# A New Control Strategy for Distributed Generation under Nonlinear loads

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## Abstract

This paper presents a new control strategy to improve voltage performance of distributed generation (DG) under nonlinear loads. The proposed voltage controller consists of a proportional-integral and a repetitive controller where the repetitive controller behaves as a bank of resonant controllers to compensate harmonic voltage drop on system impedance due to nonlinear load current. As a result, the voltage at the point of common coupling (PCC) of the DG is regulated to be sinusoidal waveform regardless of the presence of nonlinear loads. In order to validate the effectiveness of the proposed voltage controller, simulations are carried out using PSIM software and results are compared with those with the conventional PI controller.

## 1. Introduction

Nowadays, distributed generation (DG) systems based on renewable energy sources have become considerably attractive because of several serious issues of conventional energy sources such as global warming, air pollutants, and greenhouse gas emissions. The DG systems extract power from renewable energy sources and transform into electricity through a power conversion unit to supply to the local loads (in stand-alone mode) and/or to deliver to grid (in grid-connected mode). Most of DG systems are developed to operate under grid-connected mode [1]. However, in order to exploit full potential of DG units, their operation under stand-alone mode also should be investigated. In the stand-alone mode, DG system must supply a constant voltage and frequency output voltage regardless of variation of loads and various types of loads.

To supply a high performance output voltage at the point of common coupling (PCC), a proportional-integral (PI) controller in the synchronous reference frame is proposed as an effective solution [2]. However, when unbalanced and/or nonlinear loads are used in the system, PI controllers have some limitation to improve output voltage performance of DG system. Nonlinear loads draw current harmonics into the system, which cause distorted voltage drop on system impedance and consequently make the PCC voltage non-sinusoidal as shown in Fig. 1. This non-sinusoidal voltage condition will harmfully affect to other loads connected to the PCC.

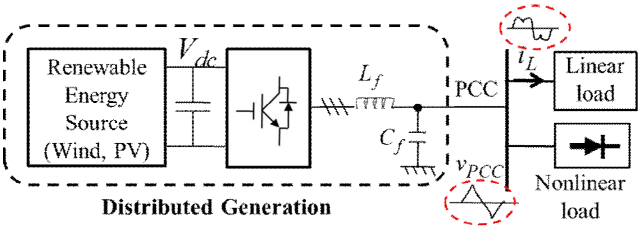

Fig. 1 Configuration of DG system connected with loads at the PCC.

In order to supply a pure sinusoidal output voltage at the PCC under a nonlinear load condition, the inverter must generate the distorted voltage components to compensate the harmonic voltage drop on the system impedance. To fulfill this goal, a solution has been introduced in [3]. In [3], authors try to improve the PCC voltage performance by using a bank of PI controller where each PI controller is used to regulate the magnitude of a harmonic voltage. In this method, many PI controllers as well as coordinate transformations are required to compensate all voltage harmonics, which makes the control strategy become too complex.

This paper presents a new control strategy to improve voltage performance at the PCC of the DG. The proposed voltage controller consists of a PI and a repetitive controller (RC) where the RC behaves as a bank of resonant controllers to compensate harmonic voltage drops on the system impedance. As a result, the PCC voltage of the DG is regulated to be sinusoidal waveform irrespective of the presence of nonlinear loads. In order to validate the effectiveness of the proposed voltage controller, simulations are carried out using PSIM software and results are compared with those of the conventional PI controller.

## 2. Proposed voltage control scheme

Fig. 2(a) shows block diagram of the proposed voltage control scheme which consists of a PI and a repetitive controller. Since the proposed control scheme is implemented in the synchronous reference (*d-q*) frame, the PI controller is able to effectively regulate fundamental voltage. Regarding to harmonic components in three-phase systems, harmonic current and voltage are in the form (6*n*±1) (*n*=1, 2, 3…) orders which become 6*n* harmonic orders in the *d-q* frame. As a result, the RC only needs to compensate 6*n*-th harmonic voltage drop to make the PCC voltage of DG to be sinusoidal.

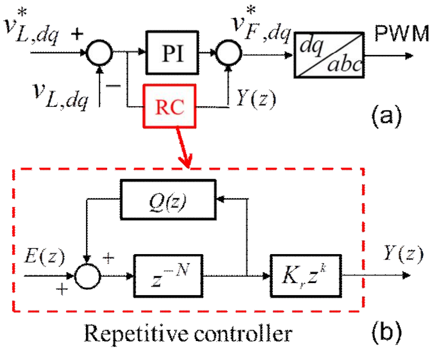

Fig. 2 (a) Block diagram of the proposed voltage control scheme, (b) detail structure of repetitive controller

Fig. 2(b) shows detailed structure of the RC which consists of a time delay unit $z^{-N}$, a filter $Q(z)$, a time advance unit $z^k$, and a gain $K_r$. From Fig. 2(b), the transfer function of the RC can be written as

$$C(z)=\frac{K_r z^{-N+k}}{1-Q(z)z^{-N}} \qquad (1)$$

As mentioned before, the RC is designed to compensate only 6*n*-th voltage harmonics. Hence, the number of samples delay *N* in (1) is one-sixth of number of samples in one fundamental period. The filter *Q(z)* can be a number less than 1 or a zero-phase shift low-pass filter which is used to reduce the gain of the RC from infinite to finite in order to keep the system stable against disturbance and noise.

Fig. 3 shows bode diagram of (1) respect to different value of $Q(z)$. It can be seen that the RC provides high gain at $6n\omega_s$ frequencies, which means the RC is capable of compensating the harmonic voltage of $6n$-th orders. In addition, the RC achieves higher gain with higher value of Q(z), which means the RC provides better performance as Q(z) is close to 1.

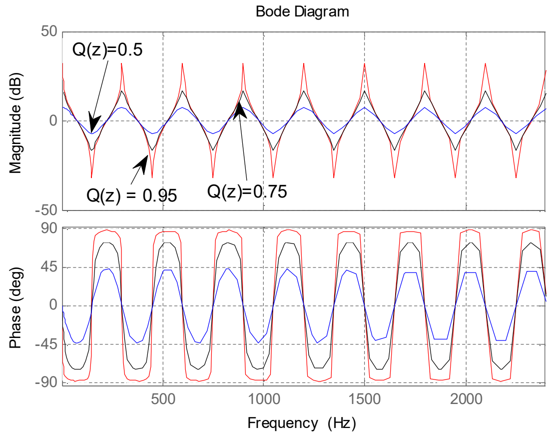

Fig. 3 Bode diagram of repetitive controller with different Q(z) values.

## 3. Simulation results

The simulation system consists of a DG, a linear load, and a nonlinear load where the total harmonic distortion (THD) factor of the nonlinear load is 22.4%. The reference PCC voltage magnitude and frequency is set to be 100V and 50 Hz, respectively. The simulations are performed by using PSIM software.

First, a simulation is carried out by using the conventional control scheme where only the PI controllers are used. The simulation results are shown in Fig. 4. As depicted in Fig. 4, the PCC voltage is non-sinusoidal with high THD factor of 6.8%. It comes from the harmonic currents due to the nonlinear load, which causes harmonic voltage drop on the system impedance and makes the PCC voltage distorted.

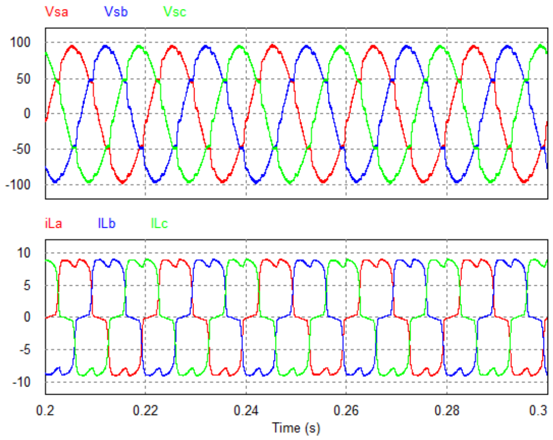

Fig. 4 Simulation results of DG with PI controllers.

Fig. 5 presents the simulation results of the proposed control strategy. In Fig. 5, the PCC voltage is regulated to be sinusoidal regardless of the presence of nonlinear load. From the FFT analysis of the PCC voltage, we can see that only fundamental component is contained in PCC voltage. The THD factor of the PCC voltage is very low, approximately 1.72%. Hence, it is clear that the proposed control scheme provides very good performance.

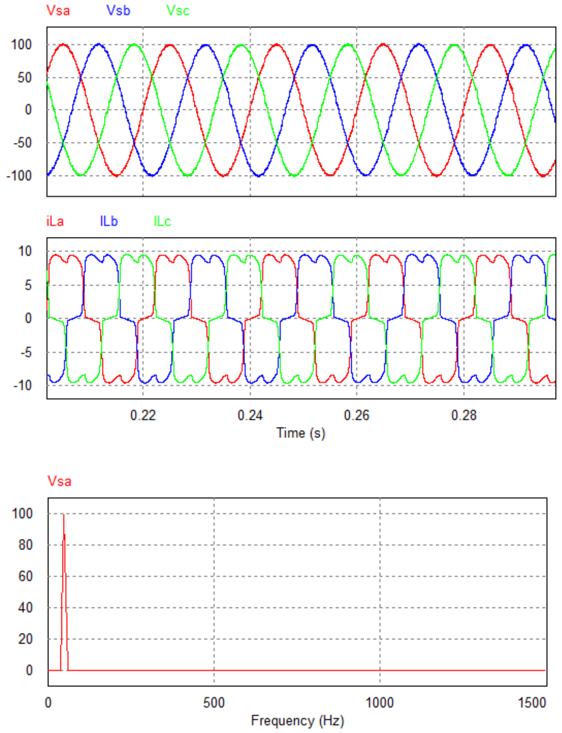

Fig. 5 Simulation results of DG using the proposed PI-Repetitive controllers.

## 4. Conclusion

This paper proposed a new control scheme for the stand-alone DG system by using the PI and the repetitive controller. By using the proposed controller, the PCC voltage is regulated to be almost pure sinusoidal irrespective of the presence of nonlinear load. A large amount of harmonic voltage components is compensated simultaneously by using only one repetitive controller. With the aid of the proposed controller, the THD factor of the PCC voltage is reduced to 1.72%, which is much lower than that with the PI controller. The effectiveness of the proposed controller is completely verified through simulation.

## Acknowledgment

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