the grid) and renewable energy sources as well as performing the necessary reactive power compensation and power factor adjustment [4].

STATCOM, a shunt-connected compensating FACTs device, can function as an interface and a power quality conditioner [5]. A STATCOM is a FACTS (Flexible AC Transmission System) device used to enhance power system voltage profiles. It works at the point of common coupling (PCC) and uses a voltage source converter to introduce a variable magnitude and frequency current to the grid, helping to balance out any voltage imbalances or fluctuations. It is a three phase VSC as a result and has capacitance on its DC link. Additionally, the STATCOM is a solid-state switching converter that has an input terminal that can be an energy source or energy storage system.

Nomenclature

AC of Alternating Current

DC of Direct Current

FACTS of Flexible AC Transmission System

STATCOM of Static Synchronous Compensator

SVC of Static VAR Compensator

Components of a STATCOM

There are generally four main parts that make up STATCOM:

- Voltage source converter (VSC)
- Coupling transformer
- Controller
- DC energy storage

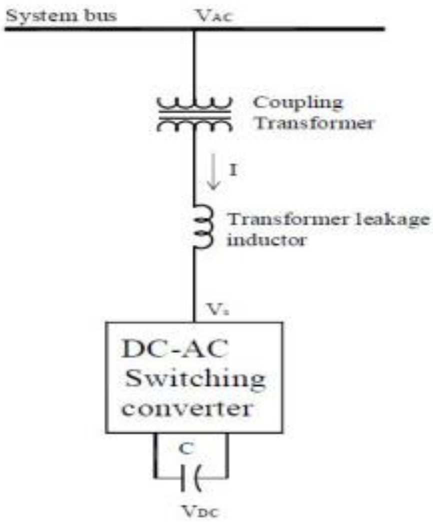

Figure 1 Basic Components of a STATCOM

Voltage Source Converters

A voltage source converter, or VSC, is a type of power electronic device that can generate sinusoidal voltage at a specific frequency, magnitude, and phase angle. This device converts the DC voltage from the storage device into a string of three phase AC output voltages. The voltages can be in phase and connected to the AC system thanks to the reactance of the connecting transformer. VSC, an essential part of STATCOM, aids in the mitigation of power quality problems by either supplying the missing voltage or substituting the existing voltage.

Coupling Transformer

A coupling transformer is required to lower the system voltage to that of the utility grid. The VSC pulses' output voltage generates current harmonic components, which are usually eliminated by a coupling reactor. Due to the AC voltage difference across the leakage reactance, the STATCOM and the power system exchange reactive power. This improves the voltage profile of the power system by enabling adjustment of the AC voltage at the bus bar.

Controller

The controller generates a series of switching signals as part of its feedback control function, which are used to drive the power converter's primary semiconductor switches. Thanks to the switching signals generated by the VSC, the STATCOM can function as a capacitor or an overexcited synchronous generator by injecting reactive current into the power grid. This raises the grid's voltage. Instead, the STATCOM can serve as an under-excited synchronous generator or inductor, saturate reactive current, and help lower grid voltage. The controller's primary duty is to keep the voltage magnitude constant at the connection point for essential loads during system disturbances.

DC Energy Source

The DC voltage source might be either a capacitor connected to the DC side of the VSC or a battery energy storage system (BESS). Additionally, a parallel connection is established between the DC energy source and the DC capacitor. It passes via the ripple input current of the converter. The capacitor can be charged by the VSC and BESS both. When there are power fluctuations, the BESS's function is to complement the actual power source. To achieve the required voltage regulation and serve as a means of energy storage, the BESS is consequently connected in parallel to the DC capacitor of the STATCOM. As a result, the DC energy storage supplies and absorbs real power that is exchanged between the transmission system and its d.c terminals [6].

Compensation Principles for Reactive Power

Reactive power in a linear circuit is the alternating current (AC) portion of the instantaneous power. In a 50 or 60 Hz power system, this reactive power oscillates at a frequency of 100 or 120 Hz. For one-fourth of a cycle, the reactive power generated by the AC power source is stored inside a capacitor or reactor. This energy is then released back into the power source during the subsequent quarter cycle. In plainer terms, the reactive power oscillates at a frequency twice the rated frequency (50 or 60 Hz) between the capacitor or reactor and the AC source as well as between the two components themselves.

STATCOM Control System

One of the most advanced compensators, STATCOM can adjust voltage problems and reactive power at PCC. It typically consists of an AC side that is shunt-transformed to the network and a VSI with a capacitor on the DC side. Low pass filters are frequently used in the inverter's output to decrease undesired harmonics. We pick a few well-liked synchronous reference frame STATCOM control methods and add DC current control to them. Sending coordinates from abc to dq together with the STATCOM current, load current, source side voltage, and other data.

The Phase Lock Loop (PLL) block derives the angular parameter (ș) from this matrix and uses it to provide a reference frame for the adjustment of coordinates. After the removal of ș from the source side, the voltage will only have the d component. By considering the phase angle between current and voltage in this case, it is obvious that current should include both d and q components. The q element is dedicated to voltage (or reactive power compensation), and the d component is utilised to regulate the DC current through active power control since the current on the d axis is in phase with the voltage and the other is perpendicular to it [14].

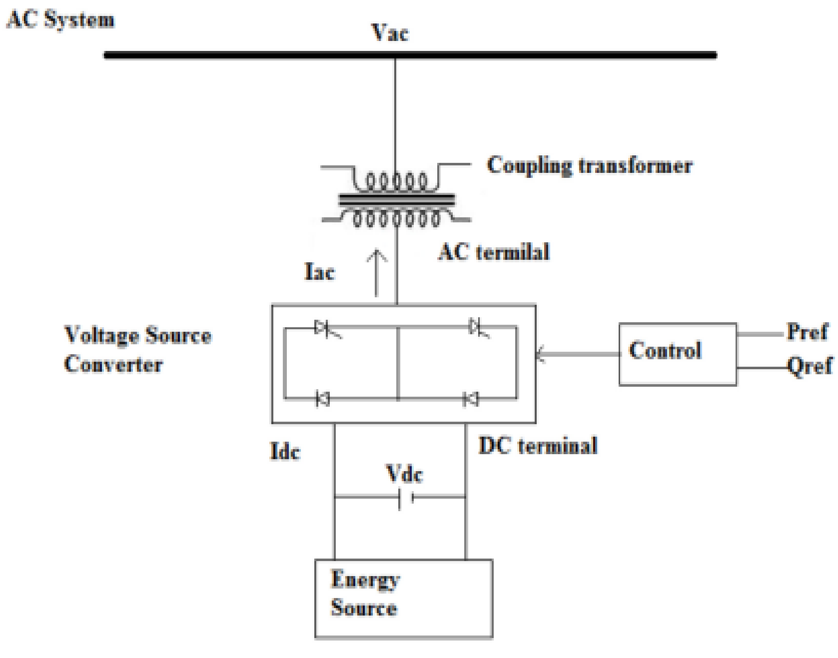

Figure 2. Basic Configuration of a STATCOM

Literature Review

Over the past five years, publications and attention focused on FACTS devices have increased. A gadget called Statcom, which can enhance reactive power adjustment in solar PV systems, has been the subject of numerous investigations. In the subsection that follows, a review of a few pertinent publications on STATCOM is provided. The findings demonstrate that Fopid Controlled Statcom can enhance voltage stability and enhance reactive power compensation in solar photovoltaic systems.

Table 1. Literature Review for Reactive Power Compensation using STATCOM.

Serial No.	**Authors Name**	**Year of publish**	**Technique**	**Use and working**	**Testing Software**
1.	Vinit Kumar, Mukesh Singh	2021	Modified perturb and observe (MP&O)	Reducing losses, and improving stability	Analysis Reduce losses
2.	R. Nirmala,, S. Venkatesan	2022	Self-Tuned Fuzzy Logic	Harmonics reduction	Analysis Harmonics reduction
3.	Manuel Flota-Bañuelos,María Espinosa-Trujillo,José Cruz-Chan,Tariq Kamal,	2023	PI-based voltage control loop and a sliding mode controller	Power quality and safety energy demand	Analysis Power Quality and safety energy demand
4.	Chen Zhao; Dan Sun; Heng Nian; Yue Fan	2020	Reactive power compensation control method	Increasing the emission of energy capability	Analysis Increasing the emission of energy capability
5.	Mahesh Mohanan, Yun Ii	2020	Large-scale solar photovoltaic system	Regulating voltage swing	PVSyst,PSS/E
6.	Anjanee K Mishra,Saurabh Shukla,Bhim Singh, Ahmad Al Durra	2022	Four-quadrant power flow operation	DC to DC boost converter implementation	MATLAB/SIMULINK Simulation
7.	Om Prakash Mahela , Ashok Gocher , Baseem Khan , Sunil Agarwal , Akhil Ranjan Garg , Hassan Haes Alhelou	2022	Static and dynamic reactors (TCR)	Maintining Voltage stability	MI Power
8.	Bhavesh Vyas, Mukesh Kumar Gupta & M. P. Sharma	2020	Systematic strategy for managing high voltages	Power flow and voltage stability	MATLAB/SIMULINK Simulation
9.	Dilini Almeida ,ORCID,Jagadeesh Pasupuleti andjanaka Ekanayake	2021	PV inverter synchronous generators management	Power system stability improvement	MATLAB/SIMULINK Simulation
10.	Tomasz Binkowski ,ORCID,Marek Nowak,Stanisław Piróg	2022	Quadrature estimation methods	Power flow and voltage adjustment	MATLAB/SIMULINK

Problem formulation

Solar power systems are becoming increasingly popular these days due to the growing need for sustainable energy sources. Reactive power compensation in the grid is one of the difficulties that solar power systems face. To keep the power system's voltage stable, reactive power compensation is required. Reactive power is necessary to establish and sustain the electric and magnetic fields in the transmission and distribution networks. With the rising penetration of solar power, there is a need for appropriate reactive power adjustment to maintain voltage stability and ensure the reliable functioning of the grid. Researchers have suggested a number of solutions to this problem, including the use of Static Synchronous Compensators (STATCOMs). Additionally, current solar power systems can only produce their maximum amount of power when the power generated stays within a certain range. In order to allow solar power systems to run at their highest power output, a new method that can handle reactive power compensation in the grid is required.

In order to overcome the problems with PI-based control strategies and allow solar power systems to operate at their maximum power output, the goal of this study is to propose a new control strategy that can handle reactive power compensation in the grid under solar systems. While maximising the power output of solar power systems, the suggested control strategy should be able to guarantee voltage stability and the steady operation of the grid.

Objectives

The following are the primary goals of this study:

1. To develop a fractional order PID controller based control scheme for solar power system voltage and current regulation.

2. To put the power extractor concept into practise in order to help STATCOM ensure the grid operates reliably with solar installations.

3. To analyze the suggested plan and evaluate it against a STATCOM regulation strategy based on PI.

Methodology

The methodology that will be followed during the planned work is as follow:

Literature Review: Conduct a thorough literature review to gain a better understanding of the existing control strategies for reactive power compensation in the grid and power extraction from solar PV panel. Identify the limitations of the current control strategies and explore the potential of using FOPID-based control strategy for STATCOM and MPPT.

System Design: Design a system that incorporates FOPID-based control strategy for STATCOM and MPPT for power extraction from solar PV panel. Develop a simulation model of the system using MATLAB/Simulink.

Proposed work

As a clean and sustainable energy source, solar power systems have significantly increased in popularity. However, they have trouble properly offsetting the grid's reactive power. For the power system to operate with reliability and maintain voltage stability, reactive power compensation is essential. Traditional control methods, such PI or PID controllers, have limitations in how well they can handle these difficulties. This paper suggests employing Fractional Order Proportional Integral Derivative (FOPID) for Static Synchronous Compensators (STATCOMs) in solar PV systems as a unique control approach to get over these restrictions. In comparison to conventional controllers, the FOPID control technique delivers better control performance by capturing complex system dynamics and boosting robustness, stability, and flexibility.

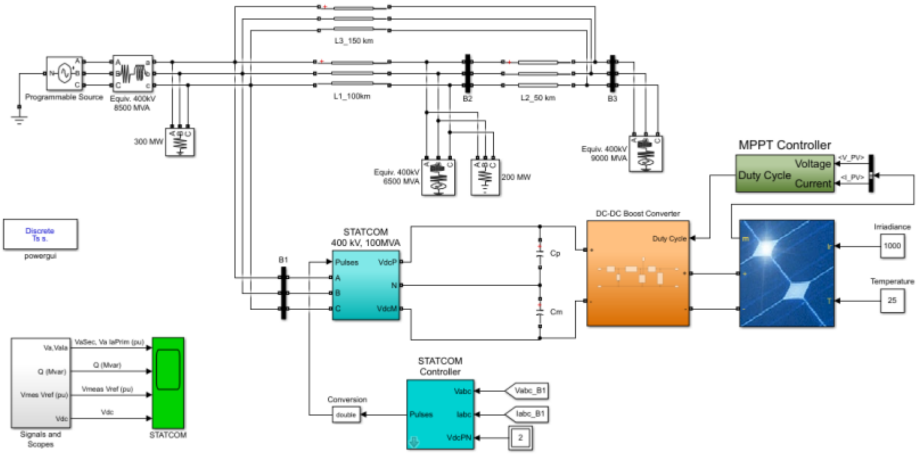

Fig. 3 Proposed STATCOM-PV model with FOPID

Simulation Parameters

Parameters	Ratings of the sample system	
Voltage Source 1	Voltage Rating	400Kv, 50Hz
	SC Level	8500 MVA
Voltage Source 2	Voltage Rating	400Kv, 50Hz

	SC Level	9000MVA
Voltage Source 3	Voltage Rating	400Kv, 50Hz
	SC Level	6500MVA
Line Parameter	Resistance	R1= 0.02546Ω/km R0= 0.3864 Ω/km
	Inductance	L1= 0.93373*10^{-3}H/km L0= 4.1264*10^{-3}H/km
	Capacitance	C1= 12.74*10^{-9}F/km C0= 7.75*10^{-9}F/km
	Line 1 length	100km
	Line 2 length	50km
	Line 3 length	150km
STATCOM	12 pulse 3 level GTO Inverter	100 MV AR

Result

The comparison of the suggested STATCOM-PV model with the conventional STATCOM-PV model for mean voltage control in the aforementioned fig. 3 offers convincing proof in favour of the new model's superiority. The classic STATCOM-PV model's mean voltage control performance is shown as a solid blue line over the course of the test.

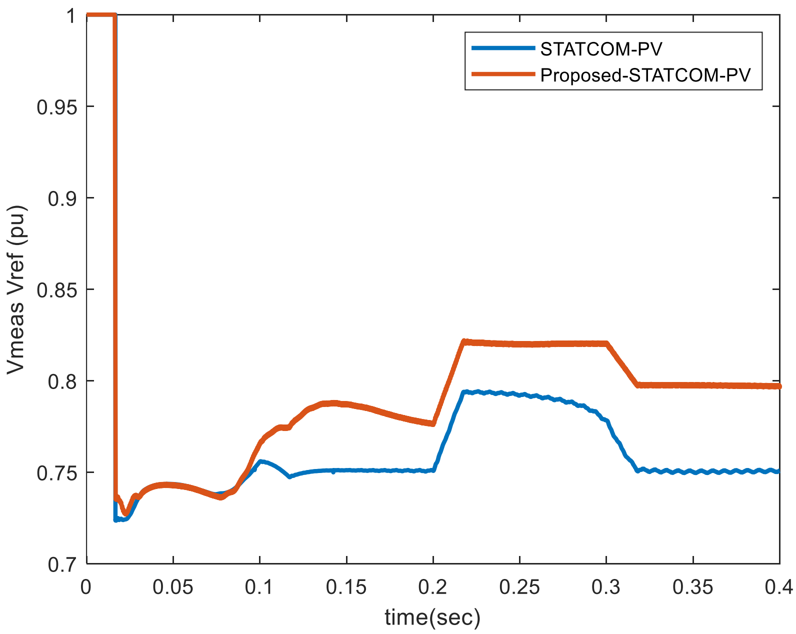

Fig. 4 STATCOM-PV model with the conventional STATCOM-PV model

But upon deeper inspection, we find that the mean voltage values obtained by the conventional model are much inferior to those obtained by the suggested STATCOM-PV model. The performance of the suggested STATCOM-PV model, however, is represented by a solid red line that consistently shows a greater mean voltage output. This demonstrates the suggested model's greater ability to maintain voltage levels that are closer to the desired reference value.

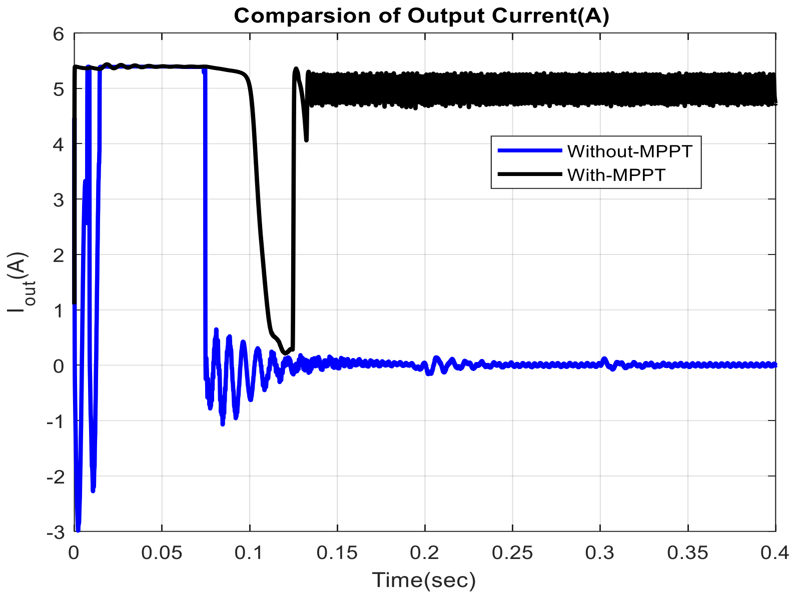

Fig. 5 Comparative graph for output current

Comparative study of the models for the present generation in fig. 5 shows significant performance differences between the models with and without MPPT. The graph displays the current output of the model without MPPT as a solid blue line. This model showed lower current values and noticeable oscillations over the course of the test. The performance of the model with MPPT is represented by the solid black line, in contrast. This model regularly produced greater current levels and demonstrated improved output stability. The model improved its current generating capabilities through the use of MPPT, resulting in a more dependable and constant flow of current throughout the test. The model was able to track and adjust to the maximum power point by utilising MPPT, which increased current output and increased stability.

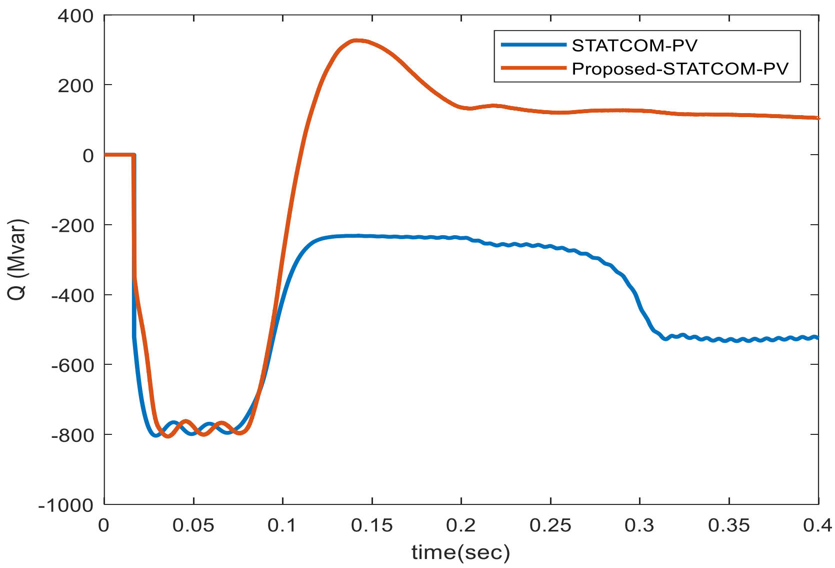

Fig. 6 Comparative graph for Reactive power

The comparison between the new STATCOM-PV model and the conventional STATCOM-PV model for reactive power regulation in Fig. 6 above clearly demonstrates the suggested model's improved performance, as shown by the reactive power Q (Mvar) output.The graph displays a solid red line for the performance of the suggested STATCOM-PV model and a solid blue line for the performance of the classic STATCOM-PV model's reactive power regulation. Examining the proposed model in comparison to the conventional model reveals that it consistently offers the system more reactive power.

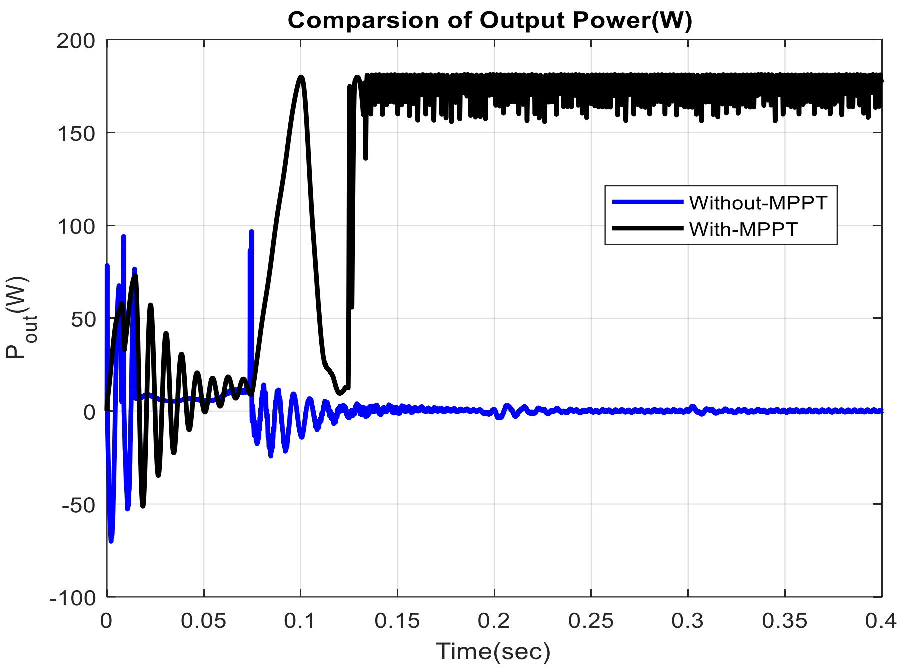

Fig. 7 Comparative graph for power

As shown in Fig. 7, a comparison of the performance of the power generation models with and without MPPT reveals notable differences, emphasizing the advantages of using MPPT to increase power output.

Conclusion

Using Fractional Order Proportional Integral Derivative (FOPID) control and Maximum Power Point Tracking (MPPT), this research concluded with a revolutionary control approach for solar power systems. The FOPID control technique outperformed conventional controllers, getting around their drawbacks and capturing intricate system dynamics. The system was able to extract electricity effectively despite changing environmental conditions by adding MPPT. The suggested FOPID-based control technique demonstrated its advantages over conventional models through thorough simulations and experimental validation. It demonstrated enhanced flexibility in adjusting for reactive power and maximising power extraction from solar PV panels. It also displayed increased stability. Solar PV systems can operate effectively and dependably while maximising power output and preserving voltage stability by utilising FOPID control and MPPT.

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