Minimization of Imbalance caused by Forecasted Demand and Actual Generation

Nuki Taggu[1], Smriti Dey[2]

[1]Department of Electrical and Electronics Engineering, Assam Don Bosco University
Guwahati-781017, Assam, INDIA.
nukitaggu.aru@gmail.com

[2]Department of Electrical and Electronics Engineering, Assam Don Bosco University
Guwahati-781017, Assam, INDIA.
Smriti.dey@dbuniversity.ac.in

Abstract*: *A conventional energy cannot meet today's continuous increase in energy demand, because of its depletion and in a verge of extinction. Renewable energy offers a solution to this problem of energy demand. Hence, more integration of renewable energy source to the existing grid in order to supply the required demand. This integration of RES brings an issue of uncertainty, which further creates a mismatch between an electricity supply and demand. In this work two steps procedure is adopted to minimize the imbalance caused by forecasted demand and actual supply. Model predictive control (MPC) is used to determine the individual imbalances and Particle swarm optimization (PSO) is applied to optimize the imbalance in the current time slot. The results show that the proposed method is able to reduce the imbalance caused by a forecasted demand and actual generation.

***Keywords*: Flexible Demand, Model predictive control, Particle swarm optimization, Uncertainty of solar generation.**

(Article history: Received: 28th January 2021 and accepted 20th June 2021)

I. INTRODUCTION

The integration of Renewable energy sources (RES) on the grid is being increasingly preferred to produce the renewable energy generation and in order to minimize the dependency on fossil fuels, leads to a reduction in greenhouse gas emissions. But more the shares of RES; such as solar and wind power generation plants on the grid, more the generation of electricity depends on the changing of the climate. And in turn more of unpredicted electricity generation. However, this uncertainty also affects the demand side as electricity consumption is also weather dependent; such as on the weather or working hours and every kWh produced must be consumed somewhere. Thus making the uncertainty more challenging for the power system operation. To avoid these issues of variability and uncertainty, a widely accepted approach to deal with these aspects is based on the concept of 'flexibility'; it stated as 'the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise'. One of the flexible resources is the demand side management or response [1]. Demand response (DR) is the change in the power consumption of the consumer from their normal consumption. DR seeks to adjust the demand rather than the supply for power. In a daily operation of the power system, the supply and demand have to be continuously balanced, otherwise, the deviation of system frequency can create a system imbalance, leads to the low quality of electric supply or damages to power facilities further into a power failure. It becomes very important to deal with this kind of unwanted power imbalance. Mainly through the electricity markets, the balancing between the supply and demand in the power system is achieved. Only the idea behind the day-ahead markets (DAM) and balancing markets are considered no real connection with the DAM and balancing markets and their buying and selling energy bids. The individual imbalance is calculated per program time unit (PTU=15 min). Transmission System Operator (TSO) is responsible for eliminating & restoring the system imbalance. Markets participants in the balanced markets have a balanced responsibility means that they are financially responsible for their individual imbalances and are penalized with imbalanced prices [2]. In the real scenario, increases in either the side (i.e. positive or negative) of the imbalances the participants are penalized with imbalance prices, when the negative imbalance occur the participants have to pay the price for each MWh of imbalance. Similarly, a positive imbalance occurs the participants earn the price for each MWh of imbalance. The term system imbalance is the net sum of all the individual imbalance of each PTU. In order to reduce the problem of imbalance, a combination of model predictive control (MPC) and particle swarm optimization (PSO) technique is used to obtain an optimized result.

II. The System Description

A. The Balancing Time Frame of the Model

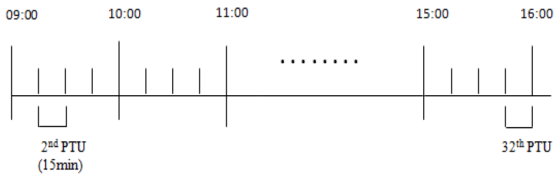

Fig. 1. Balancing time frame.

The time frame of the model starts from at 09.00 and runs at every PTU till the completion of the working hours 05.00. Since, 32th numbers of total PTUs the runs of the model is 32 times in a selected time periods of 8 hours of a day. PTU is the time resolution of the model. The Day-ahead (DA) energy exchange with the power grid is based on consumers demand predictions and day ahead solar generation forecast and the actual energy exchange with the power grid is based on the actual solar generation and non-flexible and flexible load demand.

B. Uncertainty of solar generation

The predictability of output from a variable power plant is considered to be an uncertain. In the generation of solar PV, fluctuation is often because of the passing weather and during the night no power generated. Demand forecasts for the day ahead commonly include an average error of around ±1.5%, rising to 5% for the week ahead [3].

C. Shifting of Loads

The loads were classified only in two type namely as flexible and non-flexible loads. The electricity consumptions are shifted from one time period to another time period. The loads which are shifted within a certain time limit, based on the need and requirement of the user without affecting their comfort level is known as flexible loads. Such as air conditioning systems, refrigerators, heating systems, or ventilation. And the loads that cannot be shifted within a certain time limit or without bringing discomfort to user is known as non-flexible load.

III. Optimization

In this work two steps procedure is adopted to minimize the imbalance caused by forecasted demand and actual supply.

A. Model Predictive Control

Model predictive controller (MPC) had been known for a process control industry. The concept for MPC is that it takes the reference and plant output in order to generate the control outputs. This control is sensitive to discrepancies between the control model and the real system, making it necessary to impose certain robustness to these control methods. This can be achieved by a receding horizon technique; it applies only the first control action obtained by the resolving of the optimization problem in a prediction horizon. MPC uses the model of a plant for predicting the future behavior of the plant, where the predicted behavior of the plant is fed to the optimizer which will adjust the value of the control output to make sure the predicted plant output tract the reference signal and meanwhile the plant output and control output must satisfy the given range.

- It is a basically a flexible and open formulation in a time domain.
- Through MPC future of a plant behavior can be predicted.
- Used an optimal control law.
- Can solve problems of linear and nonlinear system without changing the controller formulation.

B. Particle Swarm Optimization

Particle swarm optimization (PSO) is one of the most popular optimization techniques to solve an optimization problem. The method of the PSO algorithm is inspired by the social behaviour of organisms such as bird flocking and fish schooling. In a natural scenario of a flock of bird, the one who is in the closest position towards the food source will inform the group members of the location of the food and the rest will simultaneously move toward that location. This process will continuously occur until the food source is discovered. Thus, the process of the PSO algorithm will optimize a problem using swarm intelligence by iteratively trying to improve a candidate solution with regard to a given measure of quality. The algorithm works by having a 'population' (swarm) of 'particle' (bird) moves around in a search space. Each particle will have its own best position 'Pbest' in the search space as well as the entire swarm best position 'Gbest' which will be influenced by 'velocity' at which the particles move. The algorithm will be repeated in three steps until the stopping condition is met, evaluate the fitness of each particle, update individual and global best and update the velocity and position of each particle.

- The implementation is simple.
- Based on swarm intelligence.
- Adjustment of parameters are less, no mutation and occurrence of overlapping.

Let 'x' and 'v' denotes the 'position' and 'velocity' of a particles in the search space respectively, having a swarm of size 'n'.

$$x = [x_1, x_2, \dots, x_n]^T \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

$$v = [v_1, v_2, \dots, v_n]^T \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$v_i(t+1) = wv_i(t) + c_1 r_1 [pbest - x_i(t)] + c_2 r_2 [gbest - x_i(t)] \dots\dots\dots (3)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \dots\dots\dots\dots\dots (4)$$

$$w(t) = [(w_{max} - w_{min})/t_{max}] * t \dots\dots\dots\dots (5)$$

C. Formulated Algorithm and Equation

- Objective function to minimize the imbalances can be formulated as given below [2].

$$\text{Minimize} \sum_{t'=t}^{T} \Delta^{+}_{t,t'} + \Delta^{-}_{t,t'} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Subject to,

$$p^{act}_{t,t'} + p^{upd,pv}_{t,t'} = p^{nf}_{t,t'} + p^{schd}_{t,t'} \;\ldots\ldots\ldots(7)$$

$$\Delta_{t,t'} = p^{da}_{t'} - p^{act}_{t,t'} \;\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$p^{da}_{t'} = p^{d}_{t'} - p^{pv,f}_{t'} \;\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots(9)$$

$$p^{act}_{t,t'} = (p^{nf}_{t'} + p^{\Delta,f}_{t,t'}) - p^{upd,pv}_{t'} \;\ldots\ldots\ldots\ldots\ldots..(10)$$

$$p^{schd}_{t,t'} = \sum_{t'=\max(t-tshift,1)}^{\min(t+tshift,r)} p_{shifted} \;\ldots\ldots\ldots...(11)$$

$$p^{\Delta f}_{t+1,t'} = p^{\Delta,f}_{t,t'} - p^{schd}_{t,t'} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(12)$$

- PSO Objective function,

$$\text{Minimize} \sum_{t'=t}^{T} abs\{(-p^{pv,f}_{t'}) - [(p^{nf}_{t'} + p^{\Delta,f}_{t,t'}) - p^{upd,pv}_{t'}]\} \;\ldots\ldots\ldots\ldots.(13)$$

$$p^{f}_{min} < p^{\Delta,f}_{t,t'} < p^{f}_{max} \;\ldots.\ldots\ldots(14)$$

$$\text{Total imbalance} = abs\left(\sum_{t'=t}^{T} \Delta^{+}_{t,t'} + \Delta^{-}_{t,t'}\right) \ldots.(15)$$

D. The steps of Algorithm

Number equations consecutively. Equation numbers, within

- Starts the operation of model and initialize the parameters with $p^{nf}_{t'}$, $p^{da}_{t'}$, $p^{pv,f}_{1,t'}$, $p^{pv\,upd}_{1,t'}$
- Run the model for t=1:32 and also set the PTU for i =1:32.
- PSO (from 1 to 12) to obtain the optimized value of objective function (i.e. imbalance) for only the first PTU i.e. (i=1:1), where each i[th] particle is represented by $x = [x_1, x_2, \ldots, x_n]^T$ and 'x' is the flexible load demand. Initialize the PSO parameters and the particles position randomly and velocity according to the limits of each variable. For all the runs calculate the objective function, where penalty is not considered in the objective function. Obtain the best evaluated value 'gbest' or the optimum solution that minimizes the objective function.
- Calculate the scheduling of flexible load demand using eqn. 11.
- Calculate the flexible load for the next PTUs using eqn. 12.
- Using equation 13, calculate the possible individual imbalances occurs on the rest of the PTUs.
- Checked if the PTU> PTU max then stop.
- Repeat the steps 5 to 7 for all the next run.
- If the Run> Run max is achieved then stop the program, take the value of imbalance in all the 1[st] PTU of each runs to be the optimized results in a selected time period of a day.
- Manually calculate the total imbalance that occurs for selected time period of a day by using equation 15.

IV. Results

The main goal of this work is to reduce the imbalance error caused by forecast demand and actual generation by considering the uncertainty of a solar generation. The optimization problem is done in MATLAB environment using MPC and PSO technique.

TABLE I. PARAMETERS OF PSO

Sl. No.	PSO parameters	Values
1	Numbers of variables 'x'	1
2	Limits range	$0 \le x \le 5$
3	Numbers of population	50
4	Acceleration factor (c1 & c2)	2
5	Weight factor (*Wmax* & *Wmin*)	0.9 & 0.4 respectively

Initializing the PSO with the given parameters shown in above table I, the 'x' denotes the flexible load demand and the limit is assign to get a desirable optimized value along with the population, acceleration and weight factor. Note: The data of the day-ahead solar generation forecast and updated solar generation forecast are taken only for selected time period i.e. 9:00-16:00 between the forecast data (in kWh) and total PTU, rest of the time period is not considered and taken to be as zero. Table II shows the input data for the proposed work. Figures (2-6) shows the convergence characteristics of the objective function for different runs.

TABLE II. INPUT DATA

run	PV forecast (in kWh)	PV actual (in kWh)
1	6.175	4.175
2	6.810	4.910
3	6.995	6.015
4	7.978	7.278
5	8.590	7.945

A. Graph of PSO convergences

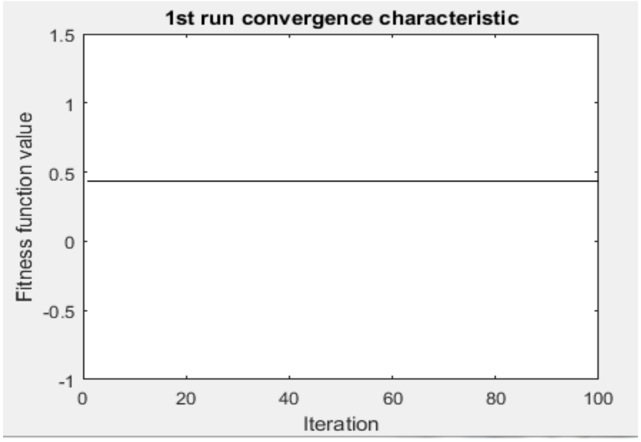

Fig.2. Convergence characteristic for the 1st run

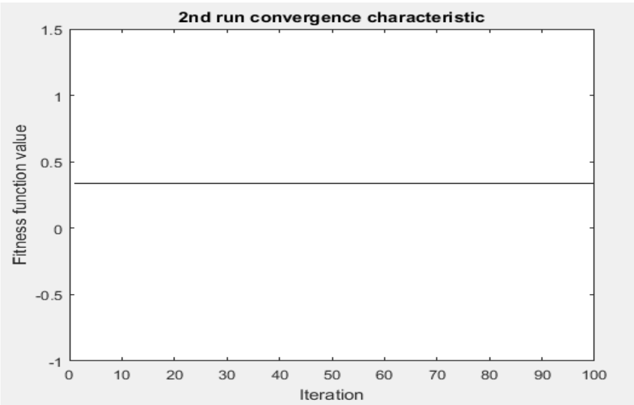

Fig.3. Convergence characteristic for the 2nd run

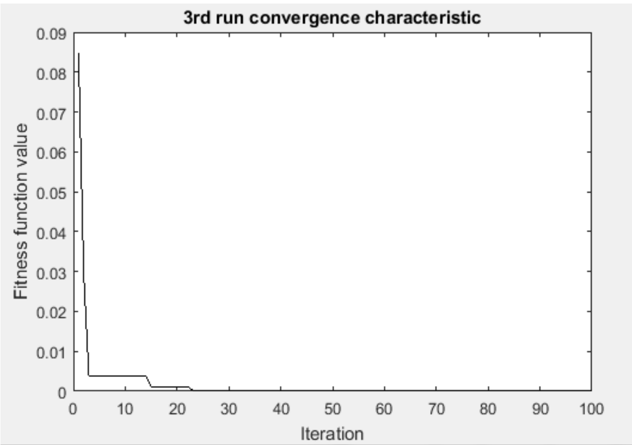

Fig.4. Convergence characteristic for the 3rd run

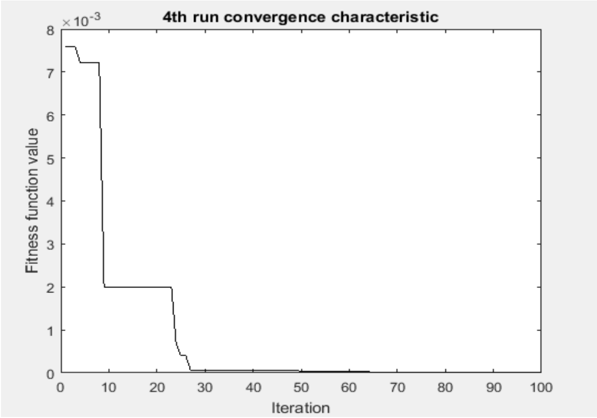

Fig.5. Convergence characteristic for the 4th run

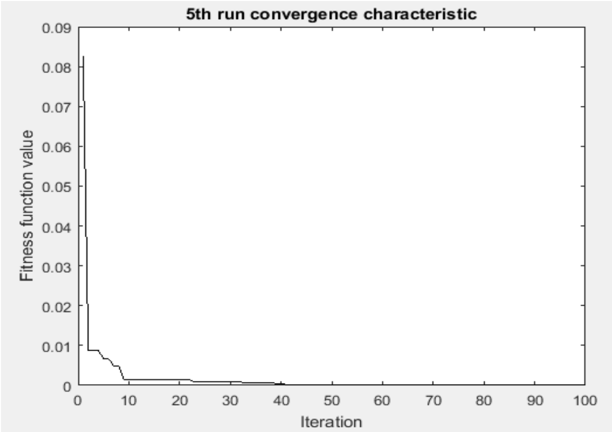

Fig.6. Convergence characteristic for the 5th run

TABLE III. MPC AND PSO OPTIMIZED OUTPUT (kWhr.)

Run	**Flexible demand**	**First's PTU of Every Run**
1	0	0.4375
2	0	0.3375
3	0.5825	3.6283e-10
4	0.8625	1.7960e-10
5	0.9175	2.1807e-11

In the table III the result of the flexible demand obtain from the PSO for every run is shown. Also after optimization, the first PTU of every run from the MPC optimization is presented.

V. CONCLUSION

The main objective of the work was to reduce the imbalance caused by actual supply and forecast demand. To reduce the individual imbalance, a combine work of model predictive control and particle swarm optimization is presented. The results show that the optimization of the imbalance caused by forecasted demand and actual generation is achieved.

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AUTHOR PROFILE

Ms. Taggu is a M.Tech student in the Department of Electrical and Electronics Engineering, Guwahati, School of Technology, Assam Don Bosco University. Her research interest is Power system Optimization.

Smriti Dey

Ms. Dey is currently working as Assistant Professor with the department of Electrical and Electronics Engineering, Assam Don Bosco University, Guwahati. Her research interests include Flexible ac Transmission systems and Power flow management.