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PSO OPTIMIZATION FOR SOLAR SYSTEM INVERTER CONTROLLER AND COMPARISON BETWEEN TWO CONTROLLER TECHNIQUES

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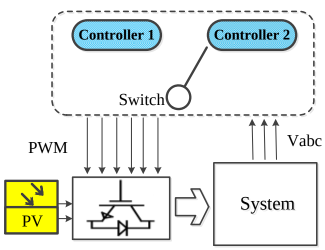
Graphical abstract



Abstract

This paper explains a deep comparison between two controller techniques firstly controller control on modulation index and the second controller use dq method. Both of these controller approaches have control on three phase voltage and use the same system unchanged. The system is a solar system together with a backup battery connected to a single housing unit. Particle Swarm Optimization (PSO) algorithm has been utilized to improve the controller performance by automatically finding its parameters in order to reduce the error in the proportional Integral (PI) controller. Optimization process has been done with a real recording data of housing unit demand in Malaka, Malaysia. System has been simulated and tested in MATLAB/Simulink environment with m-file runs PSO algorithm and simulate the system hundreds of times to get the best results showing in this paper. Comparisons were taking place in controller design and in the simulation results that express the strength and weaken points of each controller starts with THD voltage and current waveform and RMS voltage in each controller.

Keywords: PSO optimization; Modulation index; Solar system; PI controller; SPWM; particle swarm optimization.

1.0 INTRODUCTION

The rising demand of energy has created a huge concern in the last few years. This is ended worse by the fact that most of the current energy sources are exhaustible and depleting rapidly. Moreover, the combustion process of most of the current energy sources such as coal and fuel produces a sophisticated air pollution that causes global warming, which is at presentup-and-coming problem. On the other hand, supplying the customers with a quality voltage is the main challenge in a stand-alone system. Voltage variations, flickers and harmonic generation are the major power quality (PQ) problems that occur in renewable energy conversion system. The voltage variations are mainly due to the change in load.

These issues have prompted the rapid development of many renewable energy sources over recent years, particularly the clean and pollution free renewable energy that has an eligible rate of depletion. But these renewable resources some of them generate alternating current AC and other are generating direct current DC, these resources need to be converted. Also it need a controller to control it is output signal waveform [1][2]. However, all type of controller including intelligent controller are require a special care of setting its controlling parameters. Adjusting these parameters to the best values to make system perform better and for that it has been invented and it called optimization techniques. These techniques can search and find the best value for any controller by run and simulate your system hundreds of times to try each and every variables, which is very hard and wasting of time for human to so. However, the controller used in this paper was a PI controller.

PI controllers have been extensively used in control on a lot of plants because of some significant reasons perhaps their simple control structure, easy design and low cost [3]. PI controller can solve many problems for example overshoot issues, steady state error issues, oscillation of sudden changes in load. On the other hand, PI controller has a disadvantage which is hard to set up it is optimum parameters Kp and Ki. These parameters are requisite a manual tuning normally. The tuning methods for Kp and Ki are in generalutilizing Ziegler–Nichols method.

PSO has undergone many changes since its introduction in 1995, by Kennedy and Eberhart, after that it has become one of the favorites in optimization algorithm solutions [4]. PSO is based on the movements of the group behavior such as bird flocking and fish schooling. An improvement of PSO is done in 1998 by the introduction of inertia weight into PSO by Shia and Eberhart [5].

In PSO, individuals are called as particles and these particles are "evolved" by the cooperation and competition among themselves through generations. A particle represents a potential solution to a problem. Each particle adjusts its flying according to its own flying experience and its companion flying experience. By this movement, its particle can be said to have the velocity. Each particle is trying to find the optimum solution in the solution space Load.

2.0 SOLAR SYSTEM DESCRIPTION

Figure 1 consists of a photovoltaic solar system based on inverter connected energy conversion [7-8-9], Photovoltaic (PV) array, battery, low-pass filter or inductive (L) capacitive (C) LC filter and load.

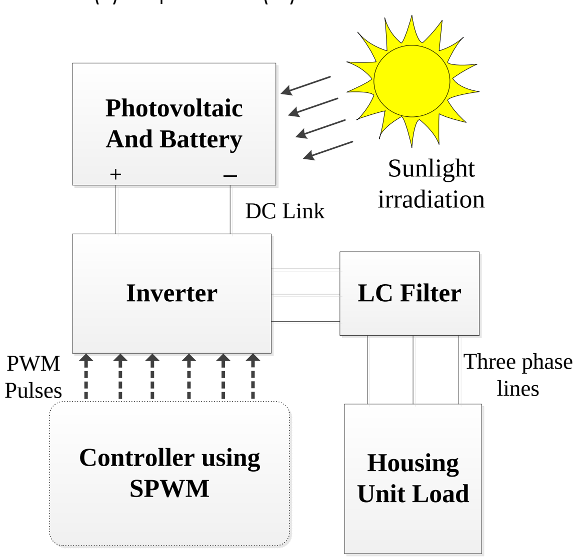


Figure 1 Solar system connected with inverter

The direct current (DC) linked to a battery storage feeding IGBT inverter and supplying three phase electricity to a housingunit nearby as shown in Figure1the inverter output needs a low pass filter to clarify the signal to be pure sinusoidal waveform. An amplitude of the waveform was approximately of 339 V phase to ground with a fixed frequency of 50Hz[9]. The RMS voltage of this waveform is approximately 240V. This system specification is suitable for supplying power for electrical equipment in Malaysia. However, MATLAB/Simulin khas been selecting for building and simulating this system by utilizing powergui in a discrete simulation type of 2µSec. Each part of the simulation was individually explained.

2.1 Photovoltaic and Battery System

PV module is the outcome of associating a group of Photovoltaic cells in series and parallel. In this simulation two arrays are connected in parallel, each array consists of 22 modules connected in series. Each module having open circuit voltage as 36.90 V, short circuit current is 8.01 A, voltage at maximum power is 30.3 V and current at maximum power is 7.10A [8]. Connected to a backup battery as a storage system to be exploited when there is no sun light for example during night or when lack of sun radiation. Lead-Acid Battery has been used with normal voltage of 760V and rated capacity of 8 Ah and 95% initial state of charge. Solar array module linked to Battery.

2.2 Inverter, LC Filter and The Load

Insulated gate bipolar transistor or IGBT inverter is a switch that is used permitted to let power flow in the ON condition and to stop power flow its voltage to a semiconductor component, therefore changing properties to block or create an electrical path [10-11]. In short is to convert the DC to Alternating Current (AC). Six IGBTs diodes are building an inverter of three bridge arms to produce power of three phases. IGBT inverter receives the SPWM signals to drive inverter gates, in order to switch the inverter On and Off with the amount of power needed. The power supplied from DC voltage is supplies form photovoltaic with 760V DC in order to get 240V RMS AC current with its amplitude of 339V phase to ground.

The switching of load side PWM inverter will generate unwanted high frequency harmonics in the output AC voltage, which is ultimately supplied to the customer, creating a power quality problem. Those high frequency harmonics can be eliminated by connecting a small passive LC filter after the inverter. A parallel inductive and capacitive with tuning different values until of L=7.6mH and C=0.008μF to get the required filtering of a pure sinusoidal signal of the voltage and the current. This filter is known as LC filter or low pass filter. In this system the load has been used was a resistive load. Three phase load with frequency 50Hz, normal voltage 415Vrms and maximum active power of 3KW [12].Figure 2 shows real Power load demand for small housing unit in Keroh Malaka area in Malaka, Malaysia. This load demand has been recorded for 24 hours to express daily energy consumptions in real unit in Malaysia. Maximum load demand was 3KW. The load was not fixed load but, it is varies from maximum to minimum as showing in Figure 2. This is the normal behavor of any load in nature. Optimization was running together with this load in the simulation to demonstrate the robustness of the controller and it is real effect on system.

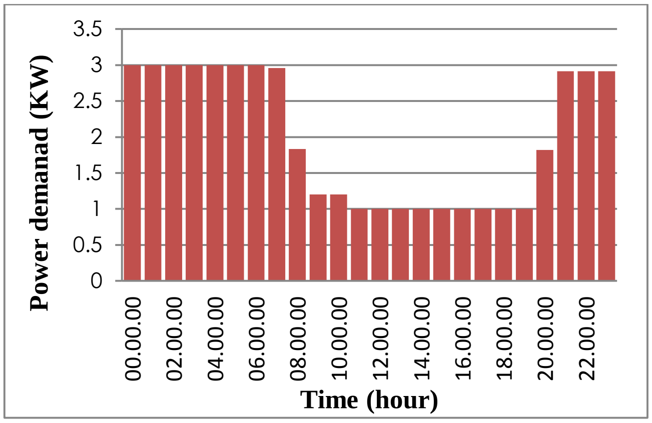


Figure 2 Real Power load demand for housing unit in Malaka, Malaysia

3.0 PROPOSED PSO OPTIMIZATION TECHNIQUES

PSO algorithm is considered one of the most excellent optimization methods, which is has advantages over the other optimizations methods in it is easy implementation, robustness and globe convergence capability. For these reasons PSO algorithm has been selected in this paper fortuning Kp and Ki parameters by searching for the best values in order to make the error as small as possible or zero. By doing that, algorithm convergence can be controlled and the best value of objective function can be found [13-14].

PSO algorithm principals are depending on two factors velocity and position. The member represent update this factors by using equations (1) (2). Figure 3 show the flow chart of the proposed method of optimization.

$$V_i^d(t+1) = wV_i^d(t) + c_1 r_1\left(P_i^d(t) - X_i^d(t)\right) + c_2 r_2\left(P_i^d(t) - X_i^d(t)\right) \quad (1)$$

$$X_i^d(t+1) = X_i^d(t) + V_i^d(t+1) \quad (2)$$

Where, c_1 is social rate and c_2 is cognitive rate. r_1 and r_2 is the random interval (0,1). V is the velocity w is the inertia factor. X is the Position factor.

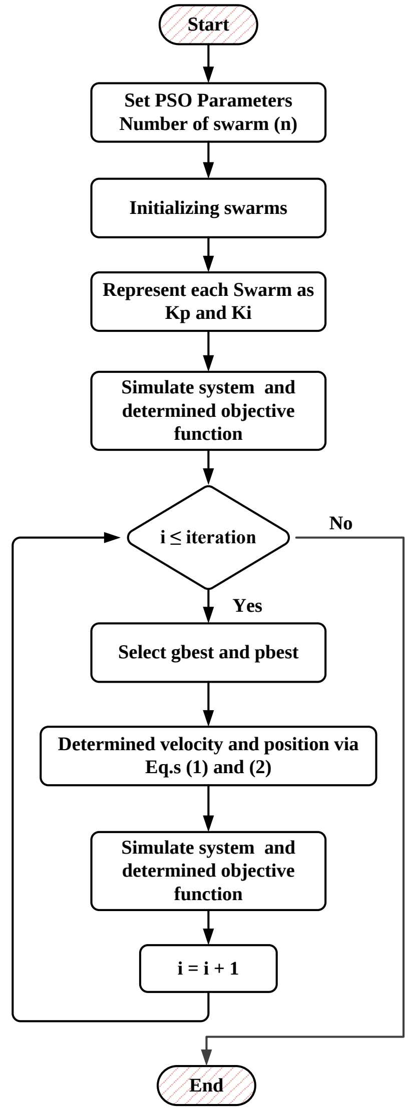


Figure 3 Flow chart for proposed PSO method

This algorithm has been utilized for search for the best values for PI parameters Kp and Ki to make the controller more effective for giving better switching for the inverter. By run the simulation together with PSO optimization for bothcontroller structure in Figure 4 and Figure 5. The Mean Square Error (MSE) has been selected as the error performance to a satisfactory transient response to the inverter or for calling the objective function [15-16].MES could calculate it as in equation (3) this will be done for several times for each iteration.

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n} e^2 \quad (3)$$

Where e is error, n is number of samples, i is the number of iteration.

4.0 CONTROLLER DESIGN

The control design has been divided into two separated controller. Each of them designed and simulated individually. The first controller controls the modulation index of the control signal of the controller, while the second controller controls using dq. Both of these two controllers using SPWM techniques and explained in details in figures below.

4.1 Controller Control on Modulation Index

Generally in distribution system, as the loads are mostly single phase in nature, the current in each phase will be different. As a result of unbalanced load being connected to the inverter so, based on unequal current in each phase, leading to irregular voltage drop across LC filters for each phase. This unbalanced voltage drop will cause the line voltages to become unbalanced and the voltage unbalance factor for example the ratio of negative sequence to positive sequence of fundamental component will go out of its allowable boundary (less 1%). Therefore, it is very important to recompense the unbalance voltage in the system. In order to perform this error between the RMS value of the phase voltages and the reference phase voltage is given to proportional plus integral (PI) controller.

Figurer 4 is based on voltage control for the three phase voltage after LC filter. All voltages Va, Vb and Vcwill be convert to RMS and then feeding into a PI controllers to find modulation index value. Then limiter set to be less than 0.907 since this is the maximum modulation index. The output of the PI controller is multiplied with unit sine wave generator to get the reference phase voltages (Va_ref , vb_ref , vc_ref). Usingva_ref, Vb_ref and Vc_ref , SPWM pulses are generated to switch on/off with cutoff frequency 25KHz. The 6 pulses getting from the SPWM generator to switch the IGBT gate drives. The schematic of the control scheme used for unbalanced voltage compensation is shown in Figure 4. The plan is to obtain different modulation indexes for three phases so as to balance out the unbalanced voltages [8].

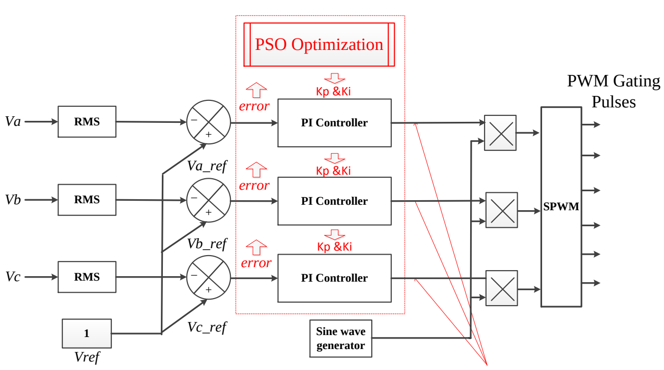


Figure 4 Controller control on modulation index using PI controller for SPWM Techniques

4.2 Controller Control Using *Dq* Method

Proposed combination of *dq0* transformations and symmetrical component analysis to make voltages balanced for the unbalanced load scenario since, *dq0* transformation is based on instantaneous values, and it is detection time is faster than RMS measurement approach. However, the sensed voltages are not purely sinusoidal because they are measured after LC filter and hence a low pass filter is required either before or after *abc /dq* transformation [15-16]. Figure 5 shows the controller structure for *dq* control method. It converts $V_abc$into *dq0* after that apply the PI controller over the Vd and Vq. Then convert back Va, Vb and Vcthen, it will go through SPWM generator with cut-off frequency of 25KHz and output signal is 6 pulses going to the inverter gate drive. This method needs a phased looked loop PLL to give the same angle for the signal.

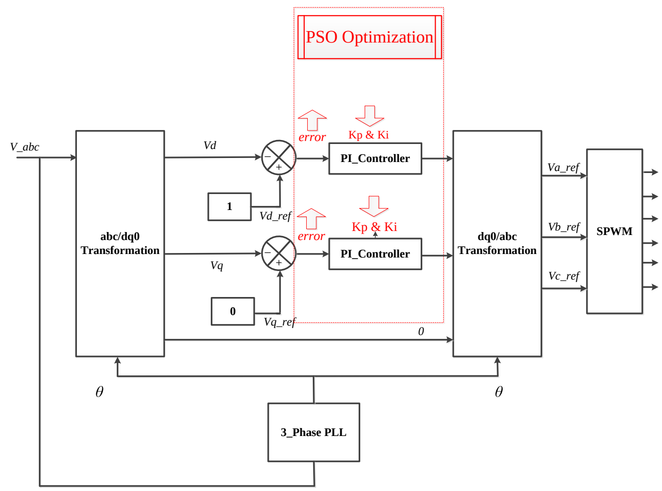


Figure 5 Controller controls on dq method using PI controller for SPWM Techniques

5.0 SIMULATION RESULTS AND DISCUSSION

In this section two results for each controller will be stated and discussed including comparison between these two controllers.

5.1 Modulation Index Controller Results

PSO algorithm has use 100 iteration to search for IP controller parameters Kp and Ki for each run of the simulation. The goal is to reduce the error as less as possible. Figure 6 shows the PSO iteration and show also how the MSE reduced sharply at the beginning then it stalled and reduced just like down satires until it will settled after more than 50 iterations.

Figure 7 shows THD for voltage seems quite good with THD of 2.20% which is very good compare to the standards of (less than 5%). This tested THD stars from 0 Sec for 5 cycles with cut-off frequency 25 kHz. The three phase voltage and current of the output of the system of this controller is depicted in Figure 8 (a). During the simulation for 0.4Sec the load change during the day based on the real load demand in Figure 2 and the change of the load was step change in the simulation so, the voltage suppose keep fixed amplitude while the current vary based on load changes as in Figure 8 (b). The step change happened on t=0.1 Sec, t=0.15 Sec, t= 0.2 Sec, t=0.25 Sec, t=0.3 Sec and t=0.35 Sec. whenever step change applied on load the voltage has an overshot and the current will increase or decrease depending on the load value. But the voltage increase slightly when the load decrease, which is consider a weakness for this controller.

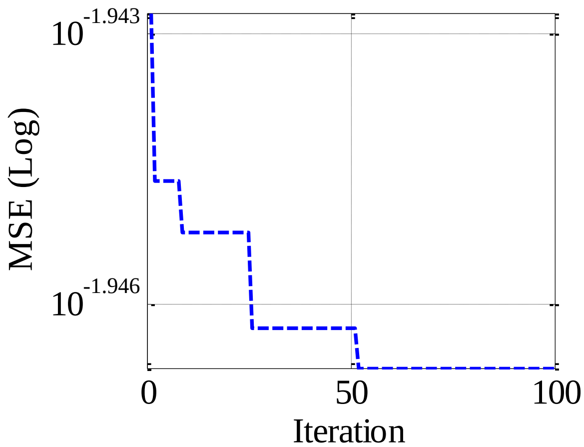


Figure 6 Relationship between MSE and iteration for modulation index controller.

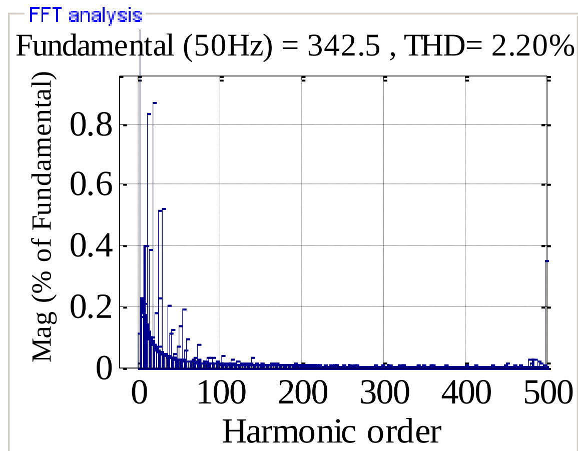


Figure 7 THD for voltage for modulation index controller

5.2 *dq* Method Controller Results

In Figure 9 PSO optimization reduce the MSE until it reach less than $10^{-2.243}$Log after maybe about 83iteration. This algorithm search for IP controller parameter Kp and Ki for each run of the simulation for d as well as q for one hundred iteration.

The three phase voltage and current output of the system of this controller is depicted in Figure 10 (a). simulation has run for 0.4Sec together with load change during the one day based on the real load demand in Figure 2 and the change on the load was step change in the simulation so, the voltage supposed to be fixed in amplitude while the change in the current as in Figure10 (b). The step change happened on t=0.1 Sec, t=0.15 Sec, t= 0.2 Sec, t=0.25 Sec, t=0.3 Sec and t=0.35 Sec. whenever step change applied on load the voltage has an overshot because of the step change between one switch to another.

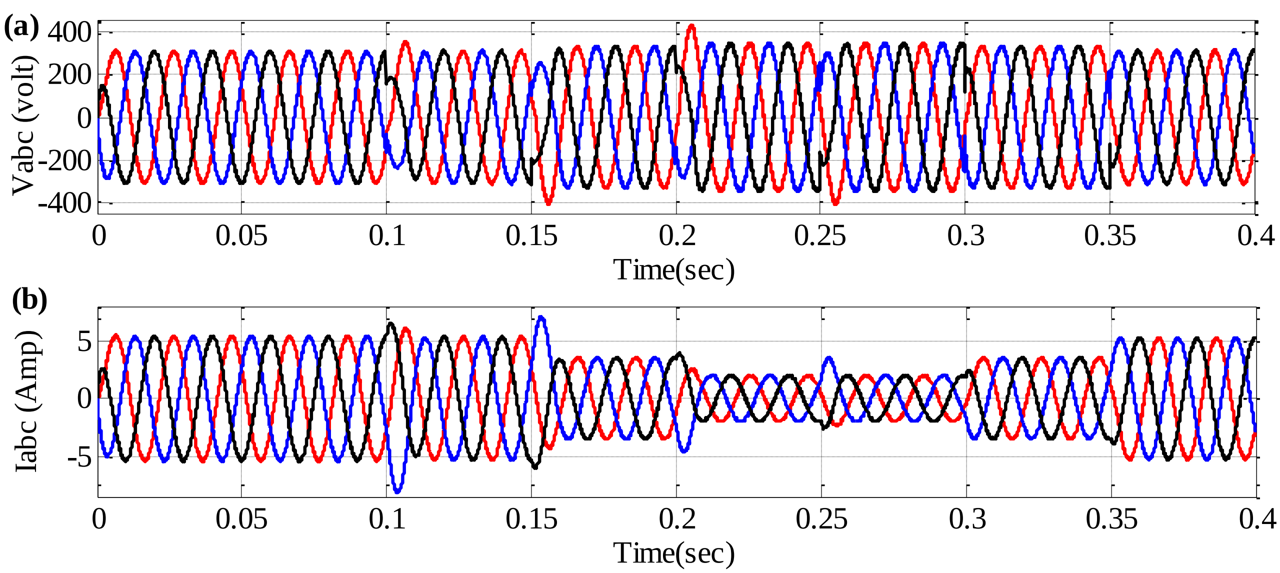


Figure 8 (a) Three phase output voltage for whole system with modulation index controller method. **(b)** Three phase output current for the system with modulation index controller method depending on the load value. However, THD of the voltage of the method was 2.11% as in Figurer 11 comparing to dq method it is less but difference is limited. The good point of this controller is voltage not affected by load change comparing to modulation index method, while currentdoes because of the change in the load which is healthy way of the current or power. As a result, response time of dq0 transformation methods may be comparable with RMS based method which is shown in Figure 12 when load data is applied at t = 0.1 Sec , =0.15 Sec, t= 0.2 Sec, t=0.25 Sec, t=0.3 Sec and t=0.35 Sec. the reaction of voltages is increase or decreases same for the two methods.

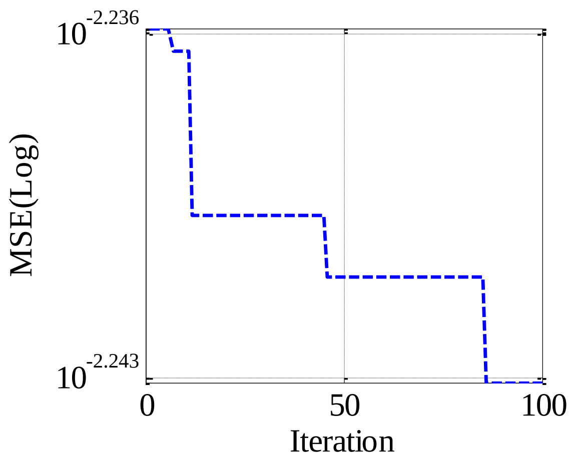


Figure 9 Relationship between MSE and iteration for controller of *dq* method

Further, the dq0 method is seriously calculated as there is a necessity of extract the symmetrical components involving complex domain calculations from the original waveforms. This can cause wasting of time especially in real time practical experiment. Therefore, RMS based method is adapted to calculate the reference line voltages for both controllers. But for the dq approach is more stable or has small changes in compare to the modulation index method. Referring to Figure 12 whenever the load decreases the voltage increase and the overshot appear in this figure is because of the circuit breaker switch for each load change in the simulation.

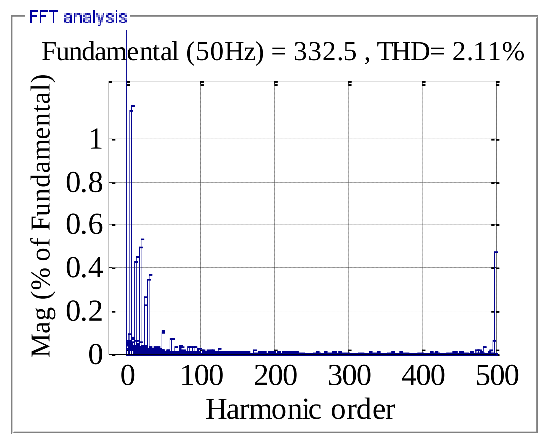


Figure 11 THD voltages for *dq* method controller.

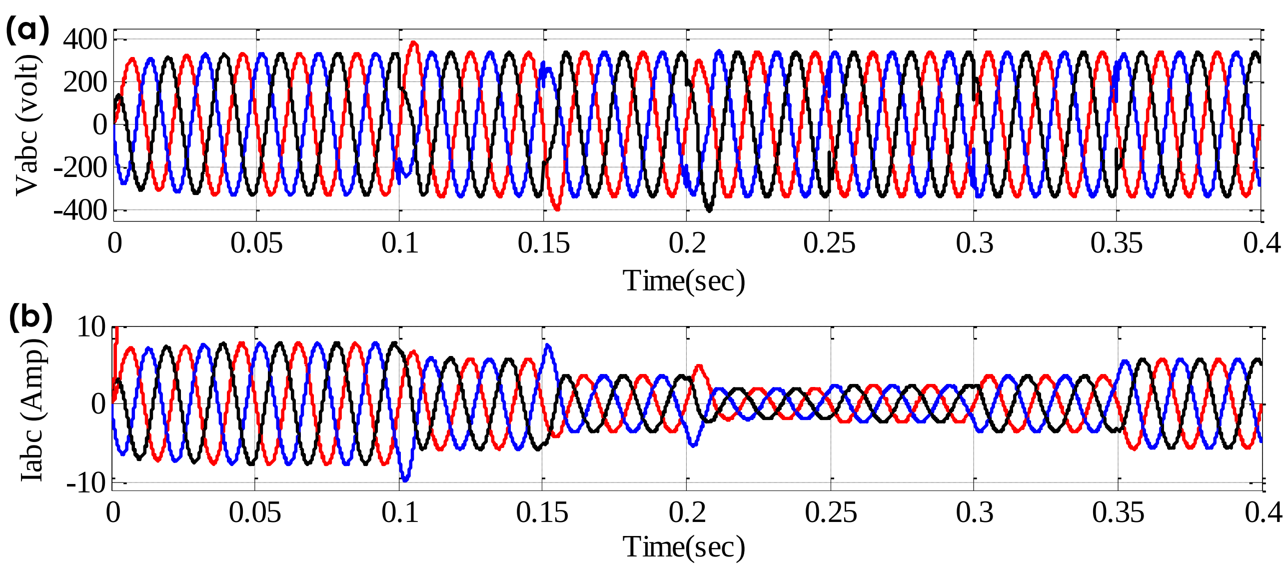


Figure 10 (a) Three phase output voltage for the system with *dq* method control. **(b)** Three phase output current for the system with *dq* method control.

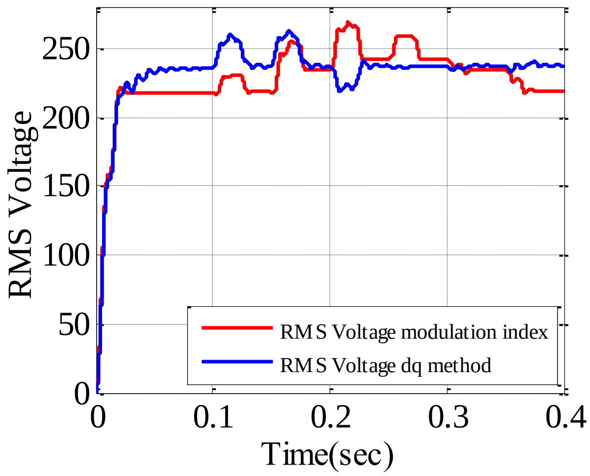


Figure 12 Comparing RMS voltages for modulation index controller and *dq* method controller

6.0 CONCLUSION

The system has been simulated and tested in MATLAB/Simulink environment with m-file included PSO optimization called by the simulink in order to search for PI controller parameters. PSO algorithm shows a great way of finding the best values for Kp and Ki which is seems to be impossible be done by human to reach to the optimum value. However, this paper demonstrates comparisons results for two controllers first were controlling on modulation index and the second was using *dq* method. *dq* approach is more effective than using controlling three phase voltage *Vabc* of modulation index. Simulation result for output wave forms of voltage and current are stable with reasonable amount of THD for both controller but, still one better than another. The combination of *dq* approach is better as seen in all the results starts with THD, voltage stability ends with RMS voltage. This paper stated a very clear comparison between these two controllers with graphics and simulation results.

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