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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Authors' contributions

This work was carried out in collaboration between all authors. Author SMM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SMS managed the literature searches, analyses of the study, performed the spectroscopy analysis and author RD managed the experimental process and identified the species of plant. All authors read and approved the final manuscript.

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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 Distributed Generation (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

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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, the 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, 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.

1. INTRODUCTION

A Micro-Grid (MG) is a cluster of Distributed Generation (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 Fig. 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. Under grid-connected mode, the output active and reactive power of the DG unit should be regulated based on their reference values, therefor VSI should adopt an appropriate power control mode. The main objective of this mode is to attain a low static error rate and a fast response, and to preserve system stability, especially during abrupt changes. To accomplish this, it is necessary to conduct this mode with the current controller scheme to ensure high power tracking, as it is not sufficient to rely only on the power control mode [5]. Thus, the current control policy of the PWM-VSI system is one of the most important aspects of the modern power electronics converters. There are two main categories for current controllers: nonlinear controllers based on closed loop current type PWM, and linear controllers based on open loop voltage type PWM [6].

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 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 [7]. 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 [8], 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 [9], 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 [10]. 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.
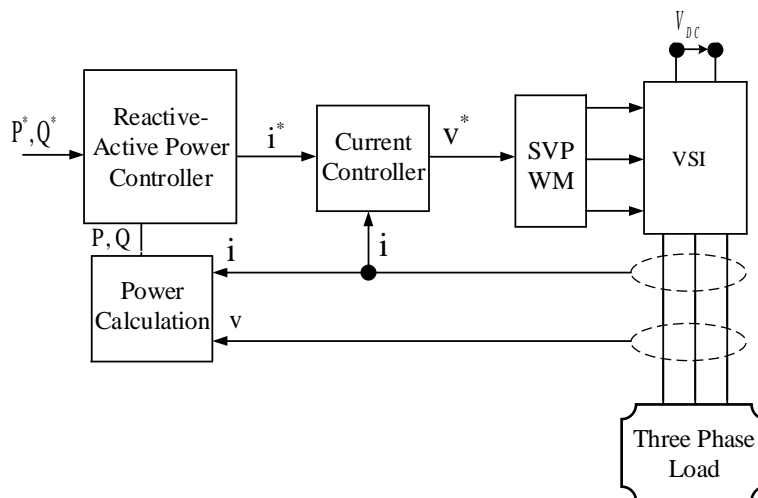

Fig. 1. Controlled power VSI system design schematic

After this stability can be analyzed by computing eigenvalues [11]. In [12], 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, [13] 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. Simulation result have been presented in part three. Conclusion has been presented in part four.

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 Fig. 2.
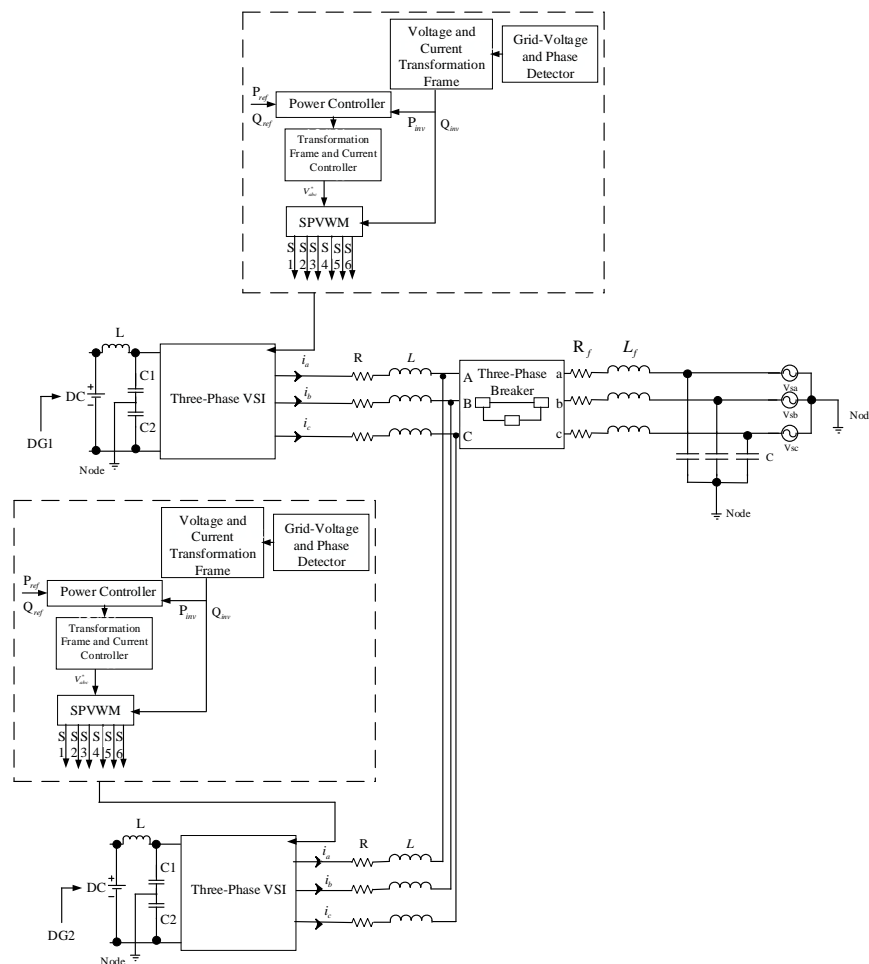

Fig. 2. Conventional three-phase VSI model connected to grid with control and power circuits of two DG unit based on VSI

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 equations 1 to 5 is shown.

In equivalent circuit reference frame system based on state space equations [14] 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, equation 1 can be expressed in reference frame as follows:

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

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,

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

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

Which $\theta = \omega_s t + \theta_0$ 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).

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

Which e is error function and t time period respectively. Therefore, 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 Fig. 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. Fig. 3 a block diagram of system P-Q control policy is shown.

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

$$P_{inv} = \left(\frac{3}{2} (V_{(d)inv} \cdot i_{(d)inv} + V_{(q)inv} \cdot i_{(q)inv}) \right) \quad (7)$$

$$Q_{inv} = \left(\frac{3}{2} (V_{(q)inv} \cdot i_{(d)inv} + V_{(d)inv} \cdot i_{(q)inv}) \right) \quad (8)$$

2.2 Proposed Control Policy

In this section is described the control scheme. The control scheme consists of three main blocks: power controller, linear current controller and PSO algorithm for power control parameters real-time self-tuning [14]. 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, both Inverter current loop, grid voltage feed forward loop to improve steady state and dynamic performance have been used.

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:

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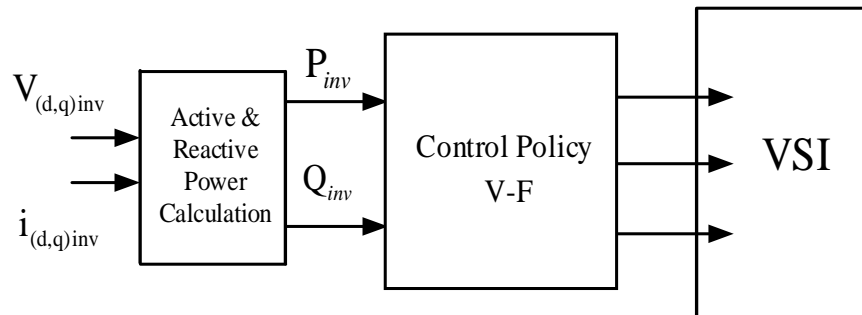

Fig. 3. VSI based on P-Q controller

In which, asterisk "*" indicates to reference values, reference represents $\dfrac{dX_d}{dt} = i_d^* - i_d$ and

$\dfrac{dX_q}{dt} = i_q^* - i_q$. Using with Clarke transformation, equation 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 equation 10 is provided:

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

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, 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 equations 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:

$$i_d^* = \left\{ (P_{ref} - P_{inv})(K_{pp} + K_{ip}/s) \right\} \qquad (11)$$

$$i_q^* = \left\{ (Q_{ref} - Q_{inv})(K_{pq} + K_{iq}/s) \right\} \qquad (12)$$

3. SIMULATION RESULT

In the paper, PSO algorithm to solve optimization problem arising from need finding the optimal and desired parameters for proposed power controller implemented [15]. 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. In the simulation expression, simulation problem is related to system under study in Fig. 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 Fig. 2 from consumption load is used in grid structure. As well as, a power key to connect and disconnect is used in infinite bus. 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 and in Fig. 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, current control parameters $K_p = 12.656$ and $K_i = 0.00215$. As well as, for SVPWM based on current controller switching and sampling frequency is $10kHZ$ and $500kHZ$ respectively. As well as inertia weight is 0.05. 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 which 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 Fig. 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 Fig. 4, method

based on a (PSO) (purple curve) includes less changes and fluctuations.

In Figs. 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.
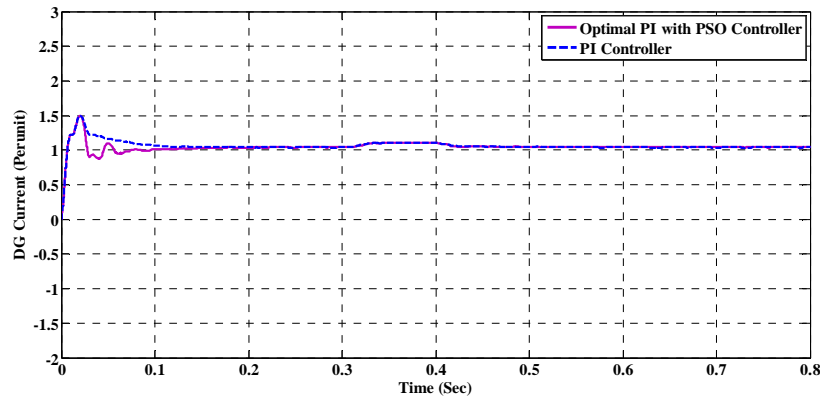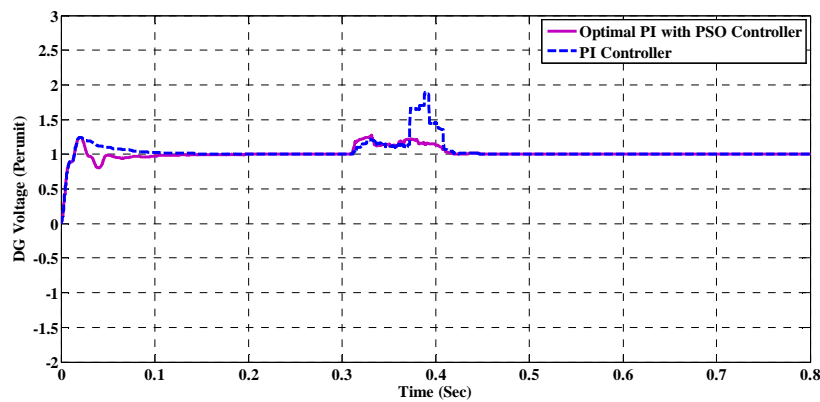

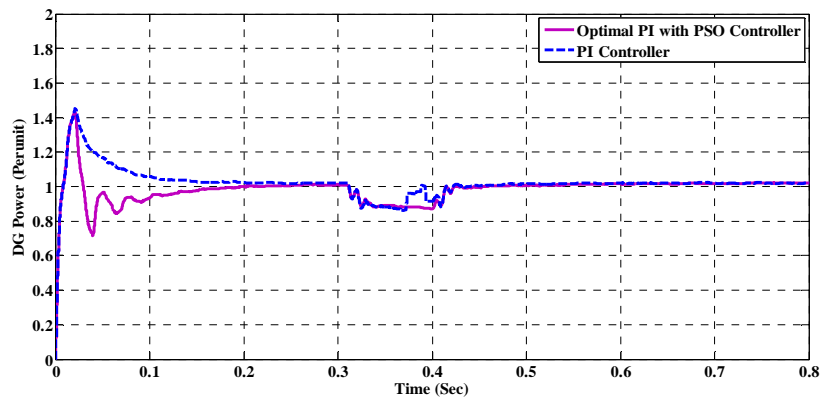**Fig. 4. DGs output current changes**

Fig. 5. DG output voltage changes

Fig. 6. DG unit output active power changes

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

It is clear in Fig. 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 Figs. 8 and 9 respectively main network current changes and main network active power changes is shown.

According to Fig. 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 Fig. 9 in conditions that DG controllers coefficients have been set by the PSO algorithm, the system includes less power fluctuations.

In Fig. 10, main network reactive power changes is shown.
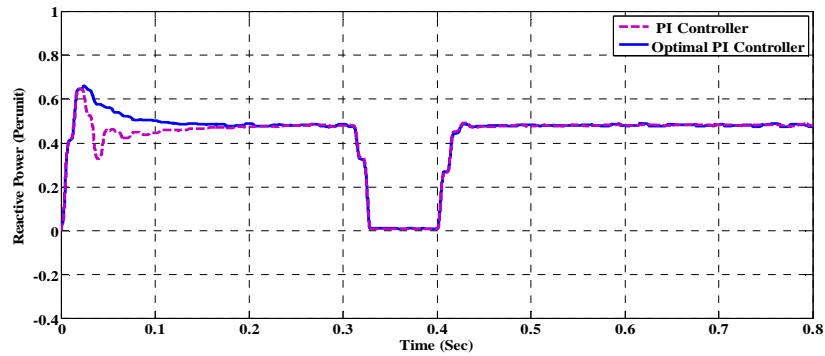
Fig. 7. DG unit reactive power changes
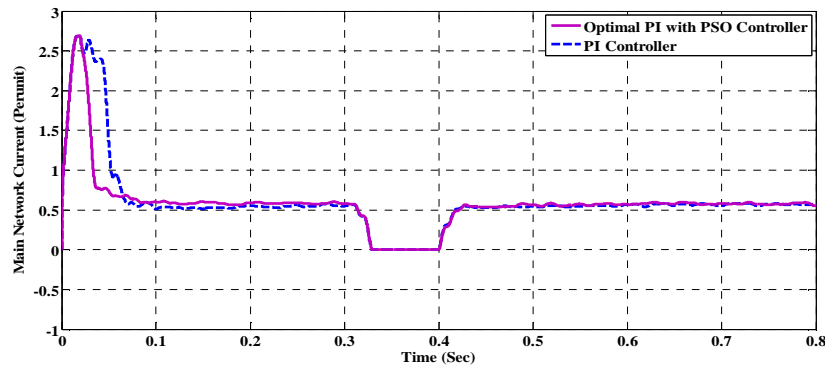
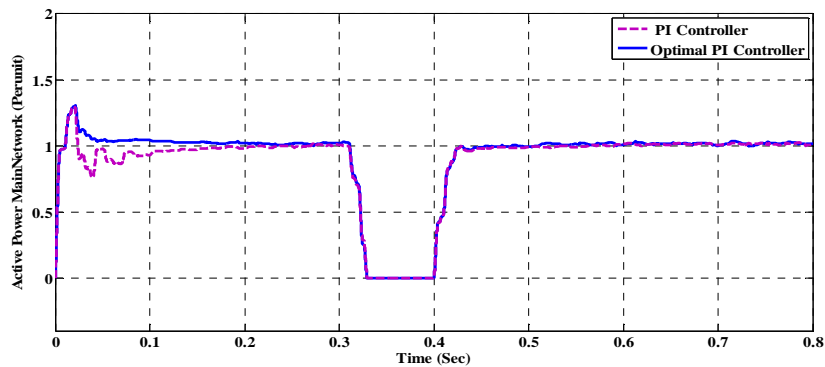**Fig. 8. Main network current changes**

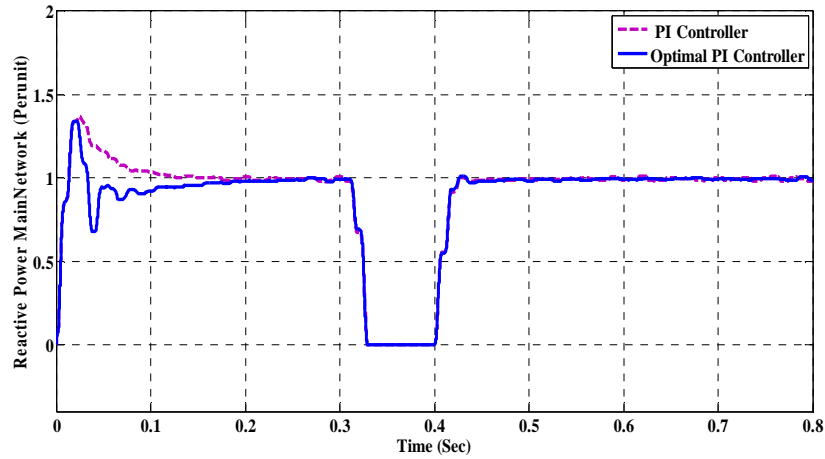**Fig. 9. Main network active power changes**

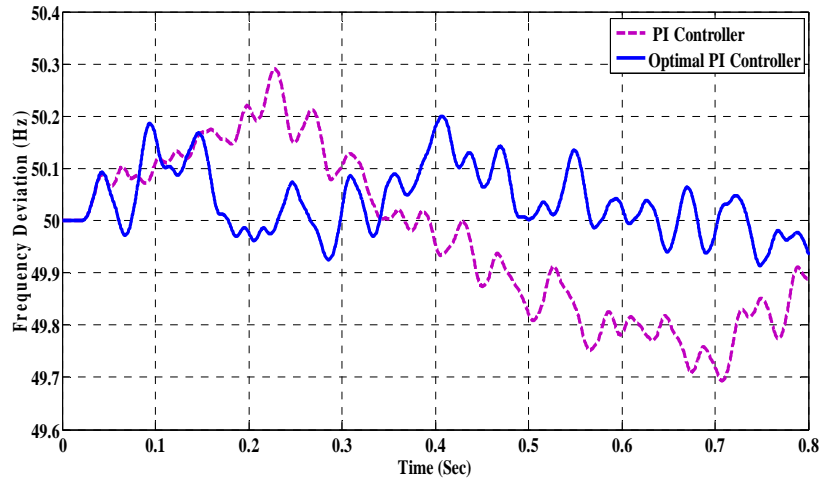**Fig. 10. Main network reactive power changes**

Fig. 11. Main network frequency fluctuations changes

According to Fig. 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 Fig. 11, main network frequency fluctuations changes is shown.

According to Fig. 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 Fig. 12, DG output total harmonic distortion is shown. Fig. 12 in terms of using system by classical controller is obtained. Total harmonic distortion (THD) obtained in this section is 14.26

percent. In all figures, expressions "Optimal PI Controller" with "Optimal PI with PSO Controller " is equivalent.

As well as, it should be noted that despite small variations in above signal figures, while if another work by comparing the results of this method with another intelligent method to be addressed, these small changes will be very visible and tangible.

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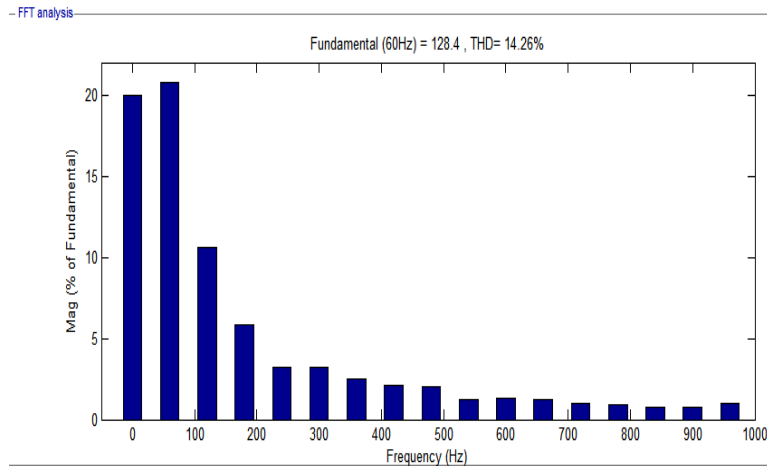
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Fig. 12. DG output total harmonic distortion in presence of classical controller
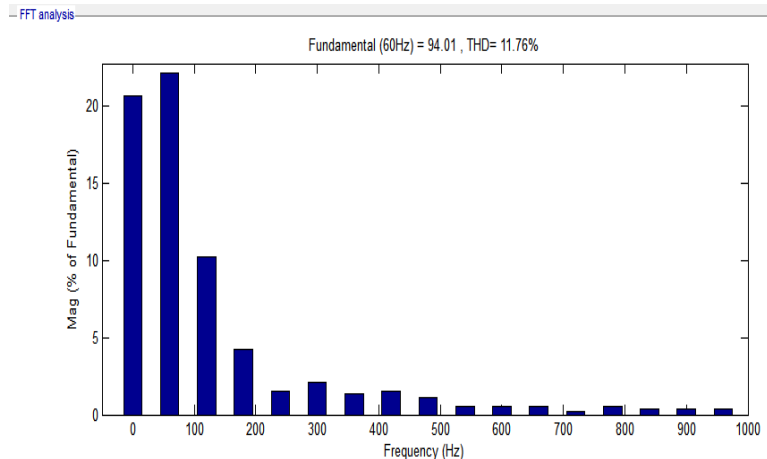

Fig. 13. DG output total harmonic distortion in presence of optimized classical controller

4. CONCLUSION

Paper's result shows 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. Time analysis in such systems could be investigated it should be noted that the authors only have addressed to analyze the stability of the system effective parameters. As suggestions for future research can be done time analysis of this model.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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