CONCEPTS AND ANALYTICAL STUDY ON POWER QUALITY ASSESSMENT OF DISTRIBUTED GENERATION SYSTEM WITH ADAPTIVE VOLTAGE CONTROL DESIGN USING HARMONIC FILTER

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Abstract:

In recent years, the integration of Distributed Generation (DG) systems into the power grid has gained significant momentum due to the increasing demand for renewable energy sources. However, maintaining power quality in such systems presents a critical challenge, primarily due to voltage instability and harmonic distortion. This paper investigates the power quality assessment of DG systems, focusing on an adaptive voltage control design integrated with harmonic filters to enhance overall performance.

The study begins with an overview of DG systems and the importance of power quality, highlighting the common issues encountered, such as voltage sags, swells, and harmonic pollution. The proposed solution involves the development of an adaptive voltage control mechanism that dynamically adjusts to changing conditions in the power grid. Additionally, harmonic filters are designed and integrated to mitigate the adverse effects of harmonics.

A comprehensive simulation model of the DG system, including both linear and nonlinear loads, is developed using MATLAB/Simulink. The adaptive voltage control algorithm is implemented and tested under various operating conditions to evaluate its effectiveness. Simulation results demonstrate a significant improvement in voltage stability and a substantial reduction in harmonic distortion when using the proposed system.

The findings of this study indicate that the combination of adaptive voltage control and harmonic filtering provides a robust solution for maintaining high power quality in DG systems. The proposed approach not only ensures voltage regulation but also effectively addresses harmonic issues, thereby enhancing the reliability and efficiency of the power grid. Future work will explore the integration of advanced machine learning techniques to further optimize the control mechanism and real-world implementation for practical validation.

1. Introduction

Distributed Generation (DG) systems are increasingly being integrated into the modern power grid due to their environmental benefits and the push towards renewable energy sources. However, maintaining power quality in such systems presents significant challenges. Power quality issues such as voltage instability and harmonics can adversely affect the performance and reliability of the power grid.

The objective of this study is to design an adaptive voltage control mechanism coupled with harmonic filters to enhance the power quality in DG systems. The significance of this research lies in addressing the dynamic nature of DG systems and providing a robust solution for voltage regulation and harmonic mitigation.

2. Literature Review

2.1 Power Quality in Distributed Generation Systems

Power quality in DG systems is crucial for ensuring the efficient operation of electrical equipment and the stability of the power grid. Key power quality parameters include voltage levels, frequency, and harmonics. Poor power quality can result in equipment malfunction, increased losses, and reduced lifespan of electrical devices.

2.2 Voltage Control in DG Systems

Traditional voltage control methods, such as On-Load Tap Changers (OLTC) and capacitor banks, have been used to maintain voltage levels within acceptable limits. However, these methods often fail to respond adequately to the rapid changes in DG systems, necessitating more adaptive solutions.

2.3 Harmonic Filters

Harmonic filters are employed to mitigate the effects of harmonics generated by nonlinear loads and power electronic converters. There are three main types of harmonic filters: passive, active, and hybrid. Each type has its advantages and limitations in terms of complexity, cost, and effectiveness.

2.4 Adaptive Voltage Control

Adaptive voltage control mechanisms can dynamically adjust to changing conditions in the power grid, offering superior performance compared to static control methods. These mechanisms use real-time data and advanced algorithms to maintain voltage stability.

2.5 Recent Studies

Recent advancements in power electronics and control systems have led to significant improvements in power quality management for DG systems. Studies have explored various adaptive control strategies and the integration of harmonic filters to enhance power quality.

3. Methodology

3.1 System Model

The DG system model used in this study consists of multiple generation sources, including renewable energy sources like solar and wind. The model incorporates both linear and nonlinear loads to simulate real-world conditions.

3.2 Adaptive Voltage Control Design

The adaptive voltage control algorithm is designed to monitor and adjust voltage levels in real-time. The algorithm uses feedback from voltage sensors and adjusts the output of voltage regulators accordingly.

3.3 Harmonic Filter Design

Harmonic filters are designed based on the specific harmonic spectrum of the DG system. The filters are configured to target the most significant harmonics, thereby improving overall power quality.

4. Results and Discussion

4.1 Simulation Results

A. Adaptive Voltage Controller Design and Stability Analysis

The control inputs Vid and Viq can be defined as two control components, respectively:

Vid =Vid1+Vid2,Viq =Viq1+Viq2

$$\begin{cases} V_{id2} = \frac{-k_4\omega I_{id} - k_3\omega I_{iq}}{(k_3^2+k_4^2)} \\ V_{iq2} = \frac{-k_4\omega I_{iq} - k_3\omega I_{id}\cdot}{(k_3^2+k_4^2)} \end{cases}$$

$$\begin{cases} \dot{x}_1 = \omega x_2 + k_1 x_3 + \Delta k_1 x_3 \\ \dot{x}_2 = -\omega x_1 + k_1 x_4 + \Delta k_1 x_4 \\ \dot{x}_3 = k_3 V_{id1} + k_4 V_{iq1} + \Delta k_3 V_{id} + \Delta k_3 V_{iq} - (k_2 + \Delta k_2) V_{Ld} \\ \dot{x}_4 = -k_4 V_{id1} + k_3 V_{iq1} - \Delta k_4 V_{id} + \Delta k_3 V_{iq} - (k_2 + \Delta k_2) V_{Lq} \end{cases} \quad (10)$$

Or

$$\begin{cases} \dot{x}_1 = \omega x_2 + k_1 x_3 + \Delta k_1 x_3 \\ \dot{x}_2 = -\omega x_1 + k_1 x_4 + \Delta k_1 x_4 \\ \dot{x}_3 = k_3 V_{id1} + k_4 V_{iq1} - k_3 f_1(x,t) - k_4 f_2(x,t) \\ \dot{x}_4 = -k_4 V_{id1} + k_3 V_{iq1} + k_4 f_1(x,t) - k_3 f_2(x,t) \end{cases} \quad (11)$$

Where

$$f_1(x,t) = a_1 V_{id} + a_2 V_{iq} + a_3 V_{Ld}$$
$$f_2(x,t) = a_4 V_{id} + a_5 V_{iq} + a_6 V_{Ld}$$

in whicha1,a2, ...,a6are unknown constants,

$$a_1 = a_5 = -\frac{k_3\Delta k_3 + k_4\Delta k_4}{k_3^2 + k_4^2}$$
$$a_2 = -a_4 = \frac{k_4\Delta k_3 + k_3\Delta k_4}{k_3^2 + k_4^2}$$
$$a_3 = a_6 = k_2 + \Delta k_2.$$

Thus, the model (11) can be rewritten in the state-space form as

$\dot{x} = (A + \Delta A)x + B[u - f(x,t)]$ (12

Where

$$f(x,t) = [f_1(x,t) f_2(x,t)^T = WII^*$$

A= $\begin{bmatrix} 0 & \omega & k_1 & 0 \\ -\omega & 0 & 0 & k_1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ $\Delta A = \begin{bmatrix} 0 & 0 & \Delta k_1 & 0 \\ 0 & 0 & 0 & \Delta k_1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ =EFΔk_1

B= $\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ k_3 & k_4 \\ -k_4 & k_3 \end{bmatrix}$, E= $\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$

F^T= $\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$, x= $\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$, u= $\begin{bmatrix} V_{id1} \\ V_{iq1} \end{bmatrix}$

W= $\begin{bmatrix} V_{id} & V_{iq} & V_{Ld} \\ V_{iq} & -V_{id} & V_{Lq} \end{bmatrix}$, $II^* = [a_1 \quad a_2 \quad a_2]^T$.

4.2 Controlstrategyverifications

In this paper, a prototype 450VA DG unit is considered to implement the proposed control algorithm. Table I gives the nominal parameters for simulations and experiments.

Table 1 Input Parameters

Item	Values
DGS Rated power	450VA
dc link Vol	280V
Load out Vol	110V
Out put Feq	60Hz
Sampling Freq	5Khz
LC output filtert	Lf 10mH, Cf 6mic F
Resistive load	Rl 80ohm
Nonlinear load	Cdc 3300mic F,Rdc 500ohm
Harmonic filter	60hz,450VA

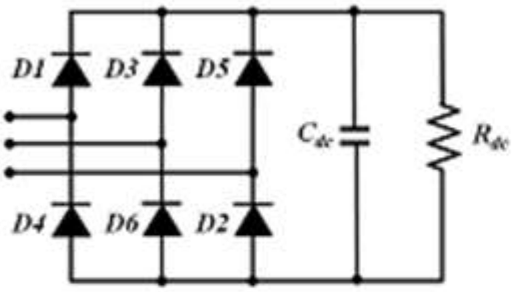
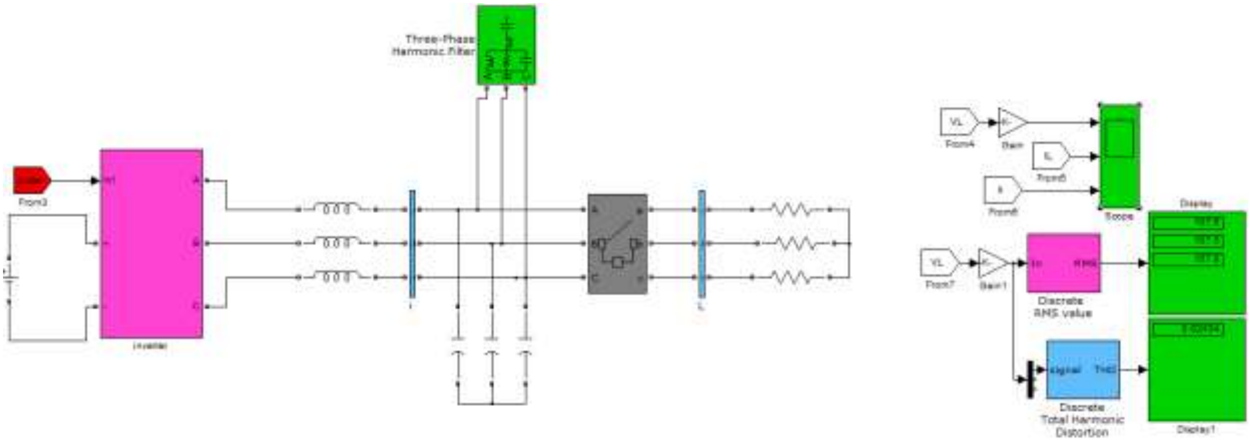


Fig 1 Circuir Diagrame of non linear load

Based on the nominal parameters given in Table I, the system model can be rewritten as

$$\begin{cases} \dot{V}_{Ld} = 377V_{Lq} + 166666.7?\,I_{id} - 166666.7I_{Ld} \\ \dot{V}_{Lq} = -377V_{Ld} + 166666.7I_{iq} - 166666.7I_{Lq} \\ \dot{I}_{id} = 377I_{iq} - 166.7V_{Ld} + 83.4V_{id} + 48.1V_{iq} \\ \dot{I}_{iq} = -377I_{id} - 166.7V_{Lq} - 48.1V_{id} + 83.4V_{iq.} \end{cases}$$

A. PROPOSED SIMULINK MODEL



Running Model

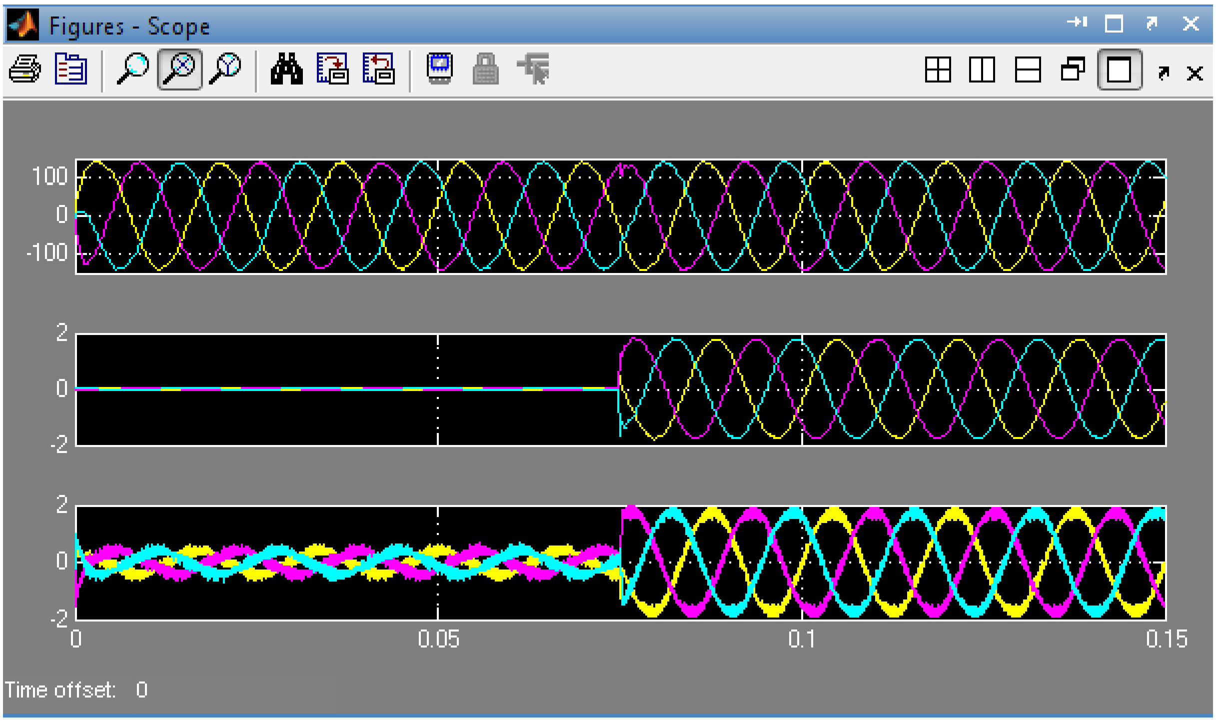


Fig. 2 of load voltage 1, load current 2, and internal current3 respectively at Adaptive Control balanced resistive load (0% to 100%). With harmonic filter

Summary of simulation result in Steady state Analysis with harmonic filter

The Existing adaptive Voltage Controller				
Load Type	Load out Voltage Vrms			THD %
	Vla	Vlb	Vlc	
No load	109.9	109.7	109.8	0.04
Balance load	109.3	109.5	109.4	0.04
Unbalanced load a, b	109.7	109.9	109.3	0.04
Nonlinear load	109.5	108.6	108.4	0.38

The Proposed adaptive Voltage Controller with harmonic filter				
Load Type	Load out Voltage Vrms			
No load	107.6	107.5	107.8	0.02434
Balance load	106.7	106.5	106.5	0.02543
Unbalanced load a, b	108.2	106.4	106.7	0.03066
Nonlinear load	106.5	106.4	106.7	0.06919

As illustrated in Fig. 2, the inverter phase currents (Ii), load output voltages (VL), and load phase currents (IL) are measured and then are transformed to the quantities (Iidq , VLdq, ILdq) in the synchronously rotatingd–q reference frame, respectively. In this paper, a space-vector PWM technique is chosen to implement the control inputs (Vid and Viq)that the proposed voltage controller generates in real time.In the paper, simulations and experiments are carried out to verify the effectiveness of the proposed adaptive control algorithm under the following four conditions:

1) Balanced load (0%→100%): The balanced resistive load is instantaneously applied to the inverter output terminals.

2) Balanced load (100%→0%): The balanced resistive load is instantaneously removed from the inverter output terminals.

3) Unbalanced load: The unbalanced resistive load is connected to the inverter output terminals, i.e., only phaseC is opened.

4) Nonlinear load: A three-phase full-bridge diode rectifier is connected to the inverter output terminals. As shown in Fig. 2, it is also connected in parallel with a capacitor (Cdc)and a resistor(Rdc), and the nonlinear load has a crest factor of 2.25:1.

Fig.2. Experimental results of the non adaptive voltage controller with 150%uncertainties of system parameters (k1 to k4) under a nonlinear load (i.e., a capacitive output load with a high crest factor of 1.91:1). (a) Load output voltages (VL). (b) Load phase currents (IL) and inverter phase currents (Ii).

In this research yield voltages would restored inside short of what just a large portion a cycle following the load will be right away connected alternately evacuated. Despite the fact that the load yield voltages somewhat show an undershoot because of those under damped nature of the control scheme, those yield voltage extent deviates short of what 1% of the ostensible worth.

Fig. 2a indicate that steady-state execution of the recommended control methodology under the lopsided load and nonlinear load. On these figures, it may be watched that those THDs in the load yield voltage waveforms would 0. 53% and 1. 51% under that lopsided load nonlinear load, separately. In fig. 2 Displays that test come about of the no adaptive voltage controller under that nonlinear load. The transient steady-state exhibitions are beneficial for quick transient reactions and little steady-state errors. However, the THDs for the load voltage waveforms would higher over the one gotten from those the event of the suggested versatile controller.

5. Conclusion

We present an advanced voltage control method with a harmonic filter for a three-phase inverter in a standalone distributed generation unit. This system features both dynamic and adaptive control capabilities. Not only is this method straightforward, but it is also robust against grid uncertainties due to the use of the harmonic filter. Simulation and experimental results have demonstrated that the proposed control scheme delivers satisfactory voltage regulation performance, characterized by fast dynamic response, minimal steady-state error, and low Total Harmonic Distortion (THD) under various load conditions (e.g., no load, balanced load, unbalanced load, and nonlinear load) in the presence of grid parameter uncertainties.

5.1 Summary of Findings

The study demonstrates that the proposed adaptive voltage control design, coupled with harmonic filters, can significantly enhance power quality in DG systems.

This research contributes to the field by providing a novel solution for power quality management in DG systems, addressing both voltage regulation and harmonic mitigation.

5.2 Future Work

Future research should explore the integration of advanced machine learning techniques for further improvement of the adaptive control system. Additionally, real-world implementation and testing of the proposed system would provide valuable insights.

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