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Power Flow Control in Grid Connected Mode Using Particle Swarm Optimization

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Abstract

The increasing application of non linear loads may raise power quality problems in distribution side. For utilizing the distributed generation (DG) units in effective manner to reduce active harmonics. In this proposed method we use current control approach that seamlessly integrates system harmonic mitigation capabilities with the primary DG power generation function. In this proposed current controller consists of two decoupled control branches to control fundamental and harmonic DG currents. In this closed loop control is used to reduce difficulty it is directly derive the fundamental current reference without phase locked loop(PLL).the impacts of steady-state fundamental current tracking errors in DG units is effectively eliminated by this proposed power control scheme. In this proposed method an accurate power control is realized by using particle swarm optimization (PSO) algorithm for fundamental current reference. Simulated results from a single phase DG unit validate the exactness of the proposed method.

***Key Words*:**Active power filter, Distributed generation, Harmonic extraction, particle swarm optimization, resonant controller

1 Introduction

In nowadays the power generation is increased in environmental friendly way, the development of renewable energy based distributed generation (DG) has received great interest in recent years as renewable energy resources are pollution free, less cost and abundant in nature. In a grid-connected renewable energy system, grid connection is normally achieved through an interfacing power electronic inverter [1]. The switching of power electronic inverter will generate harmonics at its output. in addition, the presence of non linear loads are increasing. Such as variable-speed drives, compact fluorescent lamps (CFLS), light emitting diode (LED) lamps, etc these non linear loads will decrease the efficiency and power factor and increases the risk of electromagnetic interference with neighboring communication lines. And it will degrade distribution system power quality.

To overcome distribution system harmonic distortions numbers of active and passive filtering methods are developed [3]. Installing additional filters is not favourable due to cost increases, resonance, and large in size. Alternatively the power quality improvement of distribution system using flexible control of grid connected DG units is essential [6], [9]. The ancillary harmonic Compensation capability is integrated with primary power of DG units through control references. It is more essential that DG units real and reactive power will not change in harmonic compensation techniques.

For the local load harmonic current compensation method an accurate detection of local load harmonic current is important. various types of harmonic detection methods are presented[4], such as second order generalized integrator (SOGI),the detection scheme using instantaneous real and reactive power theory, the Fourier transformation based detection ,And the delayed-signal-cancellation-based-detection.Nevertheless, harmonic extraction process substantially increases the computing load of DG unit controllers., the complex harmonic extraction methods might not be acceptable because For a cost - effective DG unit with limited computing ability. Alternatively, an interesting harmonic detection less method was proposed [7].

To make easier the operation of DG units with auxiliary harmonic compensation capability as maintained by accurate power control, this paper presents an improved current controller with two parallel control branches. The first branch is for DG unit fundamental current control, and the secondary branch is engaged to compensate the feeder resonance voltage or local load harmonic current. Compare to the conventional methods the POC voltage and local load current are directly given as proposed current controller. in addition , with simple PI regulation in the outer power control loop, the dg unit also achieves the zero steady state power tracking errors[2] even fundamental current tracking has some steady state errors. Simulated results from a single phase DG unit confirm the exactness of the proposed DG control method. In this paper, a active power filter (APF) is proposed to suppress harmonics due to non-linear loads. The APF is controlled by using PI-controller. A new algorithm using particle swarm optimization (PSO)[10],[11] is proposed for tuning process of PI-controller gains. To minimize the total harmonic distortion (THD) value. By finding the minimum THD value increases the ability of the supply system to handle more non linear loads.

2 DG UNITS WITH HARMONIC COMPENSATION

In this section, a DG unit using the compensation strategy in the conventional closed loop power control technique is briefly discussed. After that a comprehensive discussion on the proposed control approach is presented the configuration of a single-phase DG system is shown in Fig.1 the interfacing converter is connected to the distribution system with a coupling choke L_f and R_f. Local load is connected at POC. For improving the grid current(I_2) , the harmonic components of local load current (I_{Local}) shall be

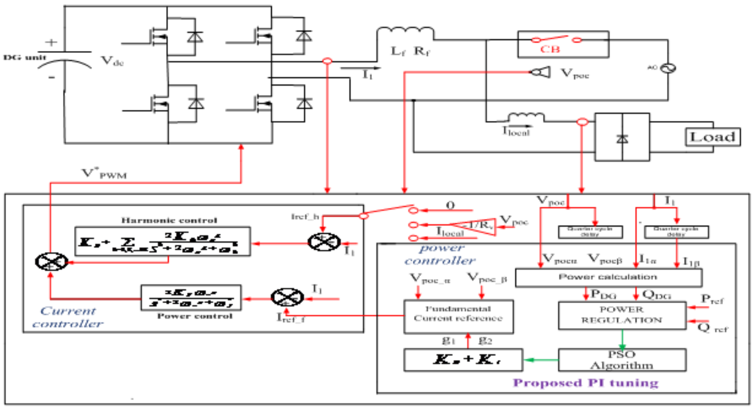


Fig.1.harmonic compensation method with closed loop power control

absorbed through DG current (I_1) regulation. The lower part of the figure illustrates the DG unit control scheme. Its current reference consists of two parts. The first one is the fundamental current reference(I_{ref_f})and harmonic current reference(I_{ref_h}). In order to accomplish precise power control performance in current controlled DG units, the direct fundamental current reference can be determined by a simple closed-loop power control approach as

$$I_{ref\_f} = g_1.V_{PoC\alpha} + g_2.V_{PoC\beta} \tag{1}$$

Where $V_{PoC\alpha}$is the non filtered POC voltage expressed in the $\alpha - \beta$ reference frame $V_{PoC\alpha}$=V_{PoC} and $V_{PoC\beta}$ is its orthogonal signal. The gains g_1 and g_2 are adjustable and the g_1 is used to control DG unit real power and g_2 is used to control the DG unit reactive power. The detailed directive law is shown as follows:

$$g_1 = (K_{p1} + \frac{K_{I1}}{s}).(\frac{1}{\tau s+1}.P_{ref} - P_{DG}) + \frac{P_{ref}}{(E^*)^2} \tag{2}$$

$$g_2 = (K_{p2} + \frac{K_{I2}}{s}).(\frac{1}{\tau s+1}.Q_{ref} - Q_{DG}) + \frac{Q_{ref}}{(E^*)^2} \tag{3}$$

Where P_{ref} and Q_{ref} are the real and reactive power references,K_P1, K_I1, K_P2, K_I2 are proportional and integral control parameters, E^* is the nominal voltage magnitude of the DG unit, τ is the time constant of first order low-pass filters. P_{DG} And $Q_{DG}$are measured DG powers with low-pass filtering as

$$P_{DG} = \frac{1}{2(\tau s + 1)}.(V_{PoC\alpha}.I_{1\alpha} + V_{PoC\beta}.I_{1\beta}) \tag{4}$$

$$Q_{DG} = \frac{1}{2(\tau s + 1)}.(V_{PoC\beta}.I_{1\alpha} + V_{PoC\alpha}.I_{1\beta}) \tag{5}$$

Where $I_1\alpha$ is the nonfiltered DG current expressed in the form of stationary $\alpha - \beta$ frame ($I_1 = I_1\alpha$) and $I_1\beta$ is its delayed orthogonal component. The closed-loop power control method eliminates the power tracking errors. It can be observed from the fundamental current reference in (1) will be distorted if the POC voltage has some ripples. When this is applied to local load harmonic current compensation controller the distorted fundamental current reference will affect the performance of the DG harmonic current tracking. To overcome this problem, an improved proportional and resonant controller with two control branches is proposed as (6). The fundamental current reference in (1) is controlled by the power control branch in (6).as only fundamental resonant controller is adopted in this branch, the effects due to harmonic components in I_{ref-f}can be automatically filtered out. Therefore this power control branch will not introduce any obvious harmonic disturbances to the harmonic control branch in (6).

$$V_{PWM}^* = \frac{2K_{if}\omega_c s}{S^2 + 2\omega_c s + \omega_f^2}.(I_{ref_f} - I_1) +$$

$$(K_p + \sum_{h=3,5,\cdots 15} \frac{2K_{ih}\omega_c s}{S^2 + 2\omega_c s + \omega_h^2}.(I_{ref_h} - I_1))$$

$$G_f(s).(I_{ref_f} - I_1) + G_h(s).(I_{ref_h} - I_1) \tag{6}$$

Meanwhile the harmonic current reference I_{ref_h} is controlled by the "harmonic controller" branch, where only harmonic resonant controllers are included. Considering some ripple harmonics present in the system, to ensure the greater harmonic current tracking a small proportional gain K_p is used. In summary the harmonic current reference in (6) can have three options as follows

$$I_{ref_h} = \begin{cases} I_{Local}, & Local nonlinear load compensation \\ -\frac{V_{PoC}}{R_v}, & Feeder resonsance voltage compensation \\ 0, & DG harmonic current rejection \end{cases} \tag{7}$$

With the compensation method in (6) and the control reference in (7) the real and reactive power should be controlled without any steady state errors. In the conventional methods are the open loops so no power control in the case of proposed closed loop power control method an accurate real and reactive power control is achieved by two PI regulators in the power control loop.

3 MODELLING OF THE DG UNIT WITH CURRENT CONTROL SCHEME

In this part, the harmonic compensation performance using the current controller is scrutinized. It is well understood that the current-controlled inverter shall be described as a closed loop Norton equivalent circuit

$$I_1 = H_c(s).I_{ref} - Y_c(s).V_{PoC} \tag{8}$$

Here the gain ($H_c(s)$ and $Y_c(s)$) can be derived based on the current controller and the DG unit circuitry parameters. The DG unit with harmonic mitigation capability, the current reference I_{ref} has two componentsI_{ref_f} and I_{ref_h}.

The transfer function of DG unit filter plant is G_{Ind} described as

$$I_1 = G_{Ind}(s).(V_{PWM} - V_{Poc}) = \frac{1}{L_f s + R_f}.(V_{PWM} - V_{Poc}) \tag{9}$$

here L_f is the inductance of DG coupling choke and R_f is the stray resistance, V_{PWM} is the average inverter output voltage. Additionally the delay of DG control is written as

$$V_{PWM} = e^{-1.5T_d.s}.V^*_{PWM} \tag{10}$$

Where T_d is the system sampling period. Here the delay includes one sampling period processing delay and half sampling period voltage modulation delay. By solving the equations (6),(9),and (10). The closed loop DG current response can be given as

$$I_1 = H_f(s).I_{ref_f} + H_h(s).I_{ref_h} - Y_P(s).V_{PocC} \tag{11}$$

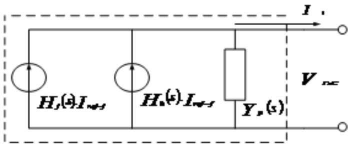


Fig.2 Equivalent circuit of DG unit using current control method

Where $H_f(s)$ and $H_h(s)$ represent the closed loop response of DG unit current to fundamental and harmonic current references respectively. $Y_p(s)$ Demonstrates the sensitivity of DG line current tracking PoC voltage disturbances [8]. The detailed terms of above equation (11) is given as

$$H_f(s) = \frac{e^{-1.5T_d.s}.G_f(s).G_{Ind}(s)}{1 + e^{-1.5T_d.s}.(G_f(s) + G_h(s).G_{Ind}(s)} \tag{12}$$

$$H_h(s) = \frac{e^{-1.5T_d.s}.G_h(s).G_{Ind}(s)}{1 + e^{-1.5T_d.s}.(G_f(s) + G_h(s).G_{Ind}(s)} \tag{13}$$

$$Y_P(s) = \frac{G_{Ind}(s)}{1 + e^{-1.5T_d.s}.(G_f(s) + G_h(s).G_{Ind}(s)} \tag{14}$$

for the DG unit with the proposed current control scheme, a modified Norton equivalent circuit with two controlled current sources can be applied to demonstrate the unique behavior of the proposed controller. As illustrated in Fig.2. The current source $H_f(s)\ I_{ref_f}$ is responsible for regulating the DG unit fundamental current. Additionally the current source$H_h(s)\ I_{ref_h}$ aims to compensate system harmonics at selected frequencies.

4 PI CONTROLLER TUNING USING PSO

In this paper, the PSO is used for obtaining the coefficients of PI controller K_P and K_i. The main aim of the optimal PI controller design is to eliminating the harmonic currents generated by the nonlinear load in the electric grid. The integral of squared error (ISE) is considered as the cost function to be minimized. The PSO technique can generate a high-quality solution within shorter calculation time and more stable convergence characteristic than other stochastic methods[12].

A).PSO Algorithm: Particle swarm optimization (PSO) is a population based stochastic optimization method proposed by James Kennedy and Eberhart in 1995[10]. It is motivated by social behavior of animals in their natural habitat, such as schooling of fish or bird flocking where they searching of food together in a definite area. In other words PSO is an iterative algorithm it search the space to find out the optimal solution for an objective function. PSO algorithm uses multiple searching points in the process to find the optimal solution, optimizing an objective function. In the PSO, each particle starts from a random location and searches the space with its own best knowledge and swarms collective experience. . It is also attracted toward the location of the current global best position X_{gbest} and its own best position X_{pbest}. The fundamental rules of the PSO algorithm can be explained in three stages.

1. Evaluating the fitness value of each particle
2. Updating local and global best fitness and positions.
3. Updating the velocity and the position of each particle

The search rule can be expressed by simple equations with respect to the position vector $X_i[x_{i1}, x_{i2}, \cdots x_{in}]$ and the velocity vector $V_i[v_{i1}, v_{i2}, \cdots v_{in}]$in the N dimensional search space. Velocity and position of the each particle in the next generation can be calculated

$$V_i^{K+1} = \omega V_i^k + c_1 r_1 [X_{pbest}^k - X_i^k] + c_2 r_2 [X_{gbest}^k - X_i^k] \tag{15}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{16}$$

Where c_1 andc_2 are the positive constants and r_1, r_2 are the uniformly distributed random numbers.V_i^k and X_i^k are the velocity and position of the particle i at the iteration k. and is the inertia weight X_{gbest}^{k} and X_{pbest}^{k} are the global best position that is achieved so far, based on the swarms experience, and local best position of each particle that is achieve so far, based on its own best position, respectively. it is worth mentioning that the second term represents the cognitive part of PSO where the particle changes its velocity based on its own opinion and memory. The third term indicates the social component of PSO where changes the particle velocity depends on the social-psychological adaptation of awareness. Depending upon updated velocities each particle changes its position by (16).

The main limitation of the PSO algorithm is the confined search space. The Limited search space provides a fast solution, but it influences the optimality of the solution if the global optimum value is located outside the boundaries. However, extended boundaries allow finding global optimum results, but require more time to find out the global optimal value in the search space. Therefore, more information about the limits of the parameters will help to determine the search boundaries

5 SIMULATED RESULTS

In order to validate the exactness of the proposed control strategy, simulated results are obtained from a single phase DG unit.

1).Compensation of local nonlinear loads: the DG unit is tested with a local diode rectifier load in this simulation. The configuration of the system is the same as shown in Fig.1and PoC is connected to a stiff controlled voltage source with nominal 50Hz frequency. The reference active and reactive power is set to 600w and 200var.the complete parameters of the system are provided in Table I. .meanwhile DG unit current is polluted with 61.87% THD.

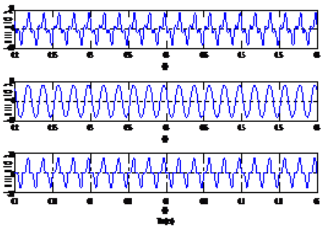


Fig.3 Performance of the DG unit during DG harmonic rejection: (a) grid current I2; (b) DG current I1; (c) local load current Ilocal

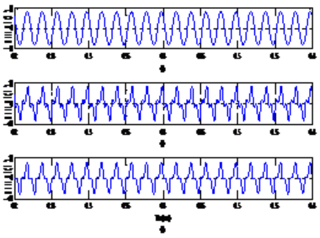
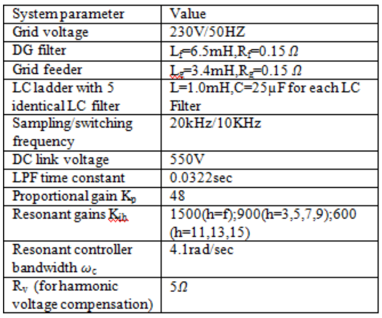


Fig.4 performance of the DG unit during local load compensation mode : (a) grid current I2 ; (b) DG current I1 ; (c) local load current Ilocal.

when the local load harmonic current is not compensated by the DG unit ,[I_{ref_h}=0 in (6)and(7)dg harmonic rejection mode],the DG unit performance is shown in Fig,3 from the Fig.3(b) shows that the DG current is sinusoidal with 5.24% Total harmonic distortion(THD).at the same time the harmonic current flowing to the grid and local load current are illustrated in 3(a) and 3(c)respectively.

By setting the $I_{ref_h} = I_{local}$ in (7) the local load harmonic current compensation method is activated, the system performance is shown in Fig.4.harmonic extractions are not used in this local load current compensation method resulted in an enhanced grid current quality with 5.13 %THD

TABLE 1.



System parameter	Value
Grid voltage	230V/50HZ
DG filter	L_f=6.5mH,R_f=0.15 Ω
Grid feeder	L_g=3.4mH,R_g=0.15 Ω
LC ladder with 5 identical LC filter	L=1.0mH,C=25µF for each LC Filter
Sampling/switching frequency	20kHz/10KHz
DC link voltage	550V
LPF time constant	0.0322sec
Proportional gain K_p	48
Resonant gains K_{ih}	1500(h=f);900(h=3,5,7,9);600 (h=11,13,15)
Resonant controller bandwidth ω_c	4.1rad/sec
R_v (for harmonic voltage compensation)	5Ω

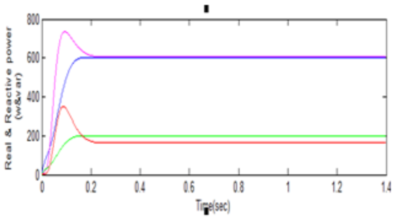


Fig.5 Power flow of the DG unit during local load harmonic current compensation mode (Pref=600 W and Qref=200 var)

The DG unit also supplies 200 var reactive power to the grid. in the conventional methods the DG output real and reactive power control is not accurate The effectiveness of the closed loop power control strategy is verified in Fig.5. Alternatively, the proposed control strategy regulate the DG output power in a closed loop manner it gives the zero steady-state power tracking error.

2).compensation of feeder resonance voltage method: to check the feasibility of the proposed method to compensating the feeder resonance voltage the DG unit is connected with a five cascaded LC ladder network. Each inductance and capacitance filter has a 1mH and 25 F respectively. The performance of the proposed controller in DG unit harmonic rejection mode I_{ref_h}=0is shown in Fig6. In the lower part of the Fig.6 shows the PoC voltage is distorted with 12.07%THD, due to the resonance aggregated in the LC ladder meanwhile the main grid current contains harmonics with 20.42 %THD

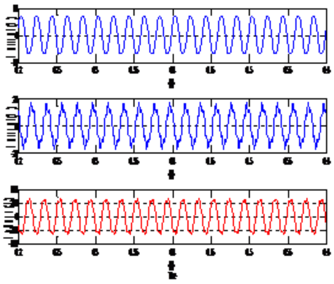


Fig.6 Performance of the DG unit during DG harmonic rejection: (a) grid current I2;(b) DG current I1; (c) voltageVpoc.

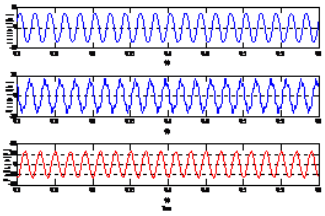


Fig.7 performance of the DG unit during feeder resonance voltage compensation: (a) grid current I2; (b) DG current!1; (c) voltageVpoc

When the feeder resonance voltage compensation is activated by controlling the DG unit as a virtual resistance [Rv=5 in (7)] at selected harmonic frequencies, the response of the system is shown in Fig.7in this case the harmonic voltages are mitigated and its THD reduces to 4. 71%.The current waveforms during the feeder resonance voltage compensation method is shown in Fig.7 that the DG current has more distortions, while the main grid current THD reduces to 7.12%.

3).harmonic reduction with PSO: by tuning the PI controller with PSO algorithm obtained the parameters K_p and K_i from these values simulate the Fig.1the THD values are reduced compared to previous method in Fig.8 the current compensation method with PSO the THD value reduces to 4.88% and Fig.8 shows the feeder resonance voltage method with PSO the distortions are reduced to 4.69%.

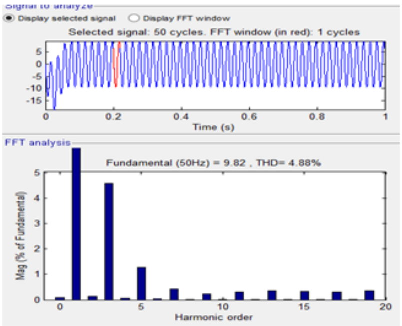


Fig.8 THD value of grid current I1 in current compensation

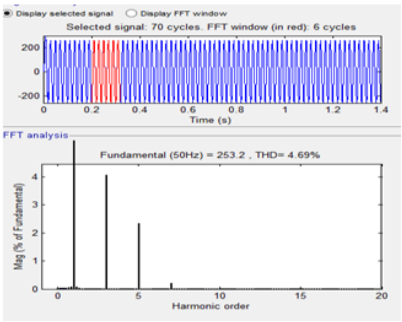
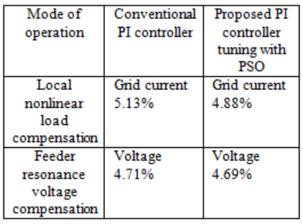


Fig.9 THD value of voltage Vpoc in feeder resonance compensation

The proposed method is compared with the conventional method the THD values are reduced is shown in table-2

TABLE 2.



Mode of operation	Conventional PI controller	Proposed PI controller tuning with PSO
Local nonlinear load compensation	Grid current 5.13%	Grid current 4.88%
Feeder resonance voltage compensation	Voltage 4.71%	Voltage 4.69%

Mode of operation Conventional PI controller Proposed PI controller tuning with PSO Local nonlinear load compensation Grid current 5.13% Grid current 4.88% Feeder resonance voltage compensation Voltage 4.71% Voltage 4.69%

6 CONCLUSION

The results expose that, the proposed implementation of PSO for finding out the optimum parameter values of PI controller gains K_p and K_i yields superior result compared to the conventional PI controller tuning approach. Moreover, the PSO algorithm is easy to implement, independent of the initial and conditions and system dynamics, computationally inexpensive, faster convergence to reach the optimum solution with reduction in maximum overshoot. This ultimately results in reducing the THD values of the grid current and voltage.

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