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A New Current Control Strategy for Grid-Connected Distributed Generation System

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Abstract— This paper Proposed another present control topology for network associated based circulated age (DG), which encourages the DG to trade a sinusoidal current into the utility matrix in spite of the mutilated lattice voltage and nonlinear neighborhood stack conditions. The proposed current controller is laid out in the synchronous reference packaging and made out of a Fuzzy controller. Thus, the control strategy can be fantastically improved successfully. Likewise, the proposed control system does not require the close-by stack current estimation or symphonious examination of the structure voltage. In this way, the proposed control strategy can be adequately grasped into the customary DG control structure without foundation of extra gear. Regardless of the decreased number of sensors, the structure current quality is out and out advanced. The activity standard of the proposed control method is inspected in detail, and its reasonability is endorsed through watching outright symphonious twisting (THD) and the outcomes confirmed through MATLAB/SIMULINK condition.

Key words—Distributed age (DG), Fuzzy controller, matrix associated inverter, consonant pay, nonlinear load, tedious control.

I. Introduction

Flow time units pervasively Renewable essentialness sources, for instance, wind turbines, photovoltaic, and control gadgets, has fundamentally extended in late decades to address stresses over the overall imperativeness crisis, fatigue of fossil fills, and biological sullying issues. Network Current Compensator for Grid-Connected Distributed Generation under direct and non straight load condition are dismembered with PI-RC controller in [1] and the operational discernments exhibit the viability of the controller forcefully. In this manner, a far reaching number of sustainable imperativeness sources have been facilitated in control course systems as spread period (DG) [2]. DG systems can offer numerous central focuses over standard power time, for instance, minimal size, insignificant exertion, high adequacy, and clean electric power time. A DG system is customarily worked in a system related mode where the most extraordinary open power is expelled from imperativeness sources and traded to the utility framework [3]-[9]. In like manner, to manhandle full purposes of enthusiasm of a DG structure, the DG can be also outfitted and worked with neighborhood loads, where the DG supplies vitality to the adjacent load and trades surplus vitality to the grid [10]-[15]. In the two setups, i.e., with and without the adjacent load, the prime focus of the DG system is to trade an astonishing current (grid current) into the utility grid with the obliged total consonant bowing (THD) of the system current at 5%, as proposed in the IEEE 1547 measures [16].

To convey a first rate system present, distinctive current control strategies have been exhibited, for instance, hysteresis, perceptive, comparing central (PI), and relative full (PR) controllers. Hysteresis control is essential and offers snappy responses; in any case, it routinely makes high and variable trading frequencies, which realizes high current swells and inconveniences in the yield channel diagram [4]. In the meantime, insightful control is an attainable response for current course of the grid related DG. Regardless, despite its quick response, the control execution of the farsighted controller immovably relies upon structure parameters [5]. In like manner, system flimsiness is a basic issue affecting the system current quality. The PI controller in the synchronously turning (d-q) reference plot and the PR controller in the stationary (α-β) reference packaging are convincing game plans that are for the most part gotten to achieve a choice system current [3], [4], [11], [12]. In any case, these present controllers are simply capable when the system voltage is ideally balanced and sinusoidal. Lamentably, due to the outstanding usage of nonlinear burdens, for instance, diode rectifiers and adaptable speed aerating and cooling motor drives in control systems, the system voltage at the reason for normal coupling (PCC) is usually not impeccable sinusoidal, yet rather can be unequal or mangled. These unordinary network voltage conditions can solidly go to pieces the execution of the coordinating cross section current. To slaughter the threatening effect of the twisted system voltage on the grid current quality, a couple of symphonious pay procedures have been displayed [7]-[9]. A novel pay approach for decreasing the THD of the cross section current under distorted framework voltage is exhibited. In this method, the symphonious parts in the system voltage are evacuated, and the Cauchy-Schwarz awkwardness theory is gotten to find the base reason for the system current THD. The network current quality in this manner depends intensely on the precision of the framework voltage consonant examination; if the symphonious parts in the network voltage are fluctuated, it is hard to keep up a decent lattice current quality. Additionally, the looking calculation requires an extensive figuring time and can work just disconnected. A few particular symphonious compensators are produced utilizing a full controller, in which the resounding controller tuned at the 6th different of the principal recurrence is added to take out the impact of fifth and seventh consonant framework voltages on the lattice current quality. The network current quality can be enhanced, because of the extra full controllers. Be that as it may, if higher request music are considered, more thunderous controllers ought to be included in light of the fact that a solitary resounding controller can manage just a single particular consonant segment [8], [9]. Tragically, including more controllers builds the multifaceted nature of the control framework. To enhance the network current quality with a streamlined control conspire, the redundant control system has been embraced [13]. A dreary controller (RC) serves as a bank of full controllers to repay countless segments with a basic postpone structure. In any case, in spite of the adequacy of the RC in symphonious remuneration, the customary RC has a long postpone time, which routinely constrains the dynamic reaction of the present controller. For instance, as reported in [13], the dynamic reaction of the framework current under a stage change of the present reference is roughly 150 ms, which is to a great degree moderate contrasted and other control techniques. Also, even with the usage of the RC, this technique can't bring the THD of the matrix current lower than the constrained esteem 5% in the IEEE 1547 benchmarks. Alongside matrix voltage mutilation, the nearness of nonlinear loads in the nearby heap of the DG likewise causes a negative effect on the lattice current quality [14]. To address this issue, the nearby load current estimation and a heap current feedforward circle are routinely received [14], [15]. In spite of the fact that these pay techniques are successful in enhancing matrix current quality, the prerequisite of extra equipment, particularly the present sensor for measuring the neighborhood stack current, is the fundamental downside of this control strategy. Moreover, most previously mentioned reviews consider and independently handle the effect of contorted network voltage or the nonlinear neighborhood stack; none of them at the same time considers those issues.

To defeat the confinements of previously mentioned reviews, this paper proposes a propelled current control system for the framework associated DG, which makes the network current sinusoidal by at the same time killing the impact of nonlinear nearby load and matrix voltage twists. To begin with, the impact of the matrix outlined in the d-q reference outline and is made out of a Fuzzy controller.

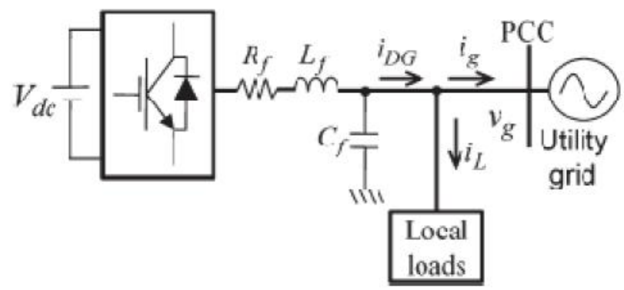


Fig. 1. System configuration of a grid-connected DG system with local load.

One single RC can repay countless parts with a straightforward postpone work. Consequently, the control procedure can be extraordinarily disentangled. Another favorable position of the proposed control strategy is that it doesn't request the neighborhood stack current estimation and the consonant investigation of the framework voltage. In this way, the proposed control technique can be effortlessly embraced into the customary DG control framework without the establishment of additional equipment. In spite of the lessened number of sensors, the execution of the proposed matrix current controller with fluffy procedure is fundamentally enhanced contrasted and that of the PI current controller. Likewise, with the mix of fluffy, the dynamic reaction of the proposed current controller is additionally enormously improved contrasted and that of the conventional PI-RC. The attainability of the proposed control methodology is totally checked by reproduction comes about.

II. SYSTEM CONFIGURATION AND ANALYSIS OF GRID VOLTAGE DISTORTION AND NONLINEAR LOCAL LOAD

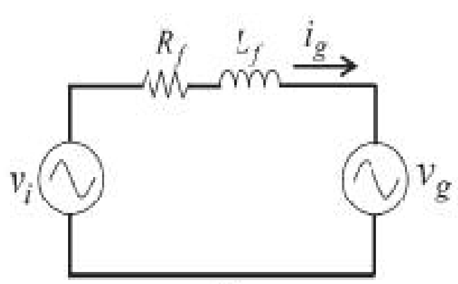
Fig. 1 demonstrates the framework setup of a three-stage DG working in lattice associated mode. The framework comprises of a dc control source, a voltage-source inverter (VSI), a yield LC channel, neighborhood loads, and the utility lattice. The reason for the DG framework is to supply energy to its neighborhood stack and to exchange surplus energy to the utility network at the PCC. To ensure brilliant power, the present that the DG exchanges to lattice (ig) ought to be adjusted, sinusoidal, and have a low THD esteem. Notwithstanding, on account of the twisted lattice voltage and nonlinear neighborhood stacks that regularly exist in the power framework, it is difficult to fulfill these necessities.

A. Impact of Grid Voltage Distortion

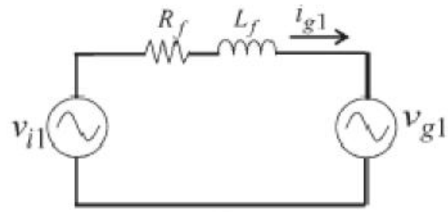
To survey the effect of framework voltage bending on the network current execution of the DG, a model of the lattice associated DG framework is produced, as appeared in Fig. 2. In this model, the VSI of the DG is disentangled as voltage source (vi). The inverter exchanges a matrix current (ig) to the utility lattice (vg). For rearrangements reason, it is expected that the nearby load is not associated into the framework. In Fig. 2(a), the voltage condition of the framework is given as

$$v_i - v_g - L_f \frac{di_g}{dt} - R_f i_g = 0 \quad (1)$$

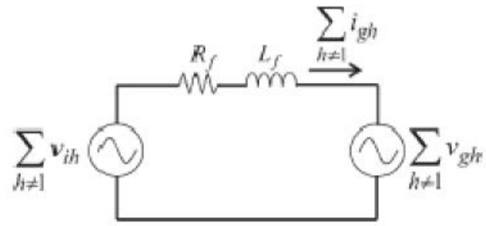
Where Rf and Lf are the equivalent resistance and inductance
of the inductor Lf, respectively.



(a)



(b)



(c)

Fig. 2. Model of grid-connected DG system under distorted grid voltage condition.
(a) General condition;
(b) at the fundamental frequency; and
(c) at harmonic frequencies.

If both the inverter voltage and the grid voltage are composed of the fundamental and harmonic components as (2), the voltage equation of (1) can be decomposed into (3) and (4), and the system model shown in Fig. 2(a) can be expressed as Fig. 2(b) and (c), respectively. That is

$$v_i = v_{i1} + \sum_{h\neq1} v_{ih}$$

$$v_g = v_{g1} + \sum_{h\neq1} v_{gh} \quad (2)$$

$$v_{i1} - v_{g1} - L_f \frac{di_{g1}}{dt} - R_f i_{g1} = 0 \quad (3)$$

$$\sum_{h\neq1} v_{ih} - \sum_{h\neq1} v_{gh} - L_f \frac{d\left(\sum_{h\neq1} i_{gh}\right)}{dt} - R_f \sum_{h\neq1} i_{gh} = 0. \quad (4)$$

B. Effect of Nonlinear Local Load

Fig. 3 shows the model of a grid-connected DG system with a local load, whereby the local load is represented as a current source *iL*, and the DG is represented as a controlled current source *i*DG. According to Fig. 3, the relationship of DG current
*i*DG, load current *iL*, and grid current *ig* is described as

$$i_{\mathrm{DG}} = i_L + i_g. \quad (5)$$

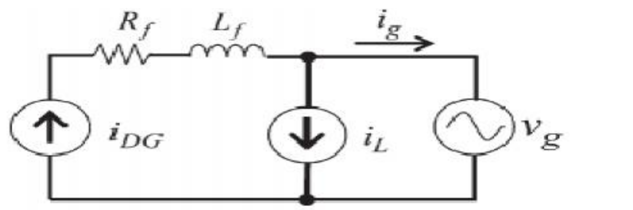


Fig. 3. Model of grid-connected DG system with nonlinear local load.

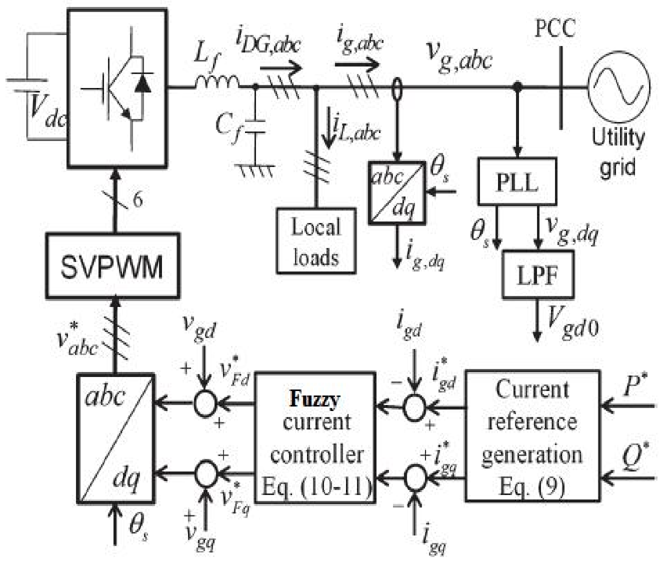


Fig. 4. Overall block diagram of the proposed control strategy.

Assuming that the local load is nonlinear, e.g., a three-phase diode rectifier, the load current is composed of the fundamental and harmonic components as

$$i_L = i_{L1} + \sum_{h\neq 1} i_{Lh} \qquad (6)$$

where iL1 and iLh are the fundamental and harmonic compo-
nents of the load current, respectively.
Substituting (6) into (5), we have

$$i_g = i_{\mathrm{DG}} - \left(i_{L1} + \sum_{h\neq 1} i_{Lh} \right). \qquad (7)$$

From (7), it is obvious that, in order to transfer sinusoidal grid current *ig* into the grid, DG current *i*DG should include the harmonic components that can compensate the load current harmonics $\sum_{h\neq 1} i_{Lh}$ Therefore, it is important to design an effective and low-cost current controller that can generate the specific harmonic components to compensate the load current harmonics. Generally, traditional current controllers, such as the PI or PR controllers, cannot realize this demand because they lack the capability to regulate harmonic components.

III. PROPOSED CONTROL SCHEME

To enhance grid current quality, an advanced current control strategy, as shown in Fig. 4, is introduced. Although there are several approaches to avoid the grid voltage sensors and a phase-locked loop (PLL) [19], Fig. 4 contains the grid voltage sensor and a PLL for simple and effective implementing of the proposed algorithm, which is developed in the d-q reference frame.

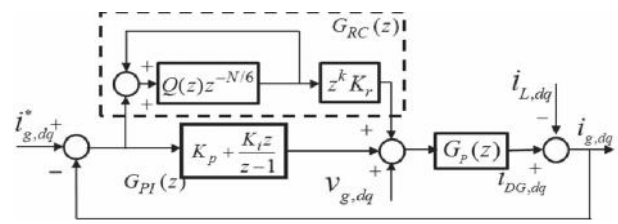


Fig. 5. Block diagram of the current controller.

The proposed control scheme is composed of three main parts: the PLL, the current reference generation scheme, and the current controller. The operation of the PLL under distorted grid voltage has been investigated, in detail, in [20]; therefore, it will not be addressed in this paper. As shown in Fig. 4, the control Fig. 6. Bode diagram of the proposed PI-RC current controller. strategy operates without the local load current measurement and harmonic voltage analysis on the grid voltage. Therefore, it can be developed without requiring additional hardware. Moreover, it can simultaneously address the effect of nonlinear local load and distorted grid voltage on the grid current quality .

A. Current Reference Generation

As shown in Fig. 4, the current references for the current controller can be generated in the d-q reference frame based on the desired power and grid voltage as follows [15]:

$$i^*_{gd} = \frac{2}{3}\frac{P^*}{v_{gd}}$$
$$i^*_{gq} = -\frac{2}{3}\frac{Q^*}{v_{qd}} \qquad (8)$$

where P ∗ and Q∗ are the reference active and reactive power, respectively; vgd represents the instantaneous grid voltage in the d-q frame; and igd and igq denote the direct and quadrature components of the grid current, respectively.Under ideal conditions, the magnitude of vgd has a constant value in the d-q reference frame because the grid voltage is pure sinusoidal. However, if the grid voltage is distorted, the magnitude of vgd no longer can be a constant value. As a consequence, reference current igd and igq cannot be constant in (8). To overcome this problem, a low-pass filter (LPF) is used to obtain the average value of vgd , and the d-q reference currents are modified as follows, whereVgd0 is the average value of vgd, which is obtained through the LPF in Fig. 4

$$i_{gd}^{*} = \frac{2}{3}\frac{P^{*}}{V_{gd0}}$$

$$i_{gq}^{*} = -\frac{2}{3}\frac{Q^{*}}{V_{gd0}} \qquad (9)$$

IV. Fuzzy controller

The word Fuzzy means ambiguity. Fuzziness happens when the limit of bit of data is not obvious. In 1965 Lotfi A. Zahed propounded the Fuzy set hypothesis. Fuzy set hypothesis shows monstrous potential for viable unraveling of the vulnerability in the issue. Fuzy set hypothesis is an astounding scientific apparatus to handle the vulnerability emerging because of dubiousness. Understanding human discourse and perceiving written by hand characters are some normal occasions where fluffiness shows.

Fuzy set hypothesis is an expansion of traditional set hypothesis where components have shifting degrees of participation. Fuzy rationale utilizes the entire interim somewhere around 0 and 1 to portray human thinking. In FLC the information factors are mapped by sets of enrollment capacities and these are called as "Fuzy SETS".

Fuzy set contains from a participation capacity which could be characterizes by parameters. The esteem somewhere around 0 and 1 uncovers a level of participation to the Fuzy set. The way toward changing over the fresh contribution to a Fuzy esteem is called as "fuzzificaton." The yield of the Fuzzier module is interfaced with the standards. The fundamental operation of FLC is developed from Fuzy control rules using the estimations of Fuzy sets all in all for the mistake and the change of blunder and control activity. Essential Fuzy module is appeared in fig.6.

The outcomes are joined to give a fresh yield controlling the yield variable and this procedure is called as "DEFUZZIFICATION."

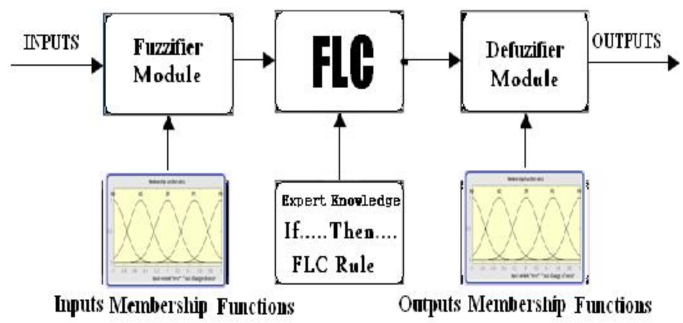


Fig.6. Fuzzy Basic Module

i. Fuzzy rules

In the fuzzy control, input and output variables are the size of the form to describe in words, so to select special vocabulary to describe these variables, generally used in "big, medium and small" Three words to express the controller input and output variables state, plus the positive and negative directions, and zero, a total of seven words : { negative big, negative medium, negative small, zero, positive small, middle, CT } , the general terms used in the English abbreviation prefix : {NB , NM, NS , ZE, PS , PM, PB}.

COE \ E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PB	NS	ZE
PS	NM	NS	ZE	PS	PM	PM	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

ii. Membership Functions

A participation work (MF) is a bend that characterizes how each point in the information space is mapped to an enrollment esteem (or level of participation) in the vicinity of 0 and 1. A participation work for a fluffy set An on the universe of talk X is characterized as $\mu A: X \rightarrow [0,1]$, where every component of X is mapped to an incentive in the vicinity of 0 and 1. This esteem, called participation esteem or level of enrollment, measures the review of participation of the component in X to the fluffy set A. Participation capacities enable us to graphically speak to a fluffy set. The x hub speaks to the universe of talk, though the y pivot speaks to the degrees of participation in the [0,1] interim. Basic capacities are utilized to construct enrollment capacities. Since we are characterizing fluffy ideas, utilizing more mind boggling capacities does not include more accuracy. The following is a rundown of the enrollment capacities we will use in the down to earth segment of this instructional exercise. Triangular capacity: characterized by a lower confine an, a maximum breaking point b, and an esteem m, where $a < m < b$.

V. SIMULATION RESULTS

A reproduction model of the DG framework is worked by MATLAB/Simulink programming to confirm the adequacy of the proposed control technique. The framework parameters are given in Table I. In the recreation, three cases are considered.

1) Case I: The lattice voltage is sinusoidal and the straight nearby

stack is utilized.

2) Case II: The lattice voltage is sinusoidal and the nonlinear

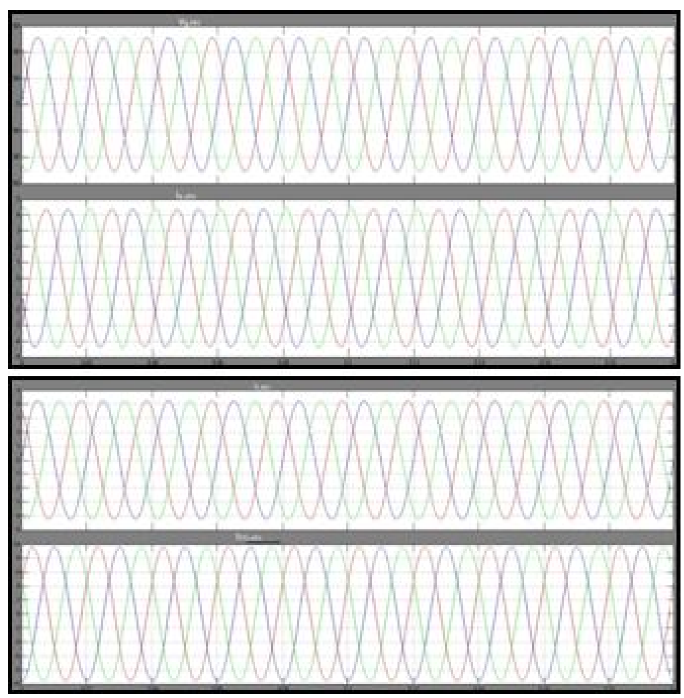
neighborhood stack is utilized.

3) Case III: The lattice voltage is mutilated and the nonlinear

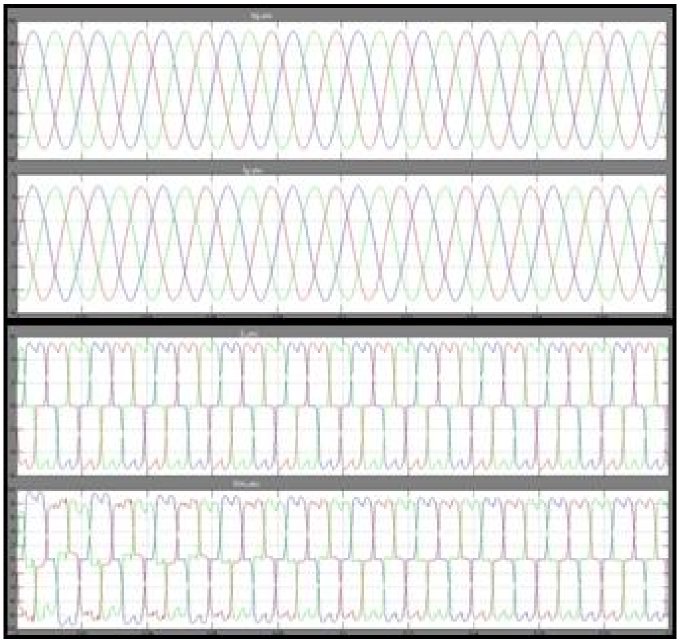
neighborhood stack is utilized.

In Cases I and II, the lattice voltage is expected as an unadulterated sinusoidal waveform. In Case III, the misshaped network voltage is provided with the consonant parts: 3.5% fifth symphonious, 3% seventh consonant, 1% eleventh consonant, and 1% thirteenth symphonious. The THD of lattice voltage is around 4.82%. This lattice voltage condition conforms to the IEEE 519-1992 symphonious limitation benchmarks, where the THD of framework voltage is under 5% . In all experiments, the reference lattice current is set at igd = 10 An and igq = 0, and the fluffy current controller is researched to look at its control exhibitions.

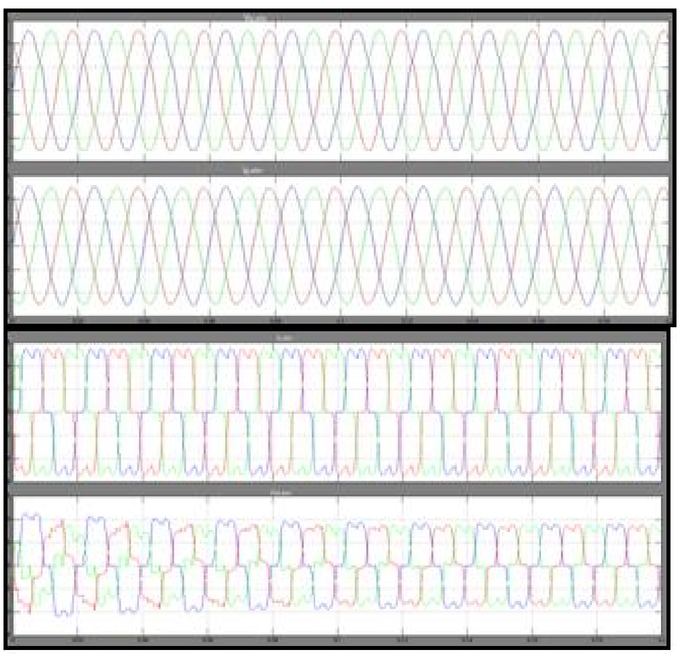
Fig. 10 delineates the enduring state execution of the framework associated DG by utilizing the Fuzzy current controller, in which the waveforms of matrix voltage (vg,abc), lattice current (ig,abc), neighborhood stack current (iL,abc), and DG current (iDG,abc) are plotted. As appeared in Fig. 10, the Fuzzy controller can offer a decent execution in Case I, when the matrix voltage is perfect sinusoidal and the nearby load is linear. In the other circumstances, due to the effect of distorted grid voltage and the nonlinear local load, the fuzzy current controller is somewhat unable to transfer a sinusoidal grid current to the utility grid. In fact, because of the popular use of nonlinear loads in the DG local load and distribution system, the ideal sinusoidal condition of the grid voltage is very rare. On the other hand, the conditions, as given in Cases II and III, frequently occur in practice. As a result, the conventional PI controller is sufficient to some extent to offer a good quality of the grid current.



(a)



(b)



(c)

Fig. 10. Simulation results with the PI current controller:
(a) Case I; (b) Case II; and (c) Case III

TABLE II
SUMMARY OF THD VALUES OF GRID CURRENT WITH
PI AND PROPOSED CURRENT CONTROLLERS

	PI & RC current controller			FUZZY LOGIC current controller		
	Case I	Case II	Case III	Case I	Case II	Case III
THD Of i_g	1.55 %	1.80 %	1.92 %	1.23 %	1.61 %	1.76 %

VI. CONCLUSION

This paper has proposed an intelligent current control strategy for the grid-connected DG to simultaneously eliminate the effect of grid voltage distortion and nonlinear local load on the grid current. The simulation results established that the DG with the proposed current controller can sufficiently transfer a sinusoidal current to the utility grid, despite the nonlinear local load and distorted grid voltage conditions. The proposed current control scheme can be implemented without the local load current sensor and harmonic analysis of the grid voltage; therefore, it can be easily integrated in the conventional control scheme without installation of extra hardware. Despite the reduced number of current sensors, the quality of the grid current is significantly improved: the THD value of the grid current is decreased considerably compared with that achieved by using the conventional current controller like PI. In addition, the proposed current controller also maintained a good quality of grid current under grid frequency variations and total harmonic distortion (THD) decreases. Moreover, the dynamic response of the grid current controller was also greatly enhanced compared with that of the traditional PI-RC topology and fuzzy controller.

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