Original Research Article

Active-Reactive Power Stability Analysis a Micro Grid in Grid to Connected Mode Based on Particle Swarm Optimization (PSO) Including Model Information

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ABSTRACT

Aims: The aim of this paper is optimal active-reactive power flow between main grid and micro-grid consists of two parallel DG units.

Study design: Design of the study is applied with optimization algorithm for proposed controller power control policy. Power controller is designed to active-reactive power (P-Q) control policy.

Place and Duration of Study: IAU, Iran, February 2015-January 2016.

Methodology: This paper, with using of particle swarm optimization (PSO) and model information analysis and control active and reactive power stability of a micro-grid includes two parallel DG units. Particle swarm optimization (PSO) model of proposed controller includes an inner current control loop and an outer power control loop based on synchronous reference frame and conventional PI regulators. PSO algorithm is used for real-time self-tuning power control parameters. Paper's simulation is modeled in MATLAB/Simulink environment. As well as, PSO algorithm is programmed in M-file of MATLAB.

Results: Simulation result show satisfactory performance active and reactive power of system. As well as, In the paper, control objectives to identify generator angle reference signal and flux, and system dynamic performance improvement are used. As well as, this paper provided active-reactive power flow control between main grid and micro-grid includes DG units, and controller response in situations where load is higher or much lower than DG unit power rate. Paper's proposed policy suggests that required load power equally between micro-grid and main grid based on PSO algorithm and using information model during load changing is shared, and to fast dynamic response and stable operation is reached.

Conclusion: The paper is presented a power (P-Q) control policy for micro-grid based on PSO algorithm. This is done by proposed active and reactive power controller based on PSO algorithm for real-time self-tuning. In the paper, active and reactive power flow adjustment when that micro-grids interconnected are connected to the network has been proposed. Therefore, peak correction effectively reduces imported power from electric utility to half. In conclusion, this policy could be have significant implications for micro-grid scenario: reducing dependence on the main power system, increasing penetration in micro-source market, reduce electricity costs, and improve sustainability.

Keywords: (Active-reactive power flow control, Connected to grid mode, Model information, PSO algorithm, Stability analysis.)

1. INTRODUCTION

A micro-grid (MG) is a cluster of DG units that interface with an electrical distribution network using power electronic devices such as the voltage source inverter (VSI) [1]. Robust and reliable micro-grid operation significantly dependent on DG units vector control scheme. Therefore, effective power control loop for an inverter-based DG unit based on inverter can play a key role in stability improving and power quality requirements [2]. In other words, as shown in figure 1, while current control loop is used for inverter output current quality improving, as well as, an outer power control loop, can be integrated with inner current control loop to regulate inverter output power. In addition, current control loop will guarantee qualified reference current signals for current controller. Accordingly, DG unit based on inverter can be controlled with considering to power rules such as voltage, frequency, active-reactive power [3]. In this case, DG unit can act as a current source power controller. In conclusion, and for both micro-grid operation mode, power controller can be chosen based on vital issues affecting in power supply quality and stability improving. For example, power flow control in connected to grid mode can be provided control main objective. Because micro-grid overall operation is fully dictated by the majority of power systems, so there are no pressure over power flow adjustment for optimal use of DG unit. In contrast, long as micro-grid from island mode passes, operation important problems are evident. In the first place, this problems related to voltage drop and frequency deviation related to different characteristics connected DG units. Additional load sharing mechanism is another important issue that to obtain efficient operation in both micro-grid operation modes should be considered [4]. Main policies of power control for DG unit based on inverter to satisfy mentioned issues in below is provided. As a result power quality and stability in micro-grids are improved.

Control over active and reactive power flow is necessary to inverter power output adjustment. This method can help to ensure reliable operation of connected DG unit, reduction injection power from grid, and support any contract between micro-grid and electric utility. Thus, active-reactive power control mode can be explained based on a micro-grid operation

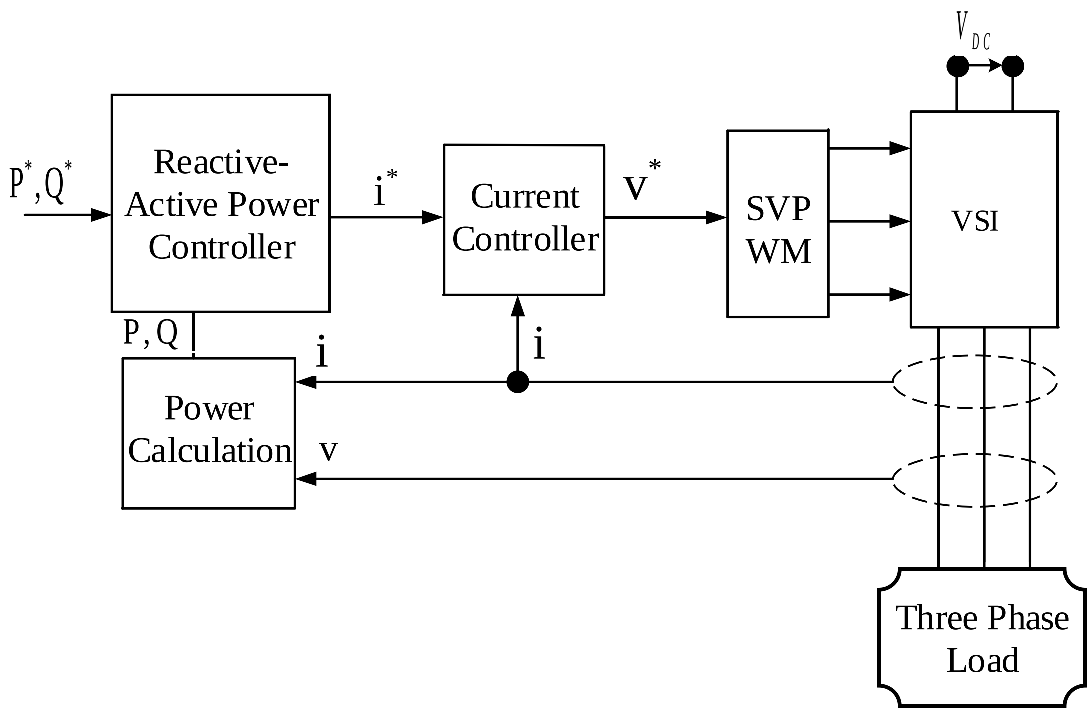

Fig. 1. Controlled power VSI system design schematic

mode. For example, control priority, in automated micro-grid mode maintain frequency and voltage system under the verge of collapse threshold. So, when power flow control obtained that micro-grid frequency and voltage adjustment to be achieved, and thus system can be reliable power quality produces in this mode. In contrast, due to many effects of huge power systems operation in grid to connected mode, each DG unit acts as active and reactive power source [5]. In this case, control over active and reactive power flow to maximize connected DG unit generation is very useful. In conclusion, an economical operation policy based on market policies can be implemented to best power management between micro-grid and electric utility.
Recently, in researchers' works, power management between micro-grid and electric utility by many researchers to obtain best use from different types of DG unit is targeted. For example, combined control from active and reactive power in order to facilitate connection between single-phase hybrid micro-grid and electric power system is

proposed. In this work, in order to compensate for load reactive power, control structure injections reactive power to the load, and after that redundancy stabilization is designed in network. However, this controller for three-phase system due to its complexity may not be possible. Shunt active filter with energy storage to reduce voltage weaken and improve supplied power to nonlinear load is proposed. This filter control with synchronous generator is coordinated, and current filter creates a unique feedback signal. Accordingly, voltage drop is manipulated, whereas active and reactive power after lengthy transient state (9 seconds) to become stable operation. In [6], mixture of genetic algorithms and power flow calculation is presented for position allocation and DG units' size related to the electric power system. This method for DG units' installation to obtain best economic conditions of operation is useful. However, active and reactive power flow control against chaos in real time operation is not considered. In [7], power flow control for DG unit based on an inverter in single-phase grid-connected operation mode is proposed. This controller adjust active and reactive power respectively by power angle and voltage filter capacitor adjustment. The main objective to achieve stable operation was considered, is low static fault, and fast dynamic response [8]. As a result, any method for active-reactive power automated adjusting is not suggested, in conclusion compiled power from upstream electric utility to the restricted rate have been reduced.

On the other hand, system stability under given operation conditions has become an important problem for micro-grid operation. This model can be defined as an analytical approach that can check system stability under normal operation conditions. Overall dynamic model includes linear state space equations which defines the composition of each component of system. After this stability can be analyzed by computing eigenvalues [9]. In [10], transient stability were studied in power systems that through a power converter with a DG unit was linked. This analysis was for a system with an infinite bus, and micro-grid operation mode of power system grid was not considered. For standalone mode, [11] control approach with parallel inverters connected to each other, which can be changed for any AC system is considered.

In the paper, control objectives to identify generator angle reference signal and flux, and system dynamic performance improvement are used. As well as, this paper provided active-reactive power flow control between main grid and micro-grid includes DG units, and controller response in situations where load is higher or much lower than DG unit power rate. Paper's proposed policy suggests that required load power equally between micro-grid and main grid based on PSO algorithm and using information model during load changing is shared, and to fast dynamic response and stable operation is reached.

Paper has been categorized as follow; description on connected to grid three phase VSI system modeling and relevant concepts has been done in part two. Describe applied PSO algorithm have been done in part three. Simulation result have been presented in part four. Conclusion has been presented at the end of the research too.

2. CONNECTED TO GRID THREE PHASE VSI SYSTEM MODELING

Conventional three-phase VSI model connected to grid with an LC filter, consumption load RLC, and control and power circuits of two DG unit based on VSI shown in figure 2.

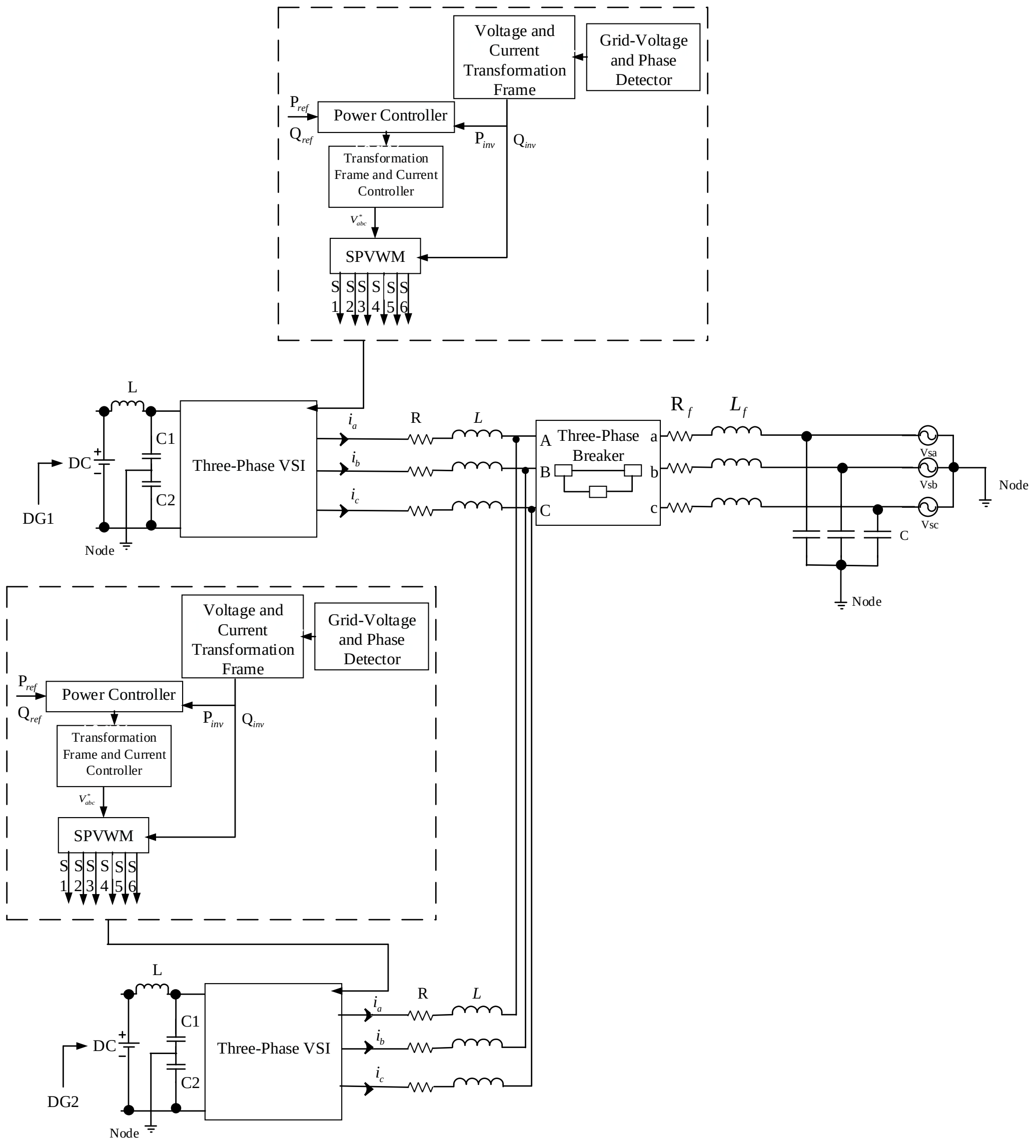

Fig. 2. Conventional three-phase VSI model connected to grid with control and power circuits of two DG unit based on VSI

Which, R_s and L_s are respectively node equivalent resistance and connection transformer filter inductance if applicable and so that network is detected by inverter. As well as, C, C_1, C_2 all are filter capacitor, L is inductance and V_s voltage of network.

Reference frame equations abc of equivalent circuit system state space in (1-5) is shown.

In equivalent circuit reference frame system based on state space equations [12] has been proposed to this form:

$$\left\{\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}\right\} = \left\{\frac{R_S}{L_S}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_S}\left(\begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} - \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}\right)\right\} \quad (1)$$

Using with Park's transformation, (1) can be expressed in reference frame as follows:

$$\left\{\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix}\right\} = \left\{\begin{bmatrix} -\frac{R_S}{L_S} & \omega \\ -\omega & -\frac{R_S}{L_S} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_S}\left(\begin{bmatrix} V_{Sd} \\ V_{Sq} \end{bmatrix} - \begin{bmatrix} V_d \\ V_q \end{bmatrix}\right)\right\} \quad (2)$$

That ω is the related angular frequency. Park's transformation can be defined as follows:

$$\mathrm{i}_{dq0} = \left(T i_{abc}\right) \quad (3)$$

Which,

$$\mathrm{i}_{dq0} = \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}, \quad \mathrm{i}_{abc} = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (4)$$

$$\mathrm{T} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin\theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (5)$$

$\theta = \omega_s t + \theta_0$ Is synchronous rotation angle, and θ_0 represents the initial value.

At first, must be expressed that the control system are looking for supply a set of characteristics in terms of measurable quantities that identifier performance of system.

In conventional mode control method are caused by trial and error method. Now, in the paper, by introducing a system performance indicator and achieve to optimal set of system parameters through minimizing the system functions can be reached to optimal and stable system results (according to the requirements of appropriate performance indicator). According to the control objectives, mainly, minimizing error integral function problem related with four measuring error includes: Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Square Error (ITSE), and Integral Time Absolute Error (ITAE) that best results of previous studies is related to using (ITAE).

$$F = Min\left\{\int_0^{t_{ss}} t\left|e(t)\right| dt\right\} \quad (6)$$

That e is difference between actual and desired output values (error function), and t_{ss} steady state period since the change of time is (point) input value. In conclusion, the controller objective function in the paper, formulated based on the ITAE which calculated with using Simpson's $\frac{1}{3}$ rule.

2.1 VSI Control Policy in a Grid to Connected Mode

As shown in figure 2, VSI power circuit based on DG unit with a control structure is associated, therefore, DG unit controlled operation is based on an inverter control mode. For example, in grid to connected mode, DG unit acts as a P-Q generator and inverter must be under active–reactive power (P-Q) control mode, while voltage and frequency adjusting is not necessary due to grid voltage is constant. Grid to connected mode should be able to flexibility and power conversion via main grid. So, power flow appropriate control policies generated from / to the grid will help. Inverter control policy is responsible providing a controlled operation grid to connected DG unit. Main objective this mode is load accumulation reducing from main grid. Thus, assuming proper power control mode is essential for ensure connected DG unit high performance. In following, power control policy related to grid to connected operation mode have been proposed.

2.1.1 P-Q Control Mode

As long as voltage and frequency are in stable condition, P-Q control mode is applicable that can be used to impress less power entered into grid (peak correction) in grid to connected mode, or to generate stable active-reactive power in the standalone mode. Usually, P-Q mode for DG units that constant power apply to them is used, so that photovoltaic cell is an example of use this application [13]. In this case, inverter amplitude and phase angle in order to inject active-reactive power predetermined amount is controlled, that can be defined locally or by micro-grid control center. Figure 3 a block diagram of system P-Q control policy is shown.

Active-reactive power measured values are expressed as follows [9]:

$$P_{inv} = \left(\frac{3}{2} (\mathrm{V}_{(d)inv} . \mathrm{i}_{(d)inv} + V_{(\mathrm{q})\mathrm{inv}} . \mathrm{i}_{(q)inv}) \right) \quad (7)$$

$$Q_{inv} = \left(\frac{3}{2} (\mathrm{V}_{(\mathrm{q})inv} . \mathrm{i}_{(d)inv} + V_{(d)\mathrm{inv}} . \mathrm{i}_{(q)inv}) \right) \quad (8)$$

2.2 Proposed Control Policy

This section provided proposed power controller for grid to connected three phase VSI system. The control scheme consists of three main blocks: power controller, linear current controller, and PSO algorithm for power control parameters real-time self-tuning. The following two sections is described proposed power control mode performance in detail.

2.2.1 Current Control Policy

Controller objective ensure from accurate tracking and inverter output current short transition. In the controller, current control loop block diagram has been designed which is based on a synchronous reference frame. Linear current controller based on SVPWM and kind of open loop voltage with using current internal feedback loop. Usually the controller used in cases where applied voltage to the resistance - impedance R - L, such that impulse current in inductor is reached to errors minimize. It is necessary use PLL block to detect voltage phase angle in order to implement a Park's transformation in control scheme. Two PI regulators for eliminate current fault, and both Inverter current loop and grid voltage feed forward loop to improve steady state and dynamic performance have been used.

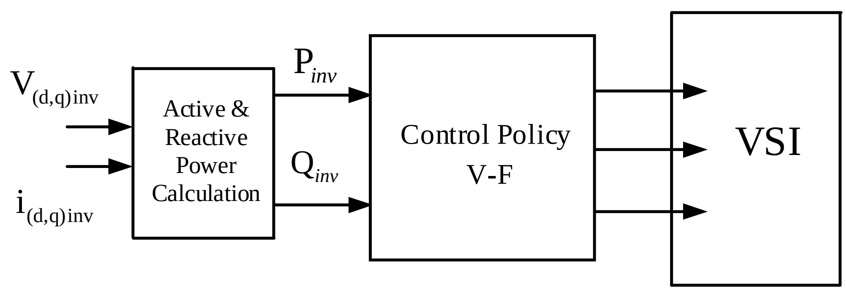

Fig. 3. VSI based on P-Q controller

In conclusion, controller output signals represents reference voltage signals in the frame dq. These are obtained by Park and Clarke transformation inverse, so that reference voltage signals generation controller in the stationary frame $\alpha\beta$, to uses a combination of six-pulse for inverter (IGBT) SVPWM. In addition, using from PWM method ensures that controller is achieved desired output voltage vectors with less harmonic distortion.

In synchronous frame dq according to (2), the reference voltage signals are presented as follows:

$$\begin{bmatrix} V_d^* \\ V_q^* \end{bmatrix} = \left(\begin{bmatrix} -K_P & -\omega L_S \\ \omega L_S & -K_P \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} K_P 0 \\ 0 K_P \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} + \begin{bmatrix} K_i 0 \\ 0 K_i \end{bmatrix} \begin{bmatrix} X_d \\ X_q \end{bmatrix} + \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} \right) \quad (9)$$

In Which, asterisk "*" indicates to reference values, and reference represents $\frac{dX_d}{dt} = i_d^* - i_d$, and $\frac{dX_q}{dt} = i_q^* - i_q$. Using with Clarke transformation, (9) can be transferred to the stationary frame $\alpha\beta$. As well as, inductor current by using a low pass filter (LPF) is obtained. In the paper, LPF as a first order transfer function is considered that in form of (10) is provided:

$$f_l = \left(f \frac{1}{(1+sT_i)} \right) \quad (10)$$

Which f is filter input value, f_1 is filtered value and T_i is time constant.

2.2.2 Power Control Policy

This policy objective is power flow control between micro-grid and main grid in supply controlled active-reactive power condition to the load. Proposed power controller block diagram is based on two PI regulators. This controller represents outer control loop that for is employed to generate current reference vectors i_q^* and i_d^*. In conclusion, relatively slow change of reference current path, ensures inverter output power high-quality, that shows control objective is obtained. In this section of paper, it has been suggested P-Q control policy based on PSO algorithm for DG unit based on inverter. Active-reactive power are main objectives of controller that should once are obtained in DG unit grid to connected mode, and or load change conditions. In this mode, whereas analysis between active-reactive power by (10) and (11) is carried out, inverter output active-reactive power controller adjust based on their reference values P_{ref} and Q_{ref}. As well as, PSO algorithm is provided optimal control parameters for qualified reference current vectors. Accordingly, in reference frame dq and based on PI regulators, reference current vector is expressed as follows:

$$\mathrm{i}_d^* = \left\{ (\mathrm{P}_{ref} - \mathrm{P}_{inv})(\mathrm{K}_{pp} + \mathrm{K}_{ip} / \mathrm{s}) \right\} \quad (11)$$

$$\mathrm{i}_q^* = \left\{ (\mathrm{Q}_{ref} - Q_{inv})(\mathrm{K}_{pq} + \mathrm{K}_{iq} / \mathrm{s}) \right\} \quad (12)$$

3. DESCRIBE APPLIED PSO ALGORITHM

In the paper, PSO algorithm to solve optimization problem arising from need finding the optimal and desired parameters for proposed power controller implemented. This algorithm are planned for optimization problems processing based on the error in real-time condition. As well as, exclusively for any control objective implemented separately. The algorithm performance provides accurate results that the approach is consistent optimization problems in many engineering programs. In this paper, PSO algorithm to improve power supply quality and its stability improvement for the micro-grid operation scenario and as well as, as third block in proposed control policy, is used.

PSO algorithm coding in MATLAB environment (M-file) have been done. PSO algorithm parameters (maximum iterations to achieve the optimal solution: 500 iterations, number of sampling: 200 particles) has been defined. As well as, this program is coded by three loop is reached to the final solution (g_{best}). In the simulation expression, simulation problem is related to system under study in figure 2. The system consists of two DG unit that in form two batteries in parallel modeled (DG1=700 volts, DG2=500 volts) and by the switching method is connected to the grid. In figure 2 from consumption load is used in grid structure. As well as, a power key to connect and disconnect is used in infinite bus.

4. SIMULATION RESULT

In this section is discussed to analysis the system simulation results. The proposed three-phase VSI system model and controller simulated with using MATLAB Simulink environment (MATLAB / SIMULINK), and in figure 2 it is clear. As well as, model parameters includes $L_s = 5mH$, $R_s = 1\Omega$, $f = 50Hz$, filter capacitor $C = 50\mu F$, DC side input capacitor $5000\mu F$, DG unit power rate, and current control parameters $K_p = 12.656$ and $K_i = 0.00215$. As well as, for SVPWM based on current controller, respectively switching and sampling frequency is $10kHZ$ and $500kHZ$ respectively. It must be noted, all of the results in terms of ($p.u.$). In the system, two DG unit is connected with each other and generally connected to the main grid and consumption load. As mentioned earlier, a grid structure is assumed in presence of different distributed generations (DGs) and consumption load. As well as, in this structure in between time 0.3 – 0.4 seconds, DGs and consumption load to lose the support of the main grid and are disconnected from the grid. Switching control structure in this section is considered as standard.

The authors' purpose from express DG in simulation results is DG1 and DG2. In figure 4 is shown DG (DG1 & DG2) output current changes in presence of two classic and intelligent method. In this figure with considering to consumption power will be supplied by two DGs, fluctuations and power changes in the micro-grid mode has declined. As well as according to figure 4, method based on artificial intelligence (PSO) (purple curve) includes less changes and fluctuations.

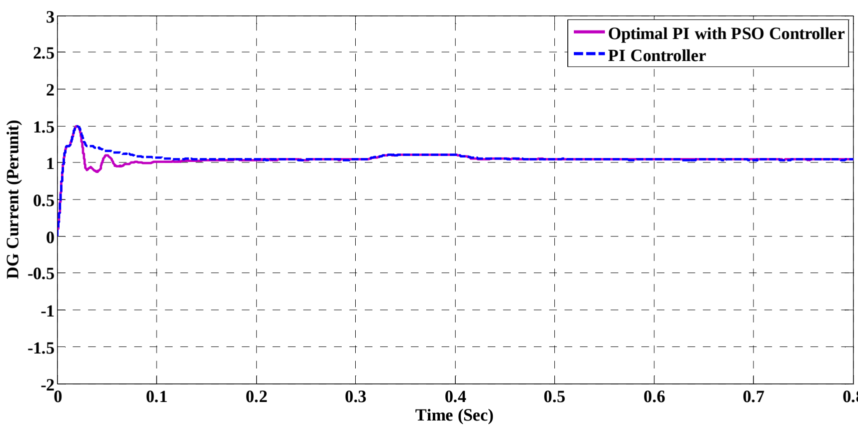

Fig. 4. DGs output current changes

In figure 5 and 6 respectively DGs voltage changes and DGs active power changes is shown. According to these figures, generation power and voltage changes are located more favorable status in conditions that optimization algorithms have been used. In conclusion has less fluctuations in compared with mode of PSO algorithm is not used.

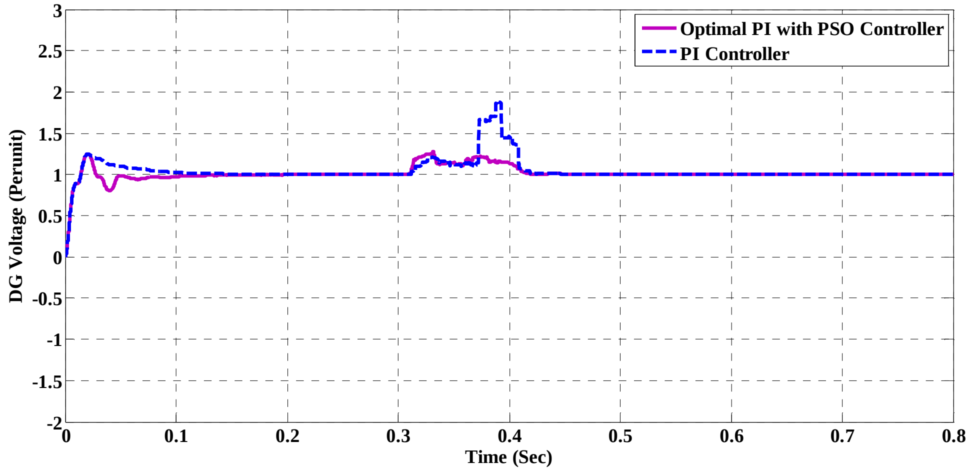

Fig. 5. DGs output voltage changes

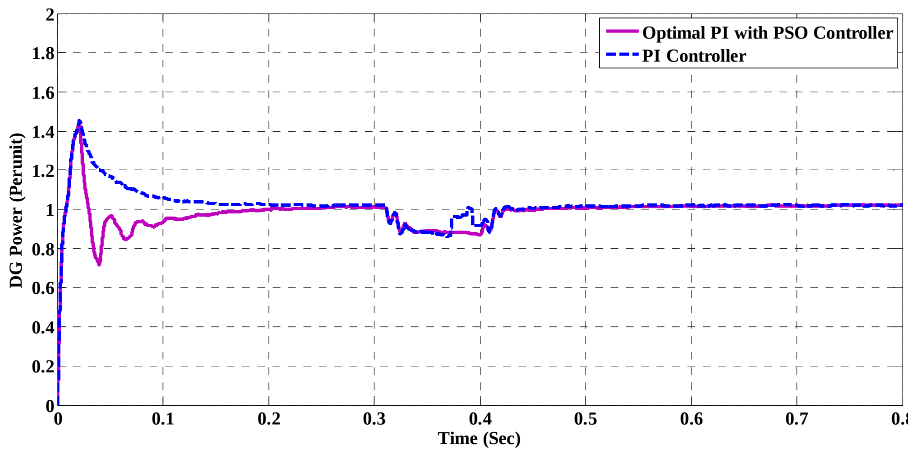

Fig. 6. DG unit output active power changes

As well as, in figure 7, DG unit output reactive power is shown.

It is clear in figure 7, with considering to reactive power consumption amount in the grid under study, generated reactive power by DG unit is less than active power.

In figure 8 and 9 respectively main network current changes and main network active power changes is shown.

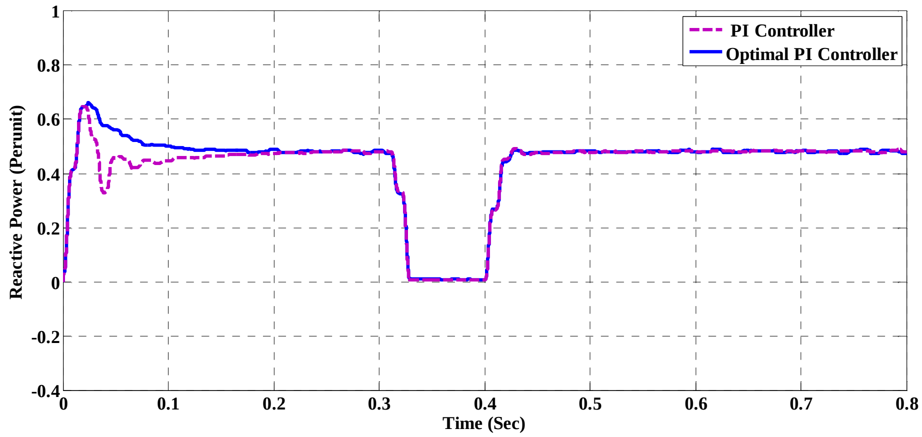

Fig. 7. DG unit reactive power changes

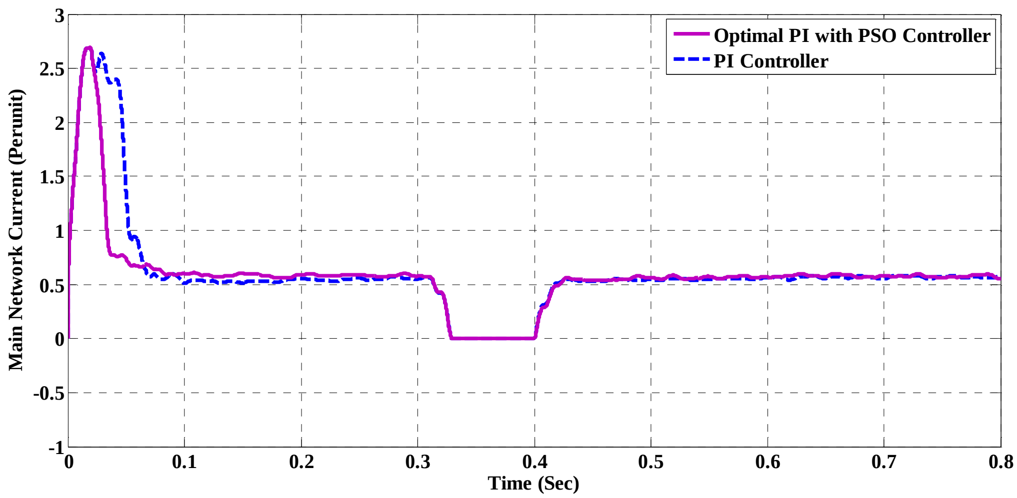

Fig. 8. Main network current changes

According to figure 8 at 0.3 to 0.4 seconds, system is isolated from main network and current is reached to its minimum (zero value).

As well as, according to figure 9 in conditions that DG controllers coefficients have been set by the PSO algorithm, the system includes less power fluctuations.

In figure 10, main network reactive power changes is shown.

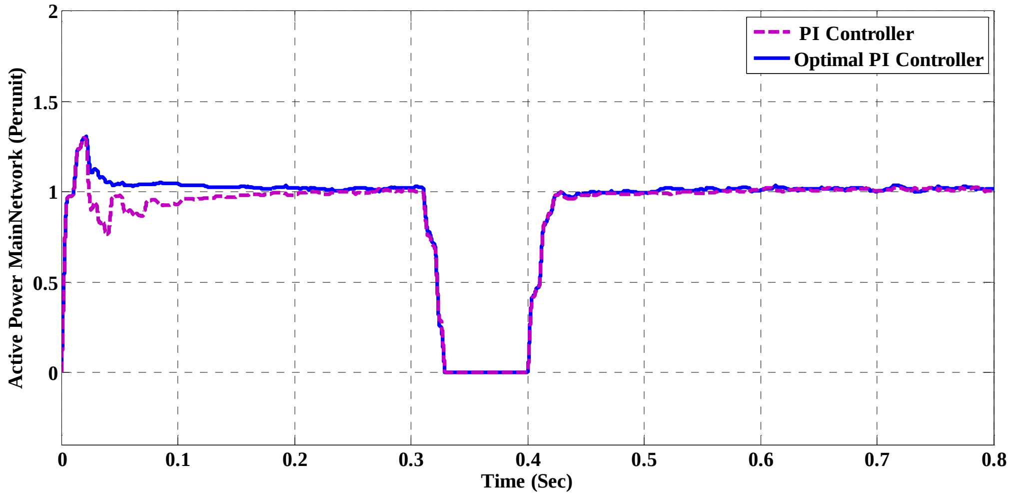

Fig. 9. Main network active power changes

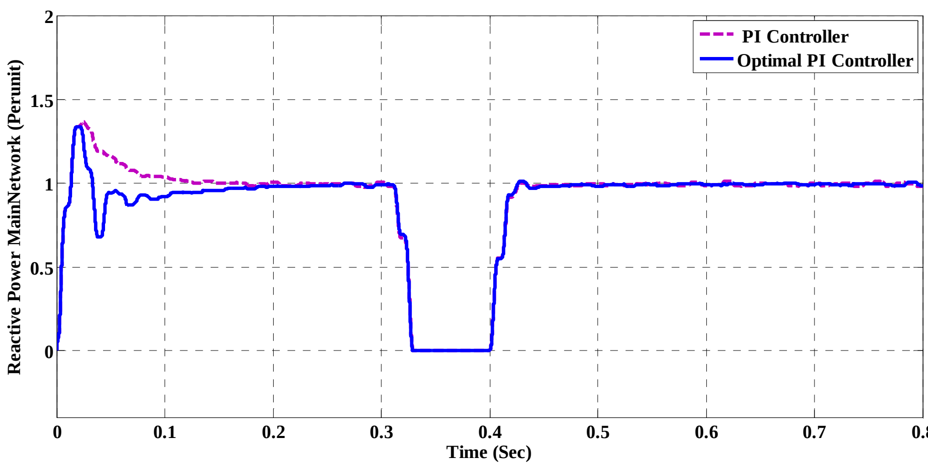

Fig. 10. Main network reactive power changes

According to figure 10, in initial times the system includes fluctuations in generation power that over time, this fluctuations has improved, in conditions that optimized system by PSO algorithm includes less fluctuations.

In figure 11, main network frequency fluctuations changes is shown.

According to figure 11, total main network frequency fluctuations is about 0.3 Hz. As well as, in conditions that optimized system by PSO algorithm (blue curve) includes less fluctuations.

In figure 12, DG output total harmonic distortion is shown. Figure 12 in terms of using system by classical controller is obtained. Total harmonic distortion (THD) obtained in this section is 14.26 percent.

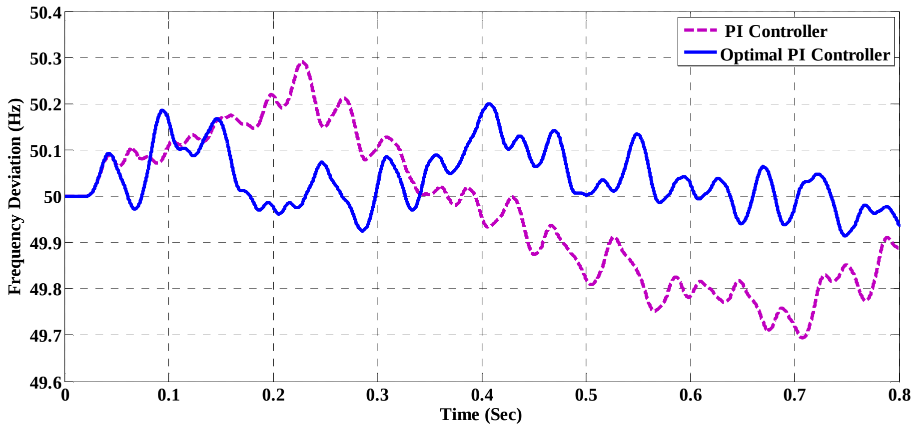

Fig. 11. Main network frequency fluctuations changes

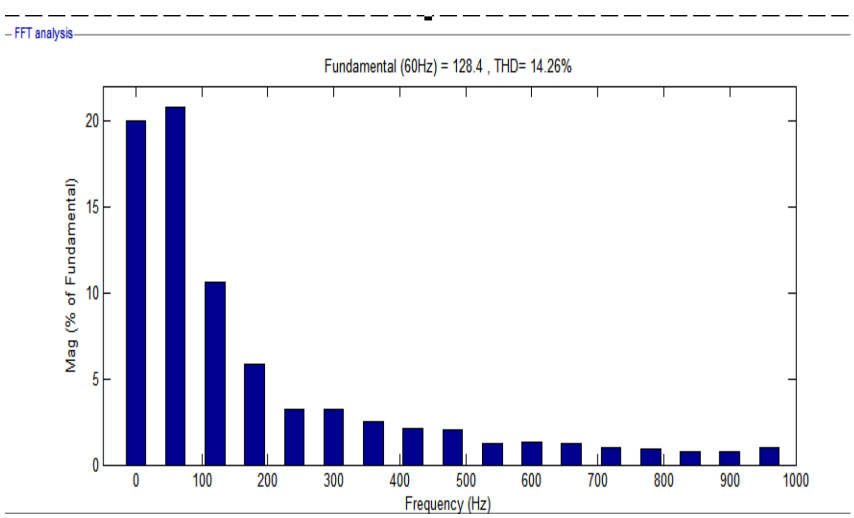

Fig. 12. DG output total harmonic distortion in presence of classical controller

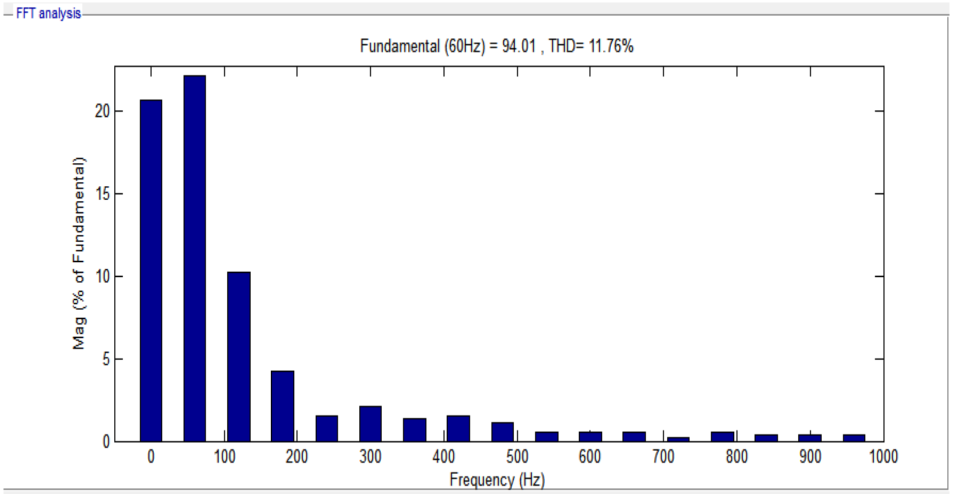

Fig. 13. DG output total harmonic distortion in presence of optimized classical controller

In figure 13, DG output total harmonic distortion using with optimized classical controller is shown. Total harmonic distortion (THD) obtained in this section is 11.76 percent, that compared to non-optimized mode had a significant reduction in the total harmonic distortion.

CONCLUSION

In the paper, active and reactive power flow adjustment when that micro-grids interconnected are connected to the network has been proposed. The goal was applied by proposed active and reactive power controller based on PSO algorithm to real-time self-tuning. In this work, load demand equally is divided between the micro-grid and electric utility especially long as micro-grid is in grid to connected operation mode or during load changes. Therefore, peak correction effectively reduces imported power from electric utility to half. In conclusion, this policy could be have significant implications for micro-grid scenario: reducing dependence on the main power system, increasing penetration in micro-source market, reduce electricity costs, and improve sustainability.

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