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An Adaptive Control for Autonomous Micro-Grid Using Swarm Intelligence Technique

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Abstract- This paper aims at improving the quality of the power supply of the micro-grid where the DG units are connected as cluster of micro sources supplying loads. The micro-grid consists of two DG units connected in parallel to configure the grid. This work presents a controller for voltage-frequency regulation. The controller is designed with outer power loop and inner current loop. The proposed strategy for the regulation of voltage and frequency is implemented in two DG units when the micro-grid is islanded. Swarm intelligence technique is applied for the optimum control of micro-grid and to enhance the power quality by auto tuning of the controller.

Index Terms— DG, MG, PSO, SVPWM

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1 Introduction

In recent years, the emerging power problems are due to the proliferation of non linear loads. The non linear loads develop current harmonics and power quality problems [1].

The interest in micro-grids has been increased extensively for the efficient utilization of renewable sources. Micro-grids are defined as the cluster of micro sources ranges from 1KW to 10MW supplying local loads. Micro sources include combination of one or more renewable energy source such as photovoltaic cells (PVs), Fuel cells, Wind energy batteries, Micro turbines, Diesel generators.

The basic architecture of micro-grid is given in the Fig.1. The figure shows the cluster of loads connected to the DG units. Power electronic converters are used for the conversion of availed source to alternating current to meet the load.

The power quality improvement in a hybrid micro-grid consists of inertial converter interfaced micro sources. A decentralized power sharing algorithm based on droop control is used in [2]. It has two DG units out of which one act as a compensator and other share power among the grid.

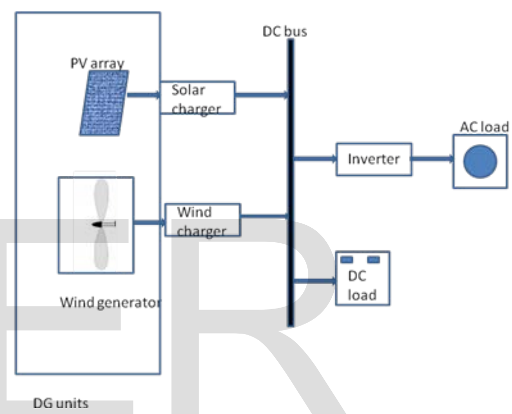

Fig. 1 Structure of Micro-Grid

Ahmed Mohammed in [3], proposed a control and enhancement of power conditioning units for PV system is performed by using DC-DC converters. The main purpose of power conditioning unit is for voltage regulation when the system is supplying sensitive loads. An adaptive fuzzy-PID controller is designed for maximizing the stable operating range of DC-DC converters. PI and PID configuration are switched to obtain minimum overshoot and ripple under variable load conditions.

Filter control strategies for the power quality improvement is performed by using PI-Fuzzy controllers in [4]. Three phase four wire systems uses instantaneous real and reactive power (p-q) and current control strategies to improve performance under balanced, unbalanced and non-ideal supply voltage condition. Two controllers are used for implementing PI and Fuzzy controller. This approach has compensated neutral and harmonic currents.

Guohui zeng designed a controller in [5], to avoid non-intentional operation of islanding mode of grid connected PV system. Islanding mode detection is done by using intelligent

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adaptive methods such as passive methods, active methods resident in grid-tied inverter.

The micro-grids are assisted with inverters in order to improve the control and protection scheme. Hence maintain the voltage stability [6]. The inverter is designed to operate in islanded and grid-connected mode. For distorting loads, inverters are operated in parallel with low bandwidth communications.

Power quality of the micro-grid can also be improved by system with Shunt Active Power Filter (SAPF) and Static VAR compensator (SVC) [7]. The SAPF is adopted near to micro source to mitigate harmonic currents and SVC is located near load for reactive power compensation.

In this paper, the micro-grid is supplying local loads such as AC and DC loads. MG is operating in islanded mode. The voltage and frequency regulation is made to improve the quality of the power. The power quality is improved by means of using Particle Swarm optimization (PSO) algorithm embedded with the PI controller named as PI-PSO controller to perform optimal control action.

2 INVERTER DESIGN

The Voltage source inverter ties the Micro-grid with the AC loads or grid. It acts as an interface and controls the MG parameters by applying suitable strategy. The entire system is regulated by controlling the input pulses to the inverter thus maintaining voltage and frequency of micro-grid at desired levels. The inverter output is depending on the type of pulses given as gating signal. It converts the DC micro sources voltage in to 3-phase AC voltages. The output behavior of the 3-phase inverter should be ensured by a modulating technique that controls the amount of time and the sequence used to switch the power valves on and off. The widely used modulating techniques are the carrier-based technique such as sinusoidal pulse width modulation (SPWM) and the space-vector pulse width modulation (SVPWM) technique [8].

The Space Vector Pulse Width Modulation technique is used in this paper for reducing the total harmonic distortion (THD) in the three phase current waveforms. In SVPWM, there are eight vectors out of which, two zero vectors and six are active vectors or non-zero switching vectors. The six active vectors form a hexagon shaped space keeping the two zero vectors as origin. Each vector is of equal magnitude and displaced at an angle of 60 degree as shown in the Fig.2. The Voltage reference is provided as revolving space vector.

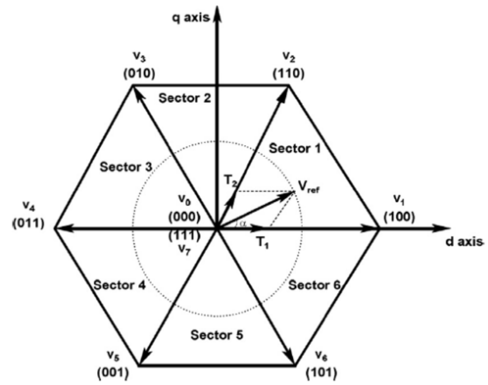

Fig. 2 SVPWM Voltage reference vector

The reference voltage can be calculated by the expression "(1)".

$$\overline{V_{ref}} = \left(\frac{T_1}{T_s} * \overline{V_1}\right)\left(\frac{T_2}{T_s} * \overline{V_2}\right)\left(\frac{T_{0/7}}{T_s} * \overline{V_{0/7}}\right) \tag{1}$$

The SVPWM vector 1 is active for the time period T1 and second vector is active for the time period T2. For the remaining sampling period Ts, there is no voltage exists. It is given in "(2)" and "(3)"

$$V_{ref} T_s = V_1 T_1 + V_2 T_2 + V_o T_o \tag{2}$$

$$T_s = T_1 + T_2 + T_o \tag{3}$$

3 INVERTER CONTROL STRATEGIES

3.1 V-F CONTROL STRATEGY

The DG units comprises of renewable energy sources such as PV, Fuel cell, wind turbine such as variable speed, variable frequency and constant speed , constant frequency etc,. Fig.3 shows the operation of Micro-grid structure operating in islanded mode.

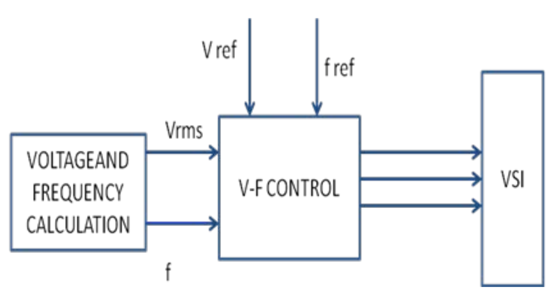

Fig. 3 Micro-Grid- Islanded mode

The DG unit is connected to the VSI to supply the local AC loads. In islanded condition the voltage and frequency of the system is not maintained constant. Hence in order to regulate the voltage and frequency of the micro-grid, the inverter is designed to suit the v-f control mode. The detection of the operating voltage and frequency is performed by the MG voltage and phase detector.

The inverter control is made by the current controllers comprises of two loops namely, power controller loop and internal current controller loop structure. Hence two control strategies are applied to the two control loops.

3.2 POWER CONTROL STRATEGY

In the Fig.4, the power controller performs the objective function for the regulation of voltage and frequency in the Micro-grid. This strategy involves the generation of the reference current vectors id* and iq*.in the outer loop.

The current trajectory improves the power quality of the system by means of small deviation in the reference current.

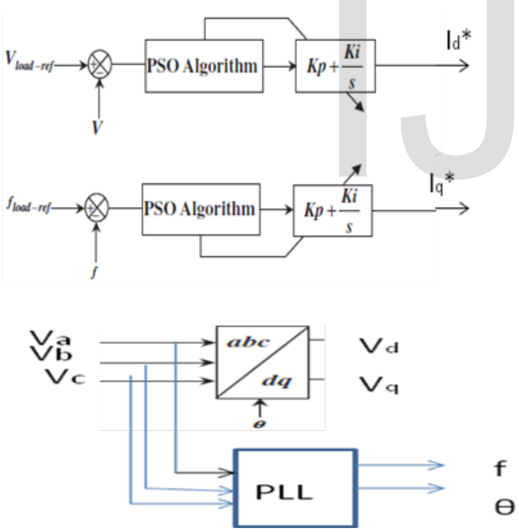

Fig. 4 Power controller

The power controller has two PI regulators for elimination of error. The error correction is performed with the help of optimization technique called PSO. The v-f strategy is applied to the MG when it is started islanding. The voltage and frequency is regulated by comparing with the reference values such as, Vref and f ref. In dqo reference frame, with the PI regulators, the PSO provides an optimum control parameters and hence obtaining the desired reference currents given in "(4)" and "(5)".

$$i_d^{\ *} = (V_{ref} - V)(K_{pv} + K_{iv}/s) \tag{4}$$

$$i_q^{\ *} = (f_{ref} - f)(K_{pf} + K_{if}/s) \tag{5}$$

3.3 CURRENT CONTROL STRATEGY

The current controller performs the minimization of error in inverter output in case of transients during load change. Park's transformation is used in this control scheme. The voltage phase angle is detected by PLL block in simulink library. The controller provides the reference voltage signal in order to compare with the actual output. Further the output signal is fed to Inverse Park's transformation and Clarke's transformation. The reference signals obtained are in αβ frame shown in Fig.5. These signals are feedback as input pulses for the SVPWM strategy to obtain controlled output with less harmonic distortion given in [9] and [10].

$$THD = 1 \div V_{o1}\Big(\sum_{n=2,3}^{\infty} V^2{}_{on}\Big)^{1/2} \tag{6}$$

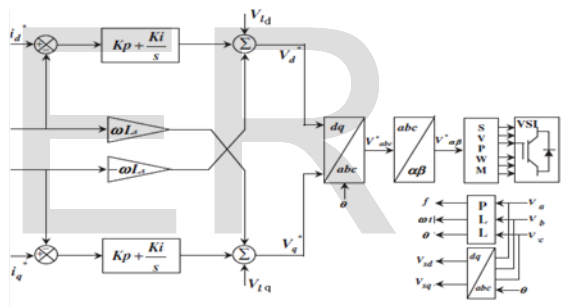

Fig. 5 Current controller

The dq frame axis is given in "(7) ".

$$\begin{bmatrix} V_d^{\ *} \\ V_q^{\ *} \end{bmatrix} = \begin{bmatrix} -K_p & -\omega L_s \\ \omega L_s & -K_p \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} -K_p & 0 \\ 0 & -K_p \end{bmatrix}\begin{bmatrix} i_d^{\ *} \\ i_q^{\ *} \end{bmatrix} + \begin{bmatrix} K_i & 0 \\ 0 & K_i \end{bmatrix}\begin{bmatrix} X_d \\ X_q \end{bmatrix} + \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} \tag{7}$$

Where,
*denotes the reference values

$$\frac{d}{dt} X_d = i_d{}^* - i_d$$

$$\frac{d}{dt} X_q = i_q{}^* - i_q$$

The Clarke's transformation for the conversion in to αβ frame in [11] is given by the formula "(8)"

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_o \end{bmatrix} = 2/3 * \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{8}$$

4 PROPOSED ALGORITHM

4.1 PARTICLE SWARM OPTIMIZATION (PSO)

The PSO is proposed by Kennedy and Eberhart in the mid 1990s while attempting to simulate graceful motion of swarms of birds investigating the notion of "collective intelligence" in biological species. It is a swarm intelligence algorithm. PSO imitates the flock of birds, schools of fish to find their food source. PSO is a population based algorithm where each individual is identifies as particles [12].

The PSO algorithm concentrates on tuning of PI controllers and hence to perform the control model for the micro-grid strategy. The Fig.6 shows the complete control by means of VSI with PI-PSO controller.

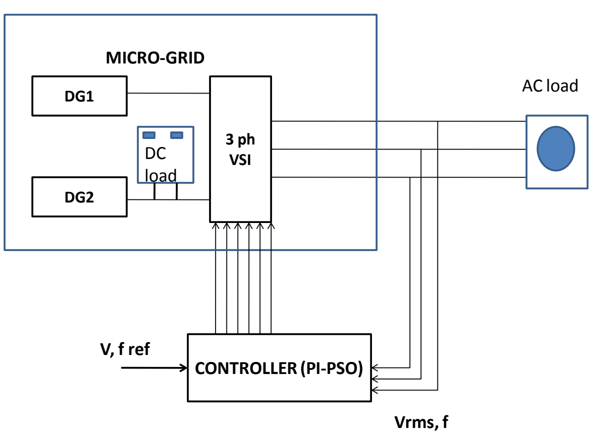

Fig.6 Controller Model for Micro-grid

4.2 PARAMETERS OF PSO

The particle swarm consists of "n" particles. Each particle has its own position X and velocity V. The best position of the particle until the current time with respect to the objective of the system is called personal best (pbest). Among all the particles in the swarm, the best position of the particle with respect to the objective function is called Global best (gbest). c1 and c2 are the acceleration coefficients usually chosen in the range between 0 and 2. The random values r1 and r2 are generated from uniform distribution in the range [0 1]. W is the inertial weight proposed by Eberhart R C,Shi Y,1998 [13]. It is the proportional agent which is responsible for speed control of the algorithm. If the x is smaller, then the searching ability is greater.

The particle in the swarm follows three principles:

(i) To maintain its inertia
(ii) To change the condition based on fitness value
(iii) To change the condition based on swarm's fitness value

4.3 ALGORITHM:

STEP:1 Initialize the swarm

(i) Define the inertial weight w, acceleration coefficients c1, c2 values
(ii) Define the bounds of the velocity Vmax and Vmin.
(iii) Assign the initial position Xi and velocity Vi
(iv) Xi = [xi1,xi2, . . . ,xin] Vi = [vi1,vi2, . . . ,vin]
(v) Initialize the population of N particles with D dimension

STEP :2 Evaluation of fitness function

The fitness function for the swarm involves the error minimization for the selected parameters say voltage and frequency. The error criterian may be calculated based in four integral functions such as Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Squared Error (ITSE), and Integral Time Absolute Error (ITAE). The error calculation using IAE is performed in [14]. In this paper, Integral Absolute Error is used for analysis. The IAE is given in "(9)",

$$IAE = \int_0^\infty e(t)dt \tag{9}$$

STEP :3 Update the particle velocity and position using "(10)" &"(11)"

$$V_i^{k+1} = wV_i^k + c_1 r_1 (Xp_{best}{}^k - X_i{}^k) + c_2 r_2 (Xg_{best}{}^k - X_i{}^k) \tag{10}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{11}$$

In velocity update equation, the first component is called the inertia component. It enhances the convergence of the problem to optimal solution.

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The second term $c_1 r_1 (Xp_{best}{}^k - X_i{}^k)$ is the cognitive component representing the particle's memory and the third term $c_2 r_2 (Xg_{best}{}^k - X_i{}^k)$ is the social component which moves the particle towards the best region.

STEP 4 Evaluate the fitness function for the entire particle after updating the velocity and position.

STEP 5 Evaluate the pbest of the population after updating the history of each particle.

STEP 6 Display the gbest after satisfying the termination criteria. Termination criteria may be

(i) Maximum number of iterations

(ii) Minimum fitness value

In this paper the numbers of iterations are set to 100. Table.1 provides the PSO output parameters and the fitness value obtained for the MG in islanded mode.

TABLE 1 PSO PARAMETERS

PSO PARAMETERS	ATTRIBUTE VALUES
C1	1
C2	1
Kp	12
Ki	0.002
X (particle Position)	12,0.002
Velocity	±125
F	4.0113

5 SIMULATION RESULTS & DISCUSSION

The model shown in the Fig.6 is tested in simulation environment using MATLAB/Simulink. The model consists of two DG units each of capacity 5 KW.

The controller design with the micro-grid model is performed with the 3-phase VSI parameters such as sampling frequency of 500 kHz and chopping frequency of 2 kHz. The control parameters obtained for the near optimal solution is KP=12 and Ki=0.002.

The harmonics in the circuit gets reduced by 20% under variable loading conditions as shown in the Table.2

TABLE 2 COMPARISON OF CURRENT HARMONICS CONTENT WITH AND WITHOUT CONTROLLER

Load			Without controller			With Controller		
			THD in (%)			THD (%)		
P (KW)	QL (KVAr)	Qc (KVAr)	R	Y	B	R	Y	B
50	10	0.1	5.92	5.60	5.90	3.14	2.97	2.86
80	10	1	5.90	5.95	5.98	4.42	4.18	4.06
50	10	1	8.86	8.38	8.75	3.13	2.95	2.85
50	10	10	5.80	5.51	5.85	4.40	4.16	4.06
2	1	0	4.34	4.18	4.07	1.84	1.78	2.18
2.5	0.5	0	4.40	4.16	4.10	2.89	2.84	3.29
2	1	0.1	5.13	4.78	4.89	1.96	1.65	1.76

For varying load conditions, the voltage and frequency get deviated. The PI-PSO controller regulates the voltage and frequency of the Micro-grid. The load current for the applied variations for the three phases with respect to time are shown in the Fig. 7.

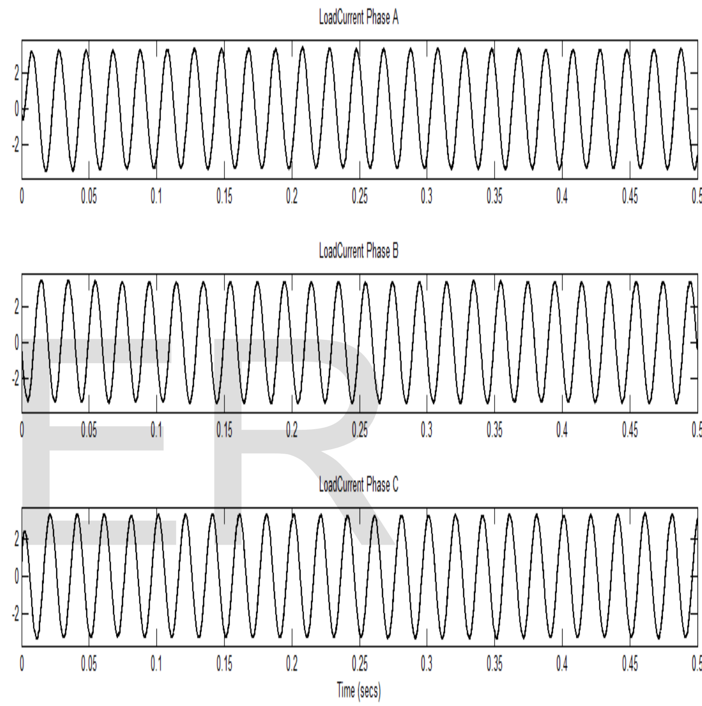

Fig. 7 Load Current for variable load conditions

For each phase of load current, single cycle out of the selected signal is considered; the total harmonic distortion is calculated for analyzing the harmonics present in the signal. It is shown in the Fig.8. "(a)", "(b)" and "(c)".

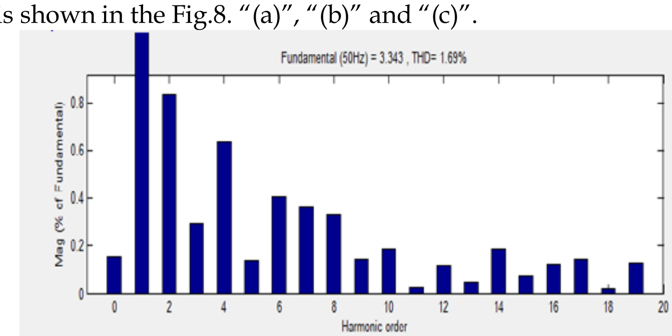

Fig. 8.a. Load Current for Phase A

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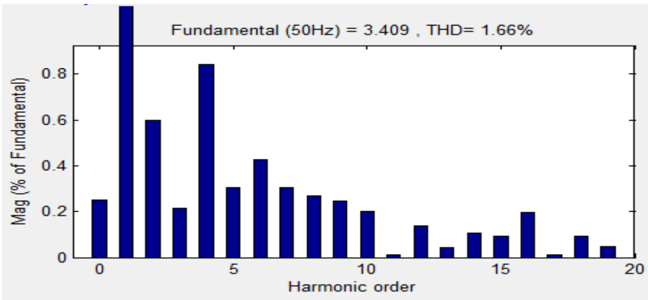

Fig. 8.b. Load Current for Phase B

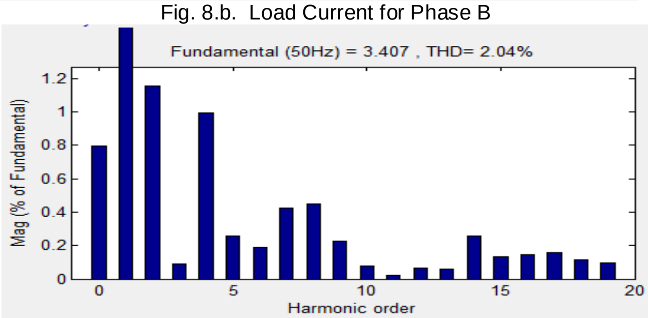

Fig. 8.c. Load Current for Phase C

It is observed that by using PI-PSO controller the voltage and frequency error has been reduced and the power quality is improved.

6 CONCLUSION

In this paper, power quality of Micro-grid in islanded mode has been improved by using power control strategy. The control strategy involves controller design with two loops. The inner current control loop and outer power control loop which regulates the voltage and frequency of the micro-grid.

The PSO algorithm performs the tuning of PI controller hence forms an adaptive tuning to improve the optimal results. The simulation provides fruitful results by the strategy implemented and thus provides better v-f regulation.

References

[1] Francisco C. De La Rosa, "Harmonics and power systems, Distribution Control Systems", Inc. Hazelwood, Missouri, U.S.A.Copyright 2006

[2]Farhad shahina, Ritwik Majumdar, Arindham Ghosh,Gerald Ledwich, Feruz zare. "Operation and Control of hybrid micro-grid containing unbalanced and non-linear loads",Electric power Sytems Research; Vol.80, pp(954-965), 2010

[3] Ahmed Mohammed, M.Elshaer, Osama mohammed."Control and enhancement of poerw conditioning units for high quality PV systems". Electric power Sytems Research; Vol.90, pp(30-41) ,2012

[4] Suresh Mikkili, A.K.panda. "Real time implementation of PI and Fuzzy logic controller based shunt active filter strategies for power quality improvement", Electric power Sytems Research; Vol.43, 2012, P.1114-1126

[5] Guohui zeng, Minnnian caoand Yuchen chen. "An intelligent adaptive method for islanding detection in grid-tied PV system", Energy procedia; Vol.17, pp(349-355) , 2012

[6] T.C. Green, M.Prodonavic,"Control of inverters based on Micro-grids". Electric power Sytems Research; Vol. 23, pp(1204-1213) , 2011

[7] Gao xiaozhi*, LiLinchuan*, Chen wenyan*. "Power quality improvemet for micro-grid in Islanded mode". Proceedia Engineering; Vol.23, pp(174-179), 2011

[8] Z.A.Ghani, M.A.Hannan*, A.Mohammed. "Simulation model linked PV inverter implementation utilizing dSPACE DS1104 controller"; Energy and Buildings, Vol. 57, pp (65–73) , 2013

[9] P.Tripura1, Y.S.Kishore Babu2, Y.R.Tagore2. "Space Vector Pulse Width Modulation Schemes for Two-Level Voltage Source Inverter", ACEEE Int. J. on Control System and Instrumentation, Vol. 02, pp(34-38) ,2011

[10] Heydt GT, Jewell WT. Pitfalls. "Fundamantals of electric power quality indices". IEEE Trans Power Delivery 1998, Vol.13, pp(570–800), 1998

[11] P. C. Krause, O. Wasynczuk and S. D. Sudhoff, "Analysis of Electric Machinery," 2nd Editon, Wiley, New York, 2002.

[12] Muhammad Ilyas Menhas *, Ling Wang, Minrui Fei, Hui Pan, Comparative performance analysis of various binary coded PSO algorithms in multivariable PID controller design, Expert Systems with Applications; vol. 39, pp(4390–4401) , 2012

[13] Qinghai Bai, "Analysis of Particle Swarm Optimization Algorithm", Computer and information science; Vol.3, 2010

[14] S.M.GirirajKumar, Deepak Jayaraj, Anoop.R.Kishan, PSO based Tuning of a PID Controller for a High Performance Drilling Machine, International Journal of Computer Applications, pp(0975 – 8887), 2010