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POWER QUALITY ENHANCEMENT IN A DISTRIBUTED ENERGY RESOURCES SYSTEM WITH PSO BASED NOVEL CONTROLLER

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ABSTRACT

Day by day increasing demand of electricity and fading of conventional fuels forces us to invent *alternative sources for electricity generation this leads to expansion of renewable energy sources. The incursion of Distributed Generators (DGs) meets the increase of demand for consistent, reasonable and spotless electricity but pretence some design and operational challenges such as changes in voltage and frequency and operating in standalone mode. Several active and passive methods have been suggested in the past to perceive islanding of distributed generators from main grid and addressing the power quality issues separately .In this paper PSO algorithm based novel controller was proposed to address these issues and support the network during islanding mode effectively and accurately. Novel controller consists of Model predictive controller with kalman filtering capability. The proposed controller was effectively developed and simulated by using MATLAB Simulink. The simulation results suggest that PSO algorithm tune the system parameters accurately and improves the controller performance effectively.*

Keywords:*-model predictive controller, kalman filter, particle swarm optimization, distributed energy resources, islanding etc.*

1. INTORDUCTION

Day by day increasing demand of electricity and fading of conventional fuels forces us to invent alternative sources for electricity generation this leads to progress in renewable energy sources. Among various alternative sources, wind and solar are gaining more attention and to its technical maturity and cost effectiveness but these sources has suffered in degradation of power quality due to power imbalance problem that is there must be a power balance between all the generating plant and the load demand. This imbalance would affect the frequency of the system which could lead to loss of synchronism between the generator and the grid. The accomplishment of a power balance between the load and the generating units is more challenging in the case of wind power generation due to its unpredictable nature; most of the existing methods have been combating with this issue reactively due to lack of prediction controllers[1].

The wind turbine generator system [2] requires a power conditioning circuit called power converter that is capable of adjusting the generator frequency and voltage to the grid.. Several types of converter topologies have been developed in the last decades; each of them has their own merits and demerits. Many of the proposed converters require line filters and transformers to improve the power quality and step-up the voltage level, respectively and thse leads to system bulky and complex and also increases the maintenance cost. Islanding is a condition in the distribution network where this network disconnected from the utility grid and the power delivered by Distributed generators only. Classification-based techniques have been recently proposed in the literature for islanding detection [3]. An intelligence-based detection method is developed in Ref. [4-5], which uses the decision-tree (DT) classifier, but with complex set of 11 characteristics for classification, including total harmonic distortion of current/voltage, gradient of the product of voltage and power factor, etc. The access of Distributed Generators (DGs) satisfies the increasing demand for consistent, reasonable and spotless electricity but containing some design and operational issues like small variations in voltage and frequency and operating in islanding mode. Several active and passive methods have been recommended in the past to identify islanding of distributed generators from main grid and solving the power quality issues separately.

In the last decade, the EKF is the widely-used estimator for stochastic nonlinear systems. The main advantage of the EKF estimator over other estimators is its ability of taking into account the stochastic uncertainties The EKF is a recursive filter based on the knowledge of the statistics of both states and noises created by system modelling and measurements [6,7]. It can be applied to nonlinear, time-varying and stochastic systems. The EKF is also known for its high convergence rate and with this transient performance of the system increases considerably. Compared with nonlinear observers, EKF is characterized by better dynamic behaviour, disturbance resistance and it can work even under standstill conditions. In the literature we can find various controllers to address the power quality issues like mode detection and harmonics elimination but those controllers suffers from various draw backs like the effect of harmonics are undesirable for achieving efficiency[8,9],the reliability of the system has to be improved[10], the voltage compensation and harmonic occurrence had to be avoided[11] and the undesirable characteristics such as high line impedance and frequency deviations has to be mitigated[12].

This paper work mainly focused on to propose MPC algorithm which decomposes the MPC optimization into two sub problems: a steady-state sub problem and a transient sub problem, which are solved in parallel in different time scales, thus reducing the computational burdens, Detecting the Mode of operation of micorgrid either it is operating in grid connected mode or in islanded mode and momentarily dispatching real and reactive power to the microgrid when it becomes islanded. Identification of harmonics present in the system with the help of EKF and effective elimination of such harmonics by employing PSO algorithm to address the power quality issues in terms of reducing the THD, support the frequency deviations, Eliminating the disturbance due to voltage Sag/Swell at the supply side or changes in the load demand, Real and reactive power control for load sharing during peak periods and power factor correction at the grid side.

2. DESCRIPTION OF THE TEST SYSTEM

The proposed system consist of various DERs like PV cell, PMSG based wind turbines and energy storage system with PSO based novel controller as shown in fig(1).

The DERs are connected to PCC through a power electronic converter where the distribution grid and loads also connected.

The proposed system has the ability to operate both in grid connected mode and in islanding mode. In grid connected mode the power electronic converter controlled such that DERs support the Distribution grid in terms of peak power sharing, declining of harmonic, improving the power factor. In islanding mode PEC controlled in a manner to supply both real and reactive power to the distribution network loads. The proposed novel controller consists of model predictive controller, extended kalman filter and particle swarm optimization algorithm. The modelling of the various DG sources were given in [13].

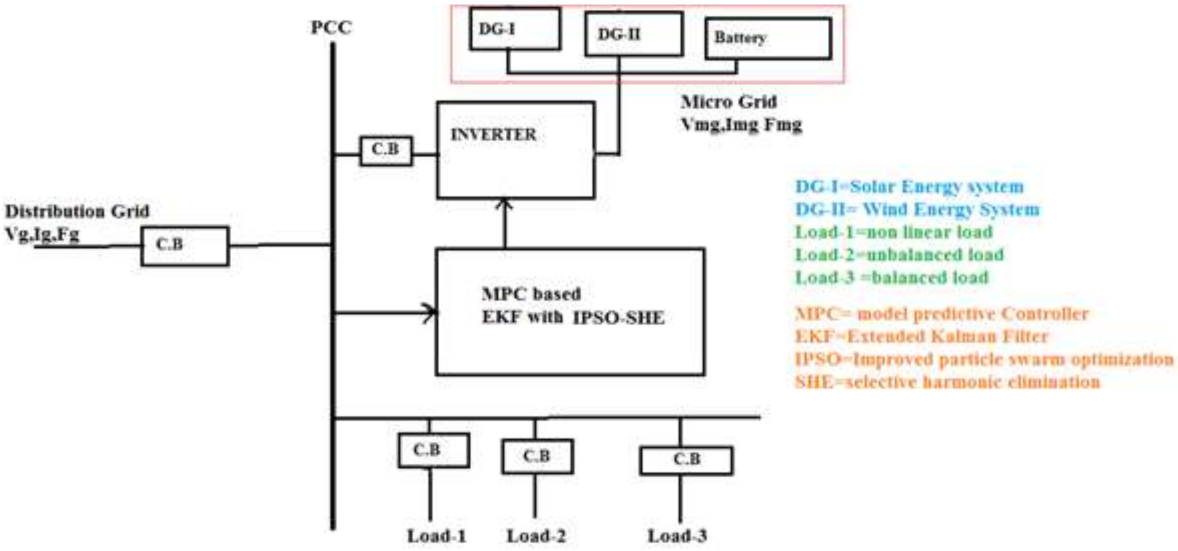

FIG:-1. Test system with PSO algorithm based MPC –EKF controller

3. MPC CONRTOLLER

MPC is a type of control algorithm that uses the process model and takes into consideration the constraints on input/ouput unlike conventional controller such as P,PI, &PID .this type of controller consist Model of the Process, Constraints and cost function as shown in Figure(2).

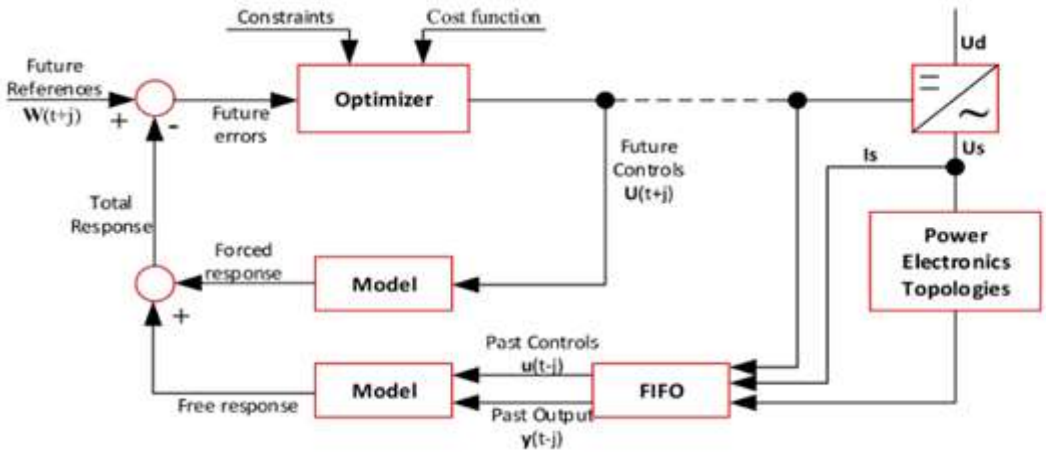

FIG:-2. General structure of an MPC controller.

In this, the future behaviour of the system is predicting with control algorithm. Here the prediction components are Free and forced responses of the system. The system output y (t+j) which is expected behaviour of system is shown by free response. In addition, it is accepted that the future values of the actuating variables will be equal to zero. The additional component of the system response is formed by forced response, which is based on the pre-calculated set of future-actuating values u (t+j. controller. The total response of system behaviour is determined as the sum of free and forced responses for the entire future system's behaviour in linear systems. By using the superposition principle the sum process has calculated. This sum is pre-calculated up to a prediction horizon, which is determined by a set of future reference values of system output. The future control error which is difference between the future reference and pre-calculated actual values is then obtained. a set of optimum future values u (t+j) from the expected error are determined by this method by taking system limitations and the cost function into account.

The MPC cost function is given as

$$J = \sum_{k=0}^{N_p} (\hat{y} - r)^T Q (\hat{y} - r) + \sum_{k=0}^{N_p} \Delta u^T R \Delta u \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where, Np is prediction horizon, r is set point, y is predicted process output, Δu is predicted change in error, Q is output error weight matrix and R is control weight matrix.

4. EXTENDED KALMAN FILTER

EKF is a powerful tool for estimating system states and parameters. The key advantage of EKF is its ability of filtering and noise rejection. EKF is designed based on the system's nonlinear discrete-time model.

The state model of the grid-connected inverter with disturbance can be formulated as

$$\dot{x} = Ax + Bu + w \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$y = Cx + Du + v \quad \ldots\ldots\ldots\ldots(3)$$

Where x is the state vector, u is the input, y is the measurement, w is the system uncertainty with covariance matrix **Q** and v is the measurement noise with covariance matrix **R**. Further, **A**, **B**, **C** and **D** are the inverter system matrices,

The system model in discrete from can be expressed as

$$x(k+1) = A_d x(k) + B_d u(k) + w(k) \quad \ldots\ldots\ldots\ldots(4)$$

$$y(k) = C_d x(k) + D_d u(k) + v(k) \ldots\ldots\ldots.\ldots.. \quad (5)$$

as the ambiguity and measurement noise of the system are unknown, hence it requires to design the EKF as follows:

$$\hat{x}(k+1) = A_d \hat{x}(k) + B_d u(k) + K(k)\,[y(k) - \hat{y}(k)] \ldots\ldots\ldots(6)$$

$$\hat{y}(k) = C_d \hat{x}(k) + D_d u(k) \quad \ldots\ldots..\ldots(7)$$

Where **K**(k) is the Kalman gain,. Finally, with two stages of prediction and correction kalman filter can be designed with the following procedure:

1. Initialize the state vector and covariance matrices.

2. Prediction of state vector

$$\hat{x}^-(k) = A_d \hat{x}(k-1) + B_d u(k-1) \ldots\ldots\ldots\ldots\ldots.(8)$$

3. Error covariance matrix prediction

$$P^-(k) = f(k) P(k-1) f(k)^T + Q \quad \ldots\ldots\ldots\ \ldots..(9)$$

where

$$f(k) = \frac{\partial}{\partial x}\left(A_d x(k) + B_d u(k)\right)\Big|_{\hat{x}^-(k)} \ldots\ldots\ \ ..\ldots\ldots(10)$$

Kalman gain calculation

$$K(k) = P^-(k) {C_d}^T \left(C_d P^-(k) {C_d}^T + R\right)^{-1} \quad \ldots\ldots\ldots.(11)$$

4. Estimation update through measurements

$$\hat{x}(k) = \hat{x}^-(k) + K(k)[y(k) - C_d \hat{x}^-(k)] \ \ldots\ldots\ldots\ldots.(12)$$

5. Error covariance matrix update

$$P(k) = P^-(k) - K(k) C_d P^-(k) \quad \ldots\ldots\ldots\ldots\ldots(13)$$

6. Go back to step 2.

5.PSO

Particle Swarm Optimization is a population-based stochastic search algorithm motivated by the social behaviour of bird flocking and fish schooling. In PSO, the population is called a *Swarm*, and each individual in the swarm is called a *particle*. Starting with an arbitrarily initialized swarm population, each member in PSO flies through a searching *N*-dimensional solution space, and remembers the best encountered position [14,15].

Note that each particle in the PSO is a candidate solution of the optimization problem and can communicate the better position to each other particle, and then particles in the swarm can regulate dynamically their own positions and velocities. Each particle in the swarm of size *N* is described by its position and velocity. The position of each particle is a possible solution, and the best position that each particle achieved during the complete optimization process is documented as best local position. The swarm as a whole memorizes the best position ever achieved by any of its particles as best global position. Position optimality is calculated from a fitness function which is defined in relation to the considered optimization problem. The position and the velocity of each particle in the iteration are updated.

At each iteration, new search points are generated from the current search points and the information regarding the p_{best} and g_{best} solutions is obtained using the following relation:

$$v_i^{n+1} = g v_i^n + c_1 r[pbest_i^n - x_i^n] + c_2 r[gbest_i^n - x_i^n] \quad (14)$$

And

$$x_i^{n+1} = x_i^n + v_i^{n+1} \quad (15)$$

Where C_1 and C_2 are the constriction factors, r is the random number between 0 and 1, *g* is the inertia weight, *V* is the particle velocity and n is the number of iterations. In the proposed IPSO algorithm the inertia weight is updated along with the pbest, gbest values after every iteration. The updation of inertia weight *g*can be expressed as:

$$g = \frac{g_{\max}(m-n)+ng_{\min}}{m} \quad (16)$$

Where m is the total number of iterations, n is the current number of iteration.

The process of the proposed IPSO with SHE algorithm is explained by the following steps.

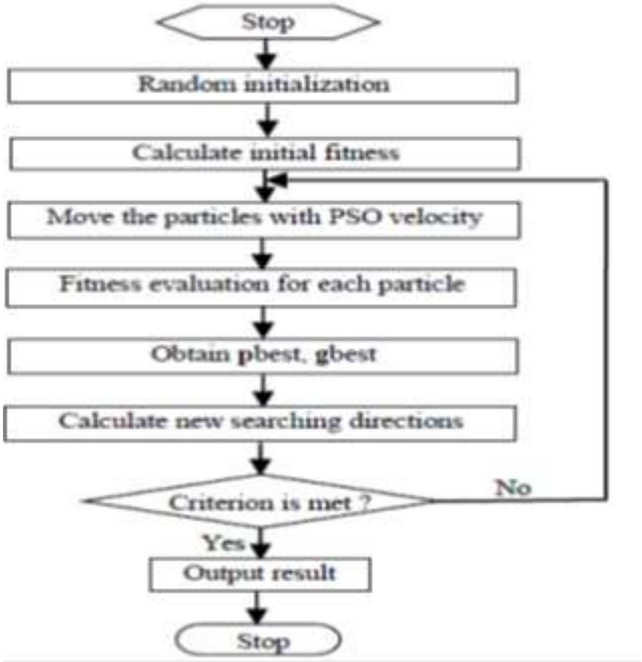

FIG:-3.PSO algorithm flow chart

5.RESULTS AND COMPARISONS

The proposed test system with PSO based novel controller was designed by using MATLAB Simulink tool. The Simulink model of the test system with various DERs, power electronic converters, controllers and different loads is shown in fig(4) and the Simulink parameters of wind turbine, solar PV cell and storage system are given in table-I

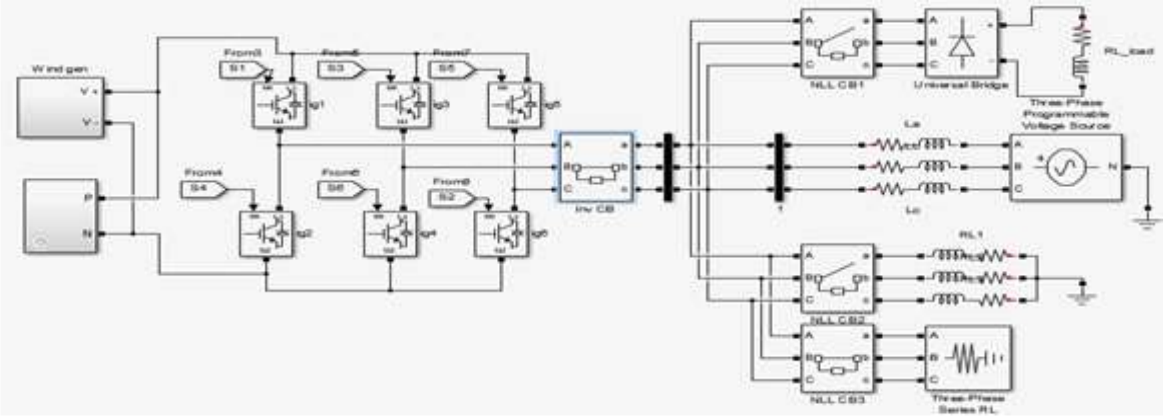

FIG:-4.SIMLINK MODELOF THE TEST SYSTEM

Table-I Simulink parameters for DG sources

S.No	Type of DG source	particulars	Rating
1	Wind DG source (PMSG)	Nominal m/c power	1.5x10^6 W
		Base power	1.66x10^6 W
		Wind speed	10m/sec
		Max. Power at base wind speed	1095kW
		Stator phase resistance	2.2 Ω
		Stator phase inductance	0.29 Mh
2	PV array (BP solar Sx3190)	No.of cells	50
		No.of series modules	10
		No.of parallel strings	132
		V_{oc}	30 V

		V_{mp}	24 V
		I_{sc}	8.5 A
		I_{mp}	7.8 A
3	Storage system (Nickel-metal-Hydride)	Nominal voltage	600V
		Rated Capacity	25Ah
		Maximum Capacity	715.4 Ah
		Initial SOC	50%

In PMSG based system, to achieve variable speed operation the systems use an extra excitation circuit, which feeds the excitation winding of PMSG. The PMSG based wind turbine generator system consisting of a step-up chopper circuit which adapts the rectifier voltage to the DC-link voltage of the inverter. The generator torque and speed can be controlled by controlling the inductor current in the chopper circuit. The Simulink model of the test PMSG based wind sources is shown in Fig(5), solar PV is given in fig(6) and storage system in fig(7). Model predictive controller helps to reduce the error, extended kalman filter liberalize the system and improves the stability and PSO helps to tune the proportional gain constants and improve the robustness of the system. The proposed novel controller was tested for different like harmonic compensation, power factor improvement, sag/swell condition and support during islanding mode of operation. and the simulation results under these test cases discussed below.

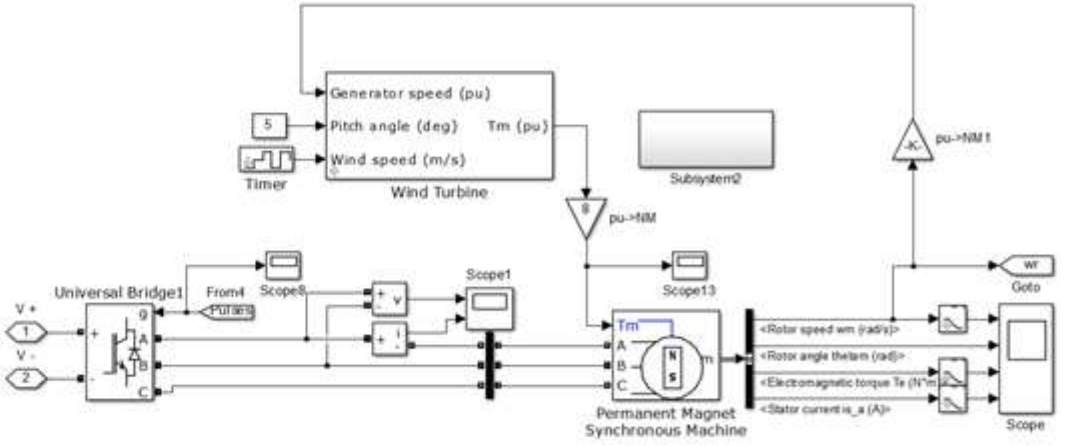

FIG:- 5. Simulink model for Wind source

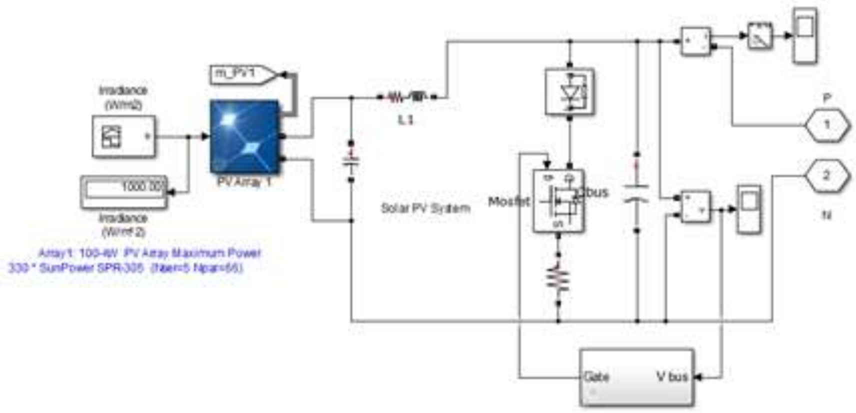

FIG:-6. Simulink model for solar PV system

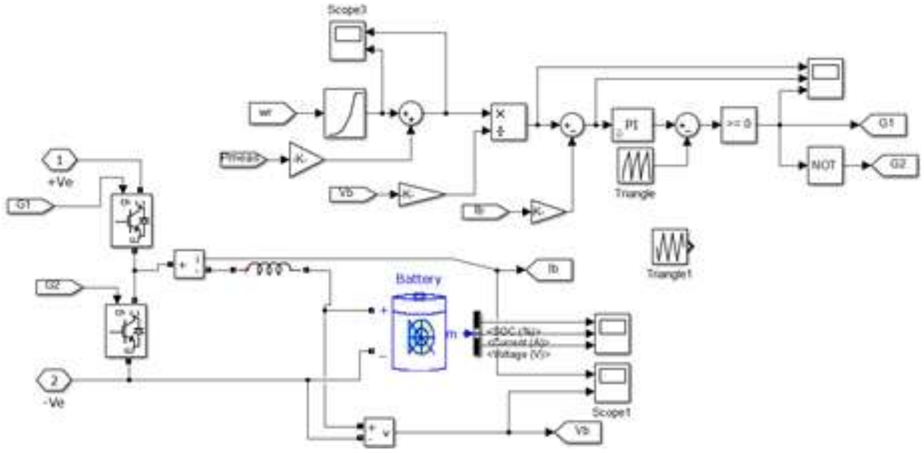

FIG:-7. Simulink model for battery storage

Test Case 1: Harmonic Compensation and Power Factor Correction During Steady-STATE OPERATION WITH LOAD SHARING

Conventional PI controller produces Very large grid source disturbance and harmonically polluted source. From simulation results shown in Fig(8 to10) we can observe that our proposed novel controller technique will compensate the harmonics at the grid source end and reactive power change demand. From table-II it is evident that MPC based EKF with PSO algorithm reduces the THD in terms of voltage and current to 2.981 and 2.909 when compared with conventional controller THD values 5.43 and 6.308 respectively. We can also observe that the power factor has been improved relatively from 0.91 to 0.99.

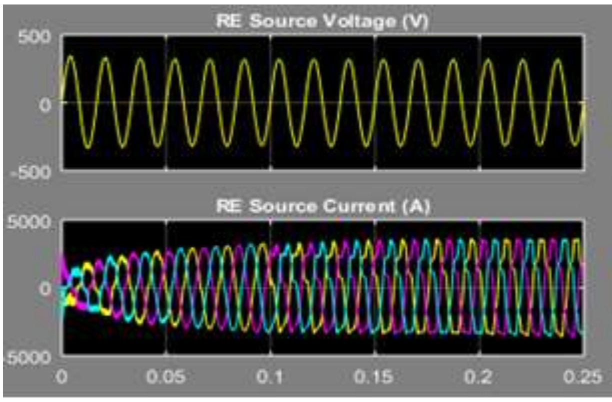

FIG:-8. DERs Voltage and current

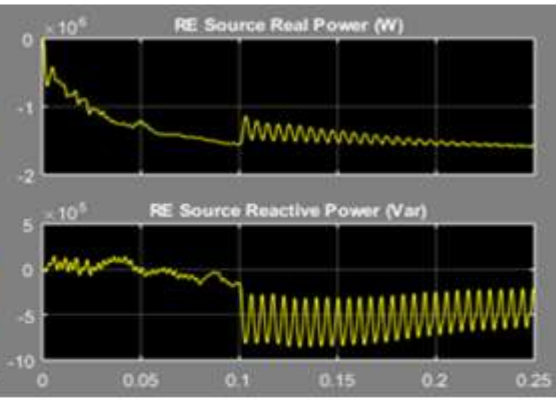

FIG:-9. DERs real and reactive power

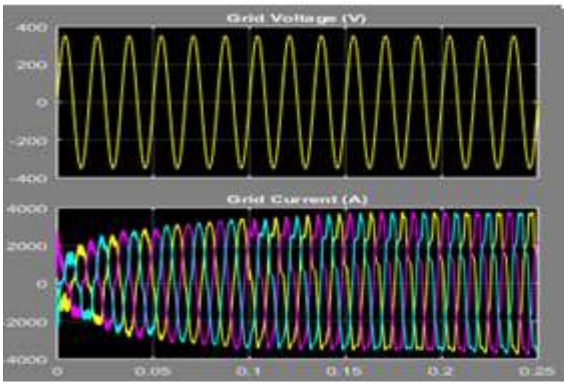

FIG:-10. Grid Voltage and Current

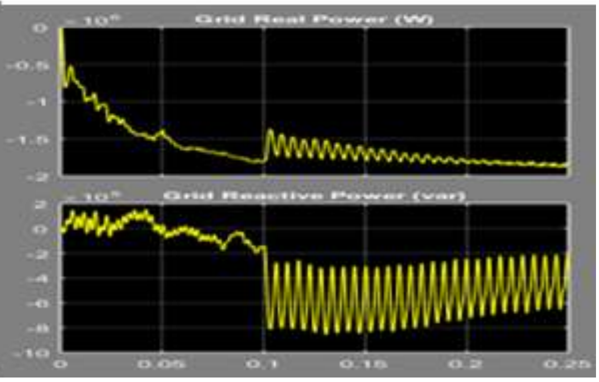

FIG:-11. Grid real and reactive power

Table-II THD values with different controllers

Sno	Particulars	Conventional method	MPC-EKF	EKF-PSO	MPC-EKF-PSO
1	THD in voltage	5.432	4.896	3.216	2.981
2	THD in current	6.308	4.981	3.821	2.909
3	POWER FACTOR	0.91	0.94	0.98	0.99

Test Case 2: Sags and Swells in the Grid Voltage

In this test case Voltage sag and voltage swell analysis were done and the corresponding results as shown in Fig(11 to 14). In the test system we created voltage sag of 0.8pu from the time instant 0.05 to 0.1 sec and a voltage swell of 1.2pu fron 0.1 to 0.15 sec. From the simulation results we observed that proposed controller supports both real and reactive power during voltage sag and swell conditions.

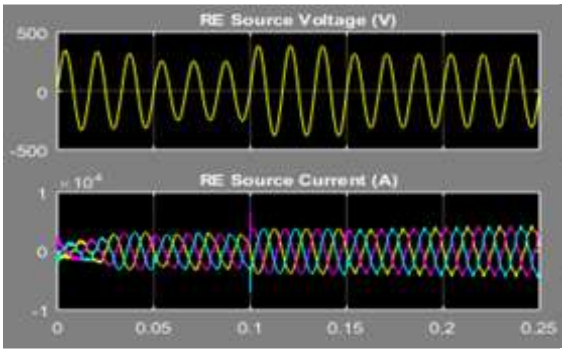

FIG (11):- DERs Voltage and Current

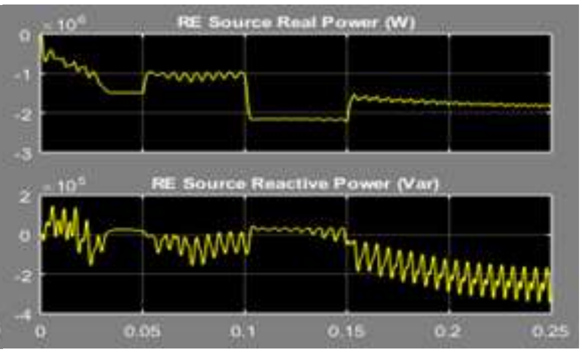

FIG (12):-DERs Real and Reactive Power

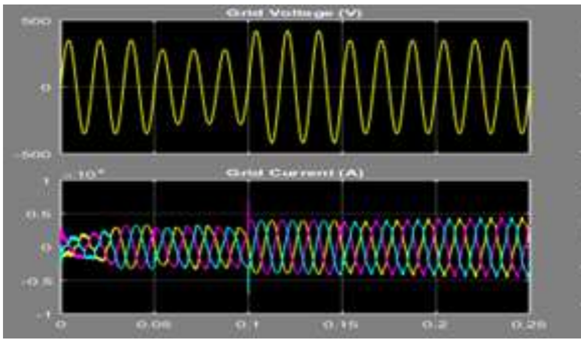

FIG (13):- Grid Voltage and Current

FIG (14):- Grid Real and Reactive Power

TEST CASE 3: FREQUENCY VARIATIONS IN THE GRID VOLTAGE

In this test case we observe the performance of our controller by creating a disturbance in terms of frequency deviation from time instant 0.075 to 0.125 sec as shown in fig(16). From table-3 we conclude that MPC based EKF with PSO algorithm maintain constant frequency and the deviation in the frequency is 0.3Hz only.

Table-3 Frequency Deviation

S.No	Name of the controller	Frequency deviation in Hz
1	Conventional controller	60.8
2	MPC controller	60.5
3	MPC-EKF-PSO	60.3

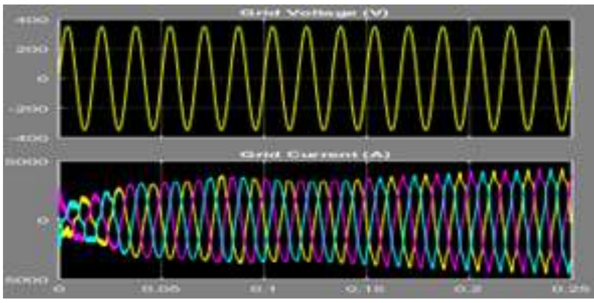

FIG (15):- Grid Voltage and Current

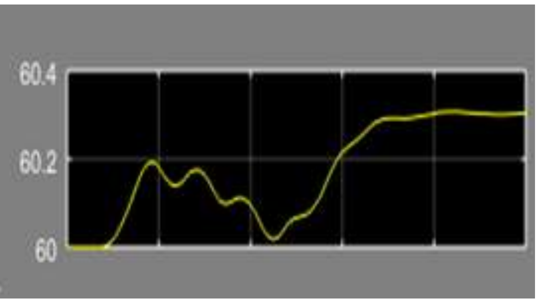

FIG (16):- Grid Frequency

TEST CASE 4: ISLANDED OPERATION (EMERGENCY MODE)

When utility grid disconnected from the system then Islanding occurs and total load is taken by DERs only. In test system we created Islanding mode by disconnecting the grid from time instant 0.05 to 0.15 sec as shown in fig(17 to 20).from simulation results we observe that DERs support the loads of 1700kW by producing 1100 kW real power and 20kVAR reactive power. i.e 64% of the total load effectively operating in the Islanding mode.

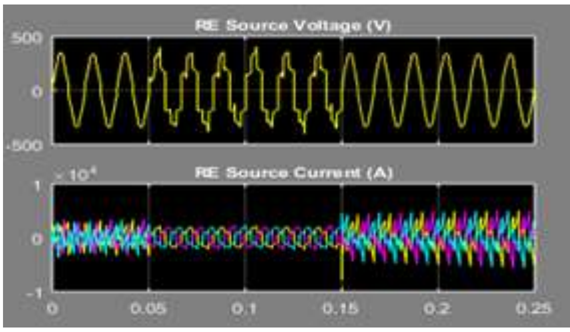

FIG (17):- DERs Voltage and Current

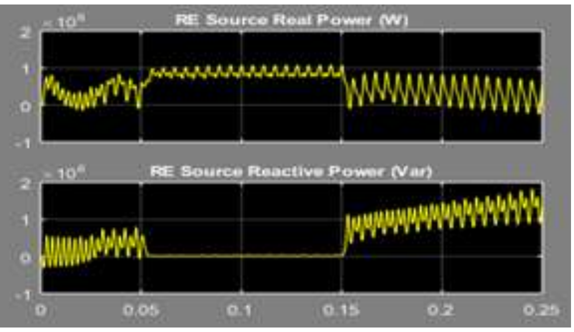

FIG (18):-DERs Real and Reactive Power

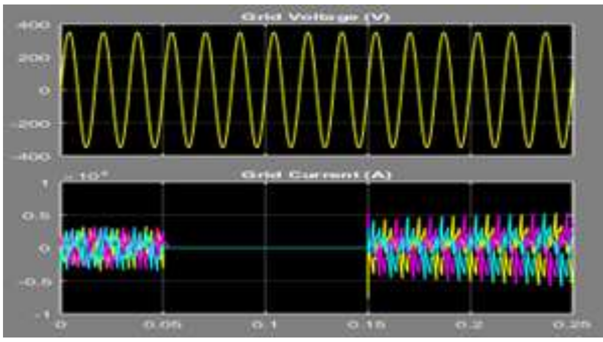

FIG (19):- Grid Voltage and Current

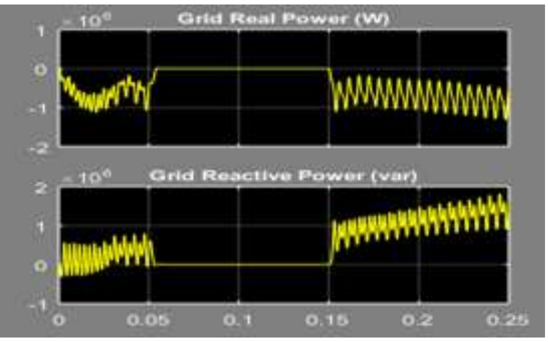

FIG (20):- Grid Real and Reactive Power

7. CONCLUSION

In this paper PSO algorithm based MPC with EKF was proposed to improve the power quality. Model predictive controller helps to reduce the error, extended kalman filter liberalize the system and improves the stability and PSO helps to tune the proportional gain constants and improve the robustness of the system. Also the proposed controller indentifies that islanding mode and provides real and reactive power to the local loads during islanding mode. From the simulation results it is evident that the total harmonic distortion was reduced effectively and also improves the power factor .The controller also support the grid frequency when ever their occurs deviations in the gird frequency.MPC based ekf controller also supports the loads during voltage sag and swell.

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