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Article

Modelling and design of HCUPQC PI Control For Power Distribution Grid

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Abstract: Modern power distribution grids face various challenges, such as voltage sags, swells, current harmonics, and unbalanced loads. These power quality issues adversely impact sensitive loads and grid reliability. The HCUPQC, an advanced power quality improvement device, combines the capabilities of series and shunt active filters to address these challenges. PI controllers are widely utilized for their simplicity and effectiveness in regulating voltage and current. By designing an optimized PI control strategy for HCUPQC, the system can provide enhanced dynamic response and accurate compensation of power quality disturbances. This paper proposes the design and implementation of a hybrid-connected Unified Power Quality Conditioner (UPQC) utilizing a Proportional-Integral (PI) controller for enhanced performance. The UPQC effectively mitigates power quality disturbances such as voltage sags/swells, harmonics, and flicker, ensuring stable and efficient grid operation. The hybrid topology combines series and parallel compensation modes, with the PI controller providing robust dynamic response and ease of implementation. Simulation results validate the proposed system's effectiveness in addressing power quality issues in diverse operational scenarios.
Keywords: HCUPQC, PI controller, Distribution Grid, Power quality

1. Introduction

The proliferation of renewable energy systems (RES) in power distribution grids has introduced new challenges, including harmonic distortions, voltage fluctuations, and unbalanced loads [1]. The Unified Power Quality Conditioner (UPQC), a combination of series and shunt active power filters, offers a comprehensive solution to these problems. Incorporating a hybrid connection topology into UPQC systems enhances its capability to interface RES with distribution grids. In this context, PI controllers are widely recognized for their simplicity and effectiveness in maintaining stable grid operation. This study focuses on the design of a hybrid-connected UPQC with a PI control strategy for improved power quality in distribution grids [2]. The Microgrid (MG) forms a localized electrical network, which consists of interconnected loads, communication systems, and distributed energy sources (DES). This grid can be standalone or in the network. The efficiency and reliability of the system increase with the grid connection of the microgrid. In rural electrification system, the standalone microgrid has many advantages [3]. At present, as the performance of electronic equipment increases, the integration of micro-sources and DC loads can be achieved better in microgrid design. The system is

also more efficient in transmitting DC power in the absence of skin effect and reactive power [4]. The microgrids use the static power converter between the loads and micro sources as the power interface. These converters' output voltage is important for the microgrid for various purposes. The voltage of the converter is controlled with two methods: i) Proportional integral voltage controller (PIVC); ii) Hysteresis current controller (HCC). The first method increases the system reliability without the need of communication and in the second method among the converters proper communication is required in terms of PIVC technique, the output voltage of the converter is determined with the help of each source connected. The proposed method improves the voltage controller and comparative analysis of PI and HCC [5]. In literature, it is understood that linear controllers are less robust against the disturbance, therefore a non-linear controller is considered for better performance and regulation The main purpose of this research is to reduce electrical fluctuation, power loss, and manage the power quality. The proposed method efficiently integrates the two models such as an adaptive proportional integral voltage controller (APIVC) and hysteresis current controller (HCC).

2. Related Work

Hossain, E., et.al.[1] This paper discusses the power quality issues for distributed generation systems based on renewable energy sources, such as solar and wind energy. A thorough discussion about the power quality issues is conducted here. This paper starts with the power quality issues, followed by discussions of basic standards. Gali, V., et.al., [2] The electrical power system polluted because of non- linear loads used in the system. Utilities always looking for cost effective and improved power quality (PQ) solutions. Initially, the conventional method of passive filtering enrich to mitigate the PQ problems Devassy, S., et.al.[3] This paper deals with the design and performance analysis of a three-phase single stage solar photovoltaic integrated unified power quality conditioner (PV-UPQC). The PV-UPQC consists of a shunt and series-connected voltage compensators connected back-to-back with common dc-link. Krishna, V. K., et.al. [4] The paper presents about the development and control of fuel cell based shunt active power filter. To compensate the shunt active power filter utilized the 3 phase harmonics filter. The SRF based control technique has been applied for the production of reference current for this system. Mishra, A. K., et.al.[5] This paper presents a Hybrid Shunt Active Power Filter (HSAPF) optimized by hybrid Particle Swarm Optimization-Grey Wolf Optimization (PSO-GWO) and Fractional Order Proportional Integral- Derivative Controller (FOPIDC) for reactive power and harmonic compensation under balance and unbalance loading conditions. Maity, A. K., et.al., [6] The Unified Power Quality Conditioner (UPQC) is used to mitigate power quality disturbances that may arise in power distribution network. It compensates voltage or current harmonics and other disturbances that may arise due to nonlinear load and provides reliable power to the load.

Kisck, D. O., et.al., [7] The paper deals with an optimized Unified Power Quality Conditioner (UPQC), which aims at the integration of series and shunt active power filters with minimum VA loading of the UPQC. The series active filter is a Dynamic Voltage Restorer (DVR), that operates in two functioning modes.Gohil, S. N., et.al., [8] This paper presents the simulation of the unified power quality conditioner (UPQC) to mitigate voltage harmonics, voltage sag, voltage swell & current harmonics. The UPQC consists of series and shunt active power filter (APF), which are connected in cascade via a common dc-link capacitor. Patnaik, N., et.al., [9] This paper exhibits a relative investigation of different governing methods on a shunt active power filter for

harmonics and VAR compensation for a balanced three phase system connected to a composite load. Karthik, M. V., et. Al., [10] This examination depends on a three-phase unified control quality conditioner (UPQC) to extend control quality in a three-phase distribution framework. It is nice for day- to-day trade and domestic sectors. Researchers have endeavored and executed different advantageous advances to induce freed of both voltage and current consonant issues, making strides the quality of control given by the control framework.

3. Methodology

The design of a hybrid-connected Unified Power Quality Conditioner (UPQC) incorporating Proportional-Integral (PI) control is a prominent solution to enhance the power quality in distribution grids. This system primarily addresses voltage sags/swells, harmonics, and other disturbances, especially in networks integrating renewable energy sources. The hybrid topology typically combines series and parallel configurations with advanced control strategies to achieve high performance., the dc-dc converter is responsible for connecting different DGs with wide voltage range to the common dc bus of the HCUPQC-DG. However, it should be noted that, there is no need to use the dc-dc converter in all cases, especially for voltage compensation. For instance, during shallow voltage sags, the dc voltage of DG is capable to generate a relatively small ac voltage, without using the dc-dc converter. This means, in this case, the series converter can work well under a low dc voltage with direct configuration, and hence the power conversion stage and power losses can be reduced. This implies that, if one combines the direct and indirect configuration and rebuilds a new hybrid configuration, it is possible to take advantage of each one. Inspired by this idea, a hybrid connected HCUPQC-DG is proposed, as shown in Fig

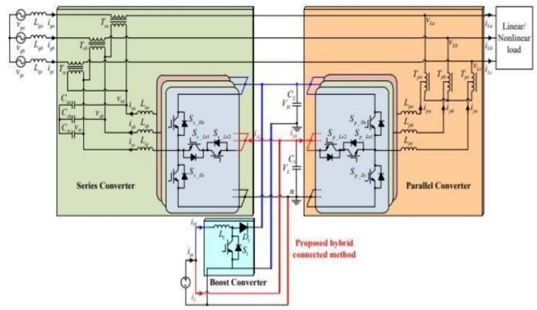


Figure 1: Typical topolgy of the praposed HCUPQC

-DG

1.1 Modelling of HCUPQC

System Equations

The HCUPQC system is modeled using the following dynamic equations for the SAF and SEAF:

3.1 Shunt Filter Model:

$$i_L(t) = i_s(t) + i_{SAF}(t)$$ ……………………(1)

$v_s(t) + v_{SEAF}(t) = v_L(t)$Series Filter Model:………………….. (2)

1.2 Design of PI Controller

The PI controller is designed to regulate the reference signals for the HC-UPQC components. It ensures accurate tracking of reference values and minimizes steady-state errors.

$u_{sh}(t) = K_p \cdot e(t) + K_i \int e(t)dt$**Shunt Filter PI Control:** To regulate the DC-link voltage and inject compensating currents to the grid

……………. (3) **Series Filter PI Control:** To maintain a sinusoidal load voltage and mitigate voltage disturbances.

$$u_{se}(t) = K_p \cdot e(t) + K_i \int e(t)dt$$ ………………(4)

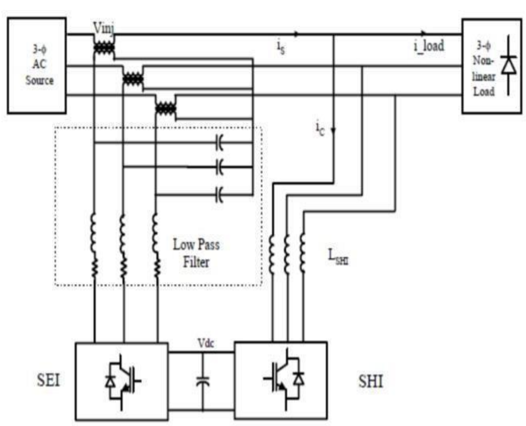


Figure 2: HCUPQC Topology and Power Flow Strategy

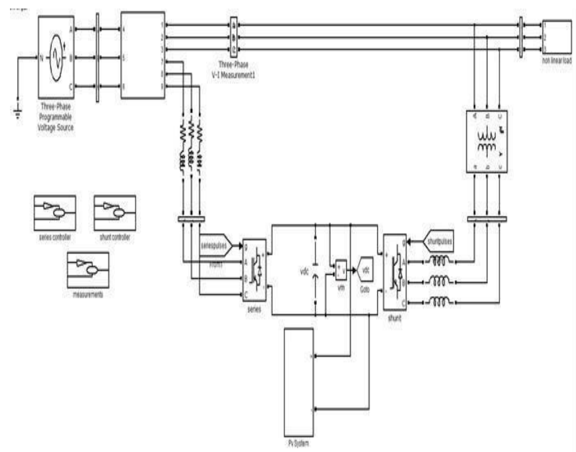


Figure 3: DG based Two model HCUPQC with PI

4. Results and discussions

The MATLAB/Simulink simulation demonstrates the hybrid UPQC’s capability to enhance power quality. The PI controller ensures effective compensation of voltage sags/swells and harmonic distortions, maintaining grid stability even under fluctuating conditions. The results validate the system's potential for practical applications in modern power distribution grids. To conducted using MATLAB/Simulink to evaluate the hybrid UPQC's performance under various conditions:

- Voltage Sag/Swells: The series compensator effectively restored voltage levels within 2% of the reference values.
- Harmonic Distortion: The total harmonic distortion (THD) in the current was reduced to below 3%.
- Renewable Integration: The system demonstrated seamless integration of solar PV, maintaining grid stability.

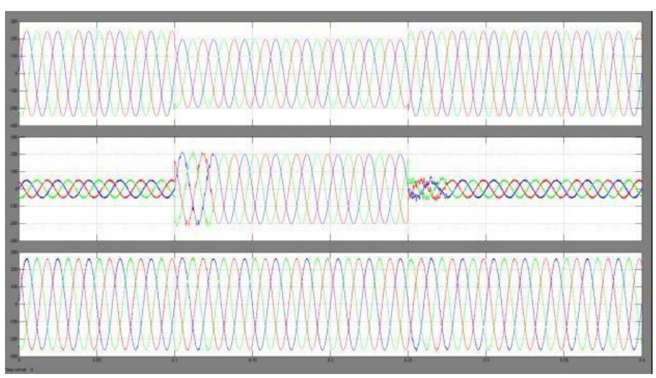


Figure 4: Voltage sag

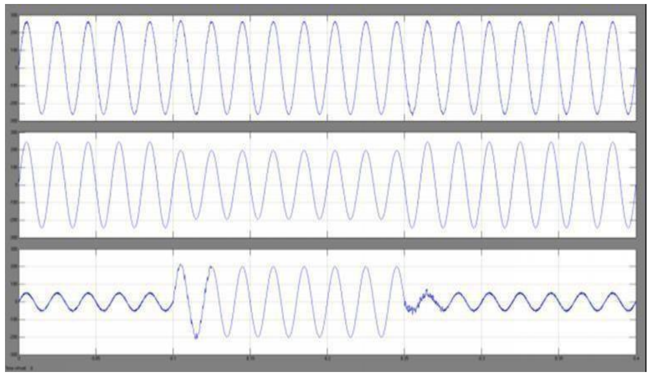
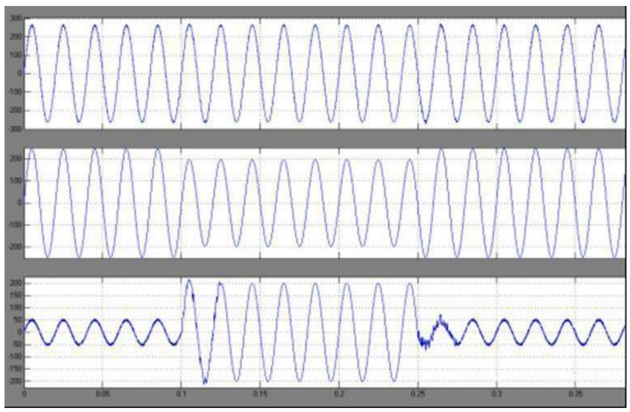


Figure 5: Single phase current



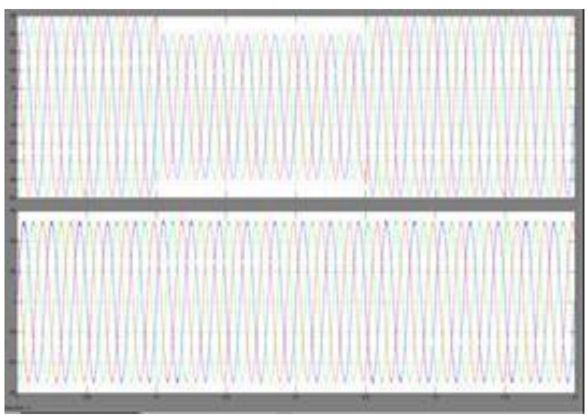


Figure 6: 3 phase voltage sag.

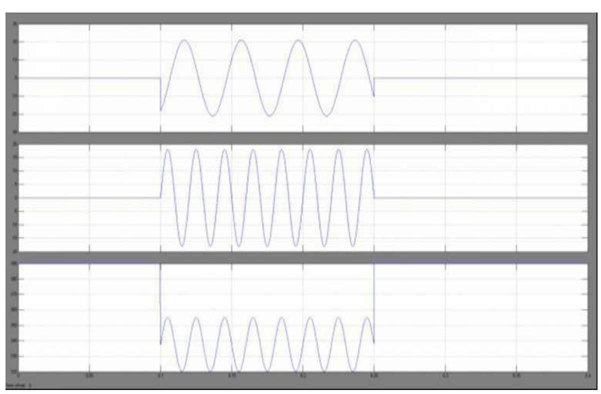


Figure 7: Single phase voltage

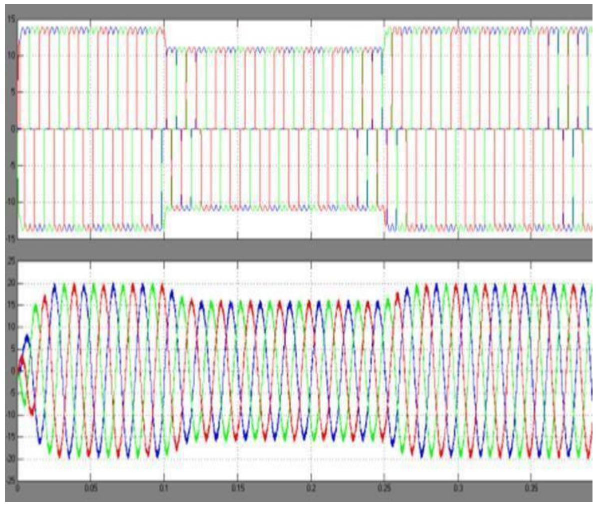


Figure 8: Load current (Iabc) and source current (Iabcs)

Figure 9: Single phase Load voltage (Vabcload), source voltage (Vabcs) and voltage (Vabc)

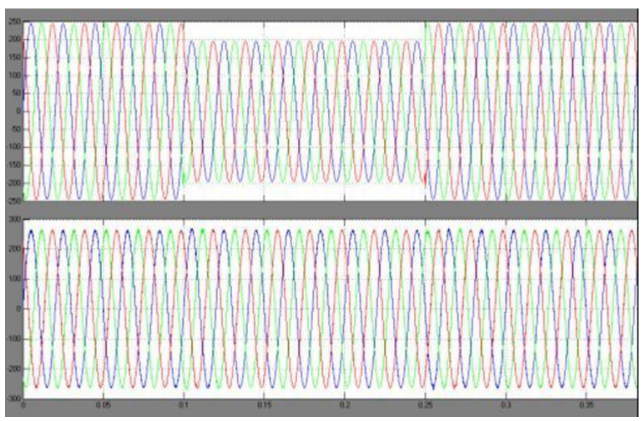


Figure 10: Source voltage (Vabcs) and load voltage (Vabcload) after HCUPQC compensation.

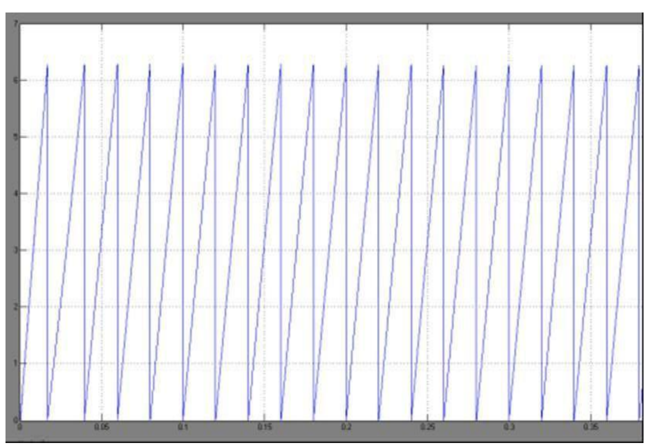


Figure 11: Wind Turbulance

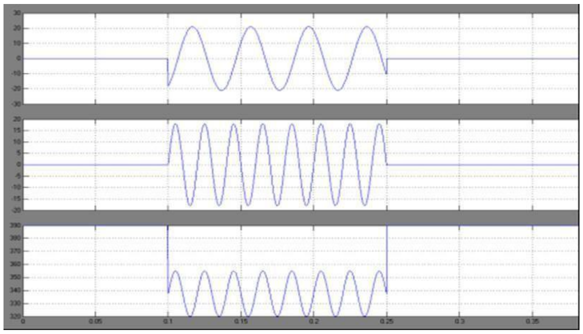


Figure 12: Direct quadrature transformation

5. Conclusion and future work

The modelling and design of HC-UPQC with PI control provide an effective solution for power quality enhancement in power distribution grids. The results demonstrate the ability of the system to maintain voltage stability, suppress harmonics, and compensate for power disturbances. Future work could explore hybrid control strategies, integrating PI control with advanced techniques such as fuzzy logic or neural networks, to The hybrid-connected UPQC with PI control is a reliable solution for improving power quality in modern distribution grids. Its ability to mitigate multiple disturbances, coupled with simplicity and robustness, makes it an attractive option for both industrial and residential applications. Future work will focus on integrating advanced control strategies, such as adaptive and predictive control, to further enhance system performance.

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