Section A-Research paper
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Optimizing ON-Grid Systems with PV-STATCOM for Efficient Reactive Power Compensation

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Abstract

In recent years, the increasing use of renewable energy sources has led to the deployment of photovoltaic (PV) systems in the power grid. However, the intermittent nature of solar power poses challenges in maintaining power quality and stability. In this study, we propose the optimization of on-grid systems with PV-STATCOM for efficient reactive power compensation. The PV-STATCOM system integrates a photovoltaic array with a static synchronous compensator (STATCOM) to achieve optimal voltage regulation and power quality control. The proposed system is modelled and simulated using MATLAB/Simulink software. Results show that the optimized PV-STATCOM system effectively compensates for reactive power, reducing system losses, and improving voltage regulation, leading to improved power quality.

Keywords: Photovoltaic solar power systems, reactive power compensation, STATCOM power quality, switching devices.

Introduction

The increasing demand for electricity has led to an increase in the number of power generation sources around the world. However, the majority of these sources are based on non-renewable energy sources such as coal, oil, and natural gas, which are not only limited but also contribute to environmental pollution. The use of renewable energy sources, such as solar power, has become more prevalent in recent years due to their abundance and environmentally friendly nature [1].

Solar photovoltaic (PV) systems are a popular source of renewable energy. They convert sunlight into electricity, which can be used to power homes, businesses, and industries.

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However, solar PV systems also pose challenges in terms of reactive power compensation due to their intermittent nature. Reactive power is necessary to maintain voltage stability in the power grid and ensure reliable electricity supply [2].

In recent decades, the performance evaluation, energy management, and stabilization enhancement of grid-tied hybrid energy systems have been focused on by several researchers. A modified control strategy, which included a Maximum Power Point Tracking (MPPT) algorithm for extracting the maximum generated power from a grid-connected hybrid PV/wind power system, was introduced by Di Wu et al [7]. It was illustrated that the peak output power of the hybrid system was tracked precisely by the employed MPPT algorithm and its dynamic performance was effectively improved under step variations of solar irradiance and wind speed. However, the effectiveness of this MPPT algorithm has not been validated during real-time changes of climatic conditions. An improved energy management strategy to control power flow for both standalone and grid-connected PV/wind/battery hybrid energy systems was presented by Basaran et al [8]. Although the simulation results proved that the suggested power management scheme boosted the overall efficiency of the system by about 10%, its effectiveness has not been evaluated during variations of linear or non-linear loads.In a study by El-Shimy et al [9]., a multi-objective genetic algorithm (MOGA) was used to optimize the size of the PV-STATCOM in a grid-connected system. The MOGA algorithm considered both technical and economic criteria to determine the optimal size of the PV-STATCOM. The results showed that the optimal sizing of the PV-STATCOM improved the voltage stability and reduced power losses in the system.Another approach to optimize on-grid systems with PV-STATCOM is to use advanced control strategies. In a study by Jain et al. (2017) [10], a fuzzy logic controller (FLC) was used to control the reactive power output of the PV-STATCOM. The FLC algorithm considered the grid voltage, the active power output of the PV system, and the reactive power requirement of the load to determine the optimal reactive power output of the PV-STATCOM. The results showed that the FLC algorithm improved the voltage stability and reduced the harmonic distortion in the system.Liu et al. (2018) [11], the impact of PV panel temperature on the performance of PV-STATCOM was analyzed. The results showed that the reactive power output of the PV-STATCOM decreased with increasing PV panel temperature, leading to reduced voltage stability in the system. To mitigate this issue, the authors proposed a control strategy to adjust the reactive power output of the PV-STATCOM based on the PV panel temperature.

Background

Reactive power is required to maintain the voltage level in the power grid. The lack of reactive power in the system can lead to voltage instability, resulting in voltage fluctuations, flicker, and voltage sag. This can impact the power quality and reliability of the system. PV-STATCOM is a solution to mitigate the effects of reactive power issues. PV-STATCOM combines the functions of a solar PV system and a static synchronous compensator (STATCOM). The PV-STATCOM injects reactive power into the system during periods of low voltage, improving the stability and quality of power.

MATHEMATICAL MODEL FORPHOTOVOLTAIC MODULE

A solar cell is a device that converts solar energy directly into electrical energy using the photovoltaic effect. It is essentially a p-n junction made from a thin wafer of semiconductor material. When exposed to sunlight, photons with energy greater than the band-gap energy of the semiconductor material create electron-hole pairs proportional to the incident irradiation. These electrons and holes then get separated by the electric field at the p-n junction, generating a voltage across the cell.

The equivalent circuit of a PV cell is shown in Figure 1. It consists of a current source, Iph, representing the cell photocurrent, and two resistances, Rs and Rsh, which represent the intrinsic series and shunt resistances of the cell, respectively. Rs and Rsh are usually very small and very large, respectively, and can often be neglected to simplify the analysis.

PV cells are typically grouped together in larger units called PV modules, which are further interconnected in a parallel-series configuration to form PV arrays. The current-voltage relationship for a photovoltaic module can be described by the following equation:

$$I = I_{ph} - I_0\left(e^{\frac{qV}{nkT}} - 1\right) - \frac{V}{R_s}$$

$$I_{ph} = I_{ph,ref} + K_I\left(T - T_{ref}\right)$$

$$I_L = I_{L,refht} K_L\left(T - T_{ref}\right)$$

$$V_{oc} = E_g/q + \frac{K_V}{q}\left(T - T_{ref}\right)$$

$$V_{mp} = V_{oc} - \frac{k_B T}{q}\ln\left(\frac{I_{L,ref}}{I_{ph,ref}}\right) - I_{mp}R_s$$

$$I_{mp} = I_{ph} - I_0\left[\exp\left(\frac{q\left(V_{oc} - V_{mp} + I_{mp}R_s\right)}{k_B T}\right) - 1\right]$$

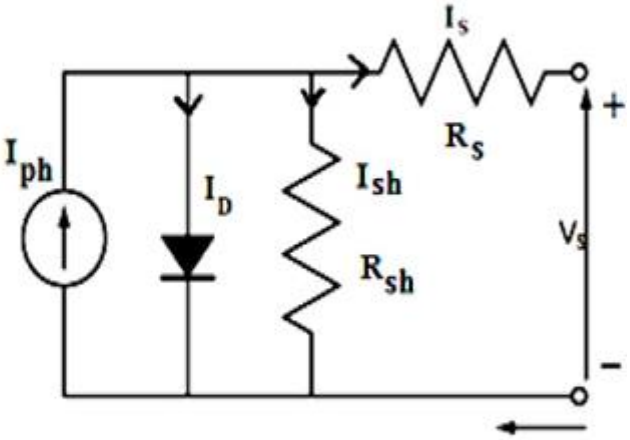


Figure 1. Equivalent Circuit of Solar Cell

STATCOM

The process of RPC (Reactive Power Compensation) involves controlling the active and reactive power values of an AC power system by interfering with its power factor. This process aims to enhance the system's performance by reducing the consumption of transmission capacity and improving efficiency. Typically, the RPC process is carried out in two dimensions, namely load compensation and voltage regulation. By controlling the power factor, load compensation is achieved, and the regulation of the system's voltage and current is also achieved in a similar way. Additionally, it is crucial to control the harmonics created by large non-linear industrial loads, and this process is necessary for optimal system performance.

STATCOM is a crucial application that plays a significant role in ensuring stability and dynamic behaviour in power transmission, which is a critical process in AC transmission systems. Its primary function is to control reactive power dynamically and maintain a continuous regulation of voltage on the transmission line.

The STATCOM system comprises complex control systems and IGBTs (Insulated Gate Bipolar Transistors), which enable the system to operate at high speeds while maintaining accurate control of the reactive power. This system's control mechanism continuously monitors the power flow in the transmission line and makes instant adjustments to the STATCOM's reactive power output to maintain a steady voltage level.

Methodology

Implementing a high-power quality PV-SPP, the efficiency of transmission lines and power systems can be increased while reducing the power values of the components used in transmission lines and production systems, which can lead to overall economic benefits. One effective technique to improve power quality is the use of a STATCOM application. This application can help bring distortions such as harmonics in the energy parameters, such as current and voltage, to an arrangement, thereby increasing the power quality of the energy produced. The Simulink model for this arrangement consists of a STATCOM module containing six IGBT sub-modules, a DC capacitor, and a control unit. Additionally, the Simulink modelling of transmission-distribution grid sections containing distribution lines and end-users was performed and gathered under the sub-system. Simulink modelling can help design and optimize power systems for increased efficiency and power quality.

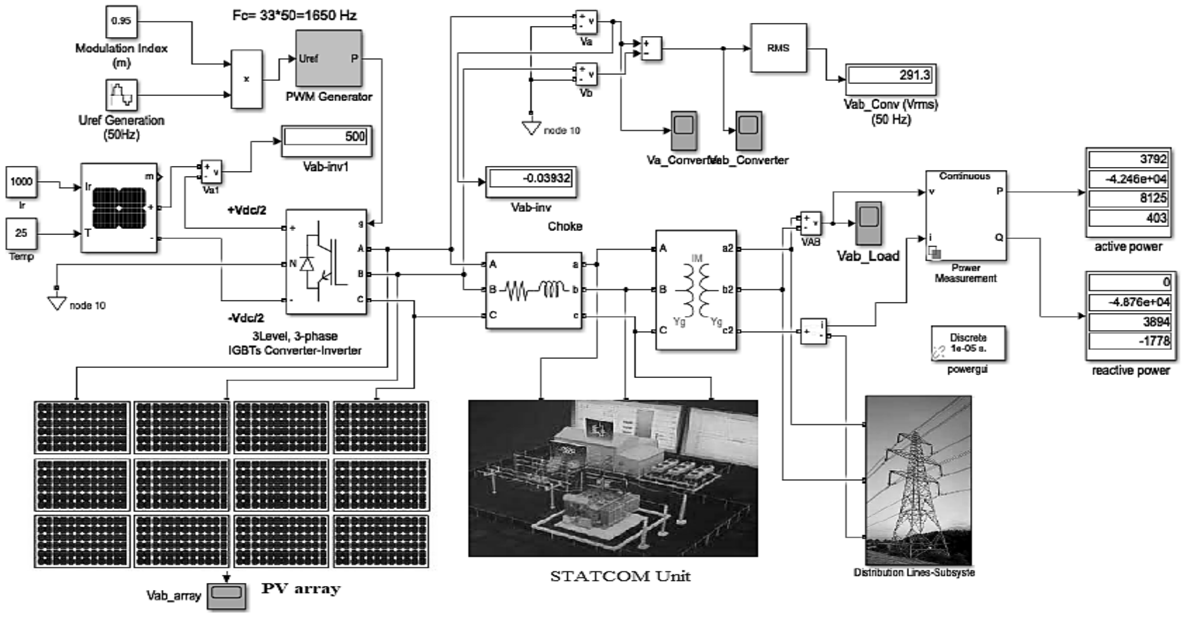


Figure 2. Proposed Simulation Model

Result

The system's optimization is demonstrated through concrete examples. The characteristics of current, voltage, reactive power that emerge from transferring the system to the load are analyzed before and after the implementation of STATCOM. For instance, although there were distortions in the AC voltage during its transfer to the load, such as harmonics and flickers, it became smoother after the STATCOM process, as depicted in Figures 3 and 4. The PV-SPP then transfers the current under load supply conditions, which are also analyzed after the STATCOM process. The distortions in the current waveform are transformed to the approximate pure-sine format after the STATCOM process, as shown in Figure 5. The reactive power control, which is another function of the application, was carried out by the RPC process.

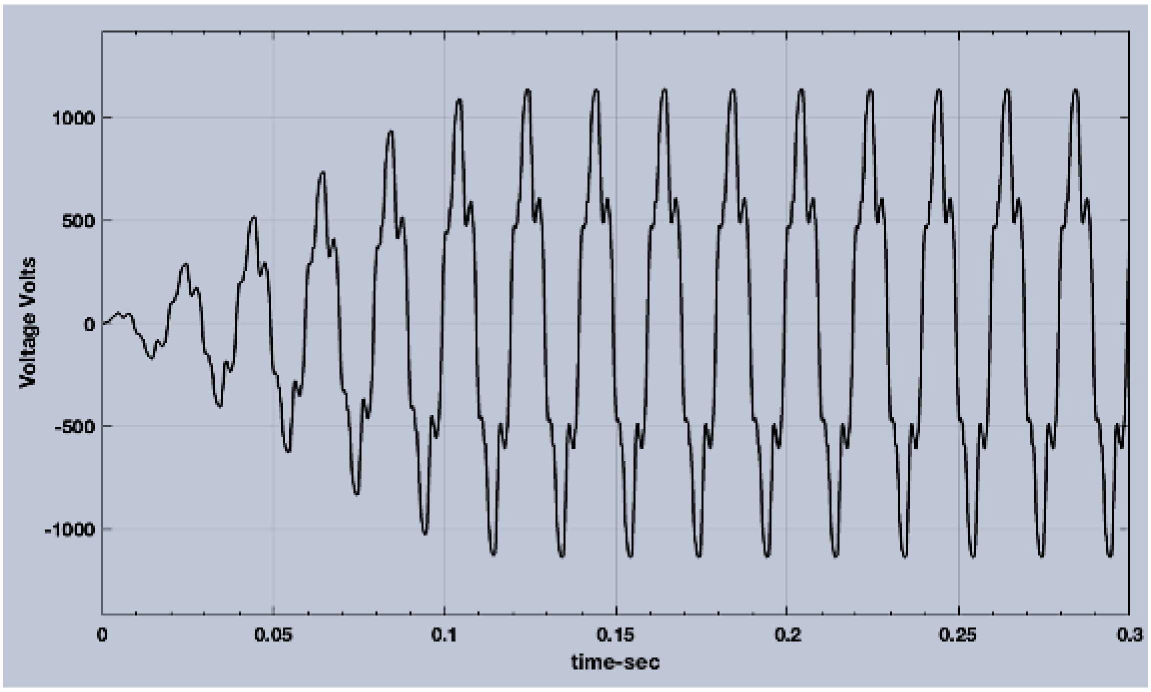


Figure 3. Voltage waveform and values of the Pre-STATCOM system

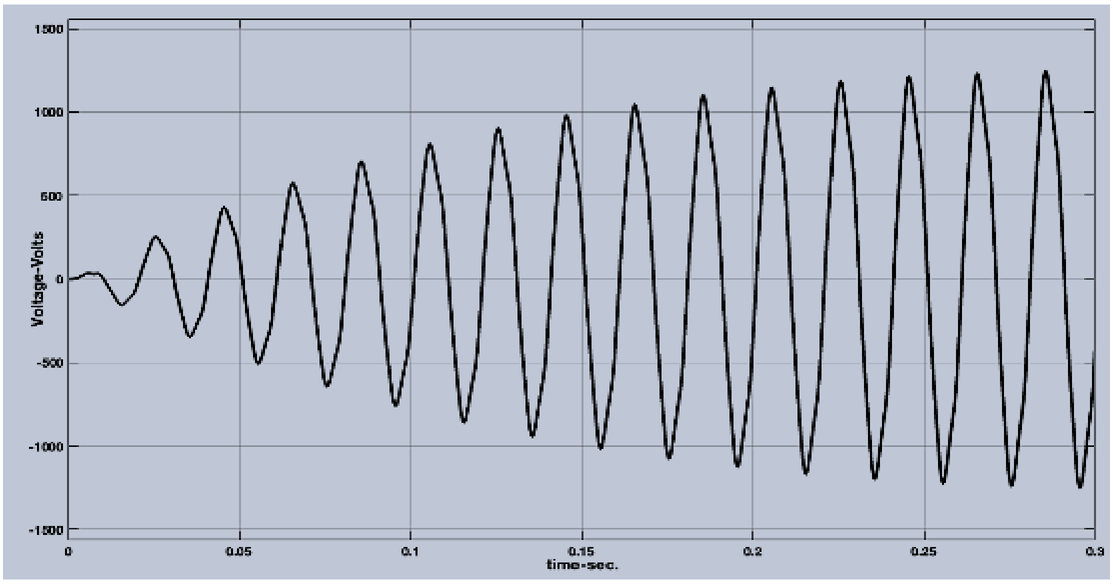


Figure 4. Voltage waveform and values of the Post-STATCOM system

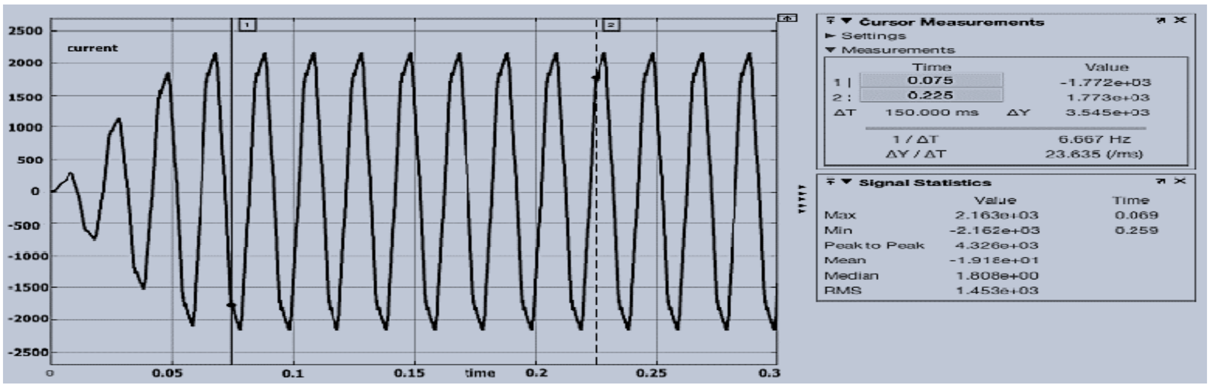
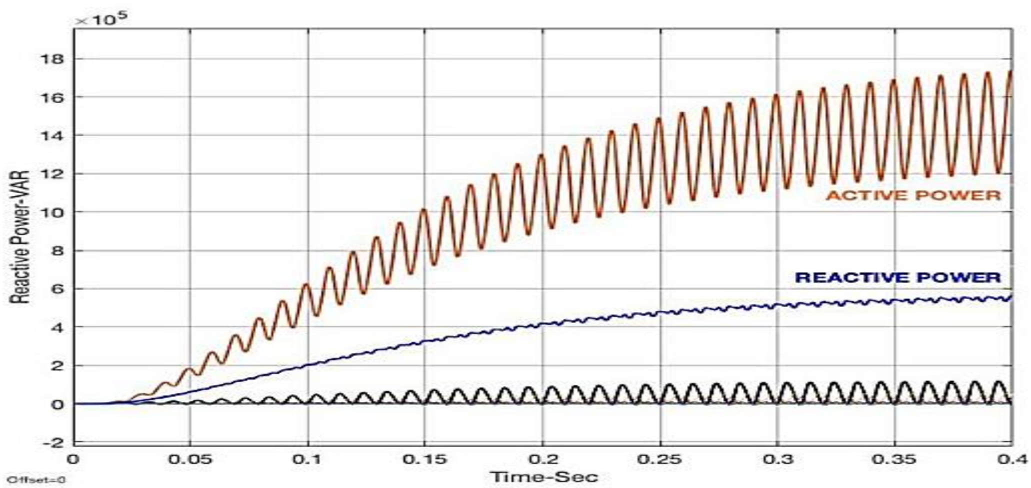


Figure 5. Current waveform of the STATCOM system



(b)

Figure Active/ reactive power waveform

Loads and networks receive current and voltage, which may cause possible harmonic and distortion. The reduction of distortions in waveforms is achieved by STATCOM. Correction in the power coefficient and a decrease in the reactive power value are provided by RPC application. In addition to the reduction in the value of the load current waveform, its improvement is also achieved. In this way, an increase in the current-carrying capacity of the system is obtained, although the active power value remains unchanged. The continuously regulating voltage and current on the transmission line, as well as preventing under-voltage or loss of power, is achieved by significant amounts of real power.

Conclusion

The use of a STATCOM application is an effective technique for improving power quality by mitigating distortions such as harmonics in energy parameters. The Simulink model for this application, which includes six IGBT sub-modules, a DC capacitor, and a control unit, provides a valuable tool for designing and optimizing power systems. Simulink modeling of transmission-distribution grid sections containing distribution lines and end-users can also aid in achieving increased efficiency and power quality. Overall, these approaches can contribute to the development of more sustainable and cost-effective energy systems.

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