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Comparison between Integration of Wind Plant and Pump-Hydro Power Plant Optimized by BFO and by Interior-Point Algorithm

[1]Rajesh Saini, [2]Karambir & [3]Kalyan Singh

[1]Department of Electrical Engineering, Asstt. Prof., Central University,Pali, Mohindergarh-123029 (India)
[2,3]Department of Electrical Engineering, Asstt. Prof., RPSCET Balana, Mohindergarh-123029 (India)

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ABSTRACT

This paper presents two new approaches to solve the generation scheduling (GS) problem of a wind–hydro power plant by BFO and by interior-point algorithm. The production of an optimal day-ahead generating schedule is considered. A bidding strategy by combining stochastic day ahead strategy and operational management strategy is used a comparison is shown with revenue generated by only day ahead strategy. In day ahead strategy we make a strategy for an advance day that we generate power from wind and store the power in pump storage unit when the price is low and generate power from wind and hydro plant when price is high. On other hand in operational management strategy we reduce the imbalance between contracted and generated power in the operating day. So we maximize the profit by minimizing the imbalance of power. For this we have used a more advanced bio optimized optimization – Bacterial foraging optimization and by interior-point algorithm and compare these result.

1. Notations Used in the paper

P_{Hi} Hydroelectric power at hour i
P_{Gi} Wind Power directly delivered to the grid at hour i
P_{Pi} Pumping Power in scenario s at hour i
E_i Energy stored in the reservoir at hour i
T_i Regulation costs in scenario s at hour i
d_i Power Imbalances in scenario s at hour i
PDL_i Dumping power loads in scenario s at hour i

2. Introduction

wind energy have many positive benefits to the utility system, such as low cost energy, long-term price stability, and some system capacity, but it also has different generation characteristics than non renewable energy resources. Unlike non renewable power generation sources, wind power generators supply intermittent power because of uncertainty in the wind resource. In a large-scale wind power penetration scenario, wind operator require the greater reserve power, in order to balance possible errors between predicted power generated and actually wind power generated output.[1]

A most important strategy for increasing profits of utility is to integrate the wind power plant with pumped storage plants. A pumped storage unit can be used to provide added value to a wind plant that is taking part in the market in comparison with individual participation of them. The possibility of storing energy in pumped storage plants can significantly reduce the risk of wind power producers self-scheduling in the market. In another strategy for decrease the deviation between contracted power and generated power is also used. In this strategy the power imbalance between predicted power generated and actually wind power generated can be reduced by pumped storage unit.

The wind power predicted and actually measured at Illinois State for a day as shown in figure 1.

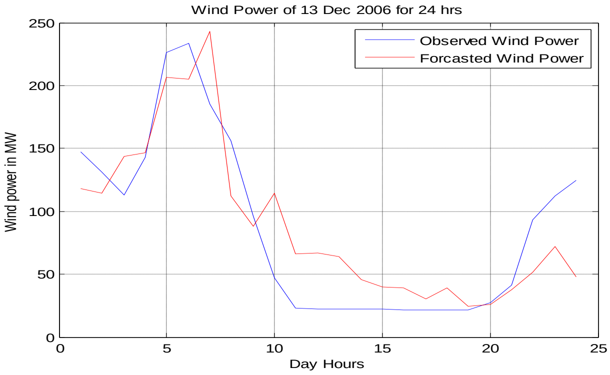

Figure 1: Forecasted and observed wind power of a day

The figure shows the 24 hrs wind power profile. In night hours wind speed is high so energy generation is also high but in day hours it decreases because of decrease in wind speed. The difference between predicted and observed power is also high. This figure shows the stochastic forecasting of wind power.

This large deviation in wind speed and difference with forecasted data will change the spot price as shown in figure 2.

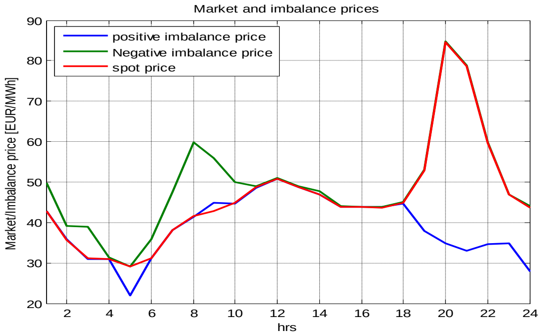

Figure 2: spot price fluctuation due to variation in wind speed

It shows that when wind generation was high, prices were low but with decrease in generation, prices also rise per hrs.

To mitigate this problem a solution of using pump-hydro generation power plant with wind power plant came into existence. A proper coordination of pump-hydro plant generation with wind plant results in maximum revenue collection [2].

The rest of this paper is organized as follows. In Section II, problem formulation and constraints of the problem are discussed. In section III, the results of Comparison between Integration of a wind–hydro power plant Optimized by BFO and by interior-point algorithm are discussed. This model is applied to a test system (1 wind farms and 1 pumped storage plants) and the results of this optimization problem were presented in this section. At last conclusion is drawn in Section VI.

3. Problem Formulation

Wind plants have small controllability due to the variability of the wind speed and direction. One solution to overtake this problem consists in coordinate wind and pump-hydro generation by adding a Pumping-Hydro Storage (PHS), thus increasing the systems flexibility and profitability. The optimization derived from the joint operation can be performed in two different Strategies:

Day Ahead Strategy: This action is performed before the operating day by using price and wind forecasted data to optimize the energy bids made to the day-ahead market. Water is pumped into the reservoir when prices are low at night hours, and used to generate electricity afterwards when prices are higher at day hours [24]. Thus performing price is arbitrage. In Figure 3, it is illustrated the typical operation of a pump-hydro plant. In the period b, the pump unit takes advantage of the lower spot market prices to store energy from pump water into the reservoir. Then, when a more profitable opportunity arises that is when piece is high (period d) the hydro power plant generates energy from the stored water.

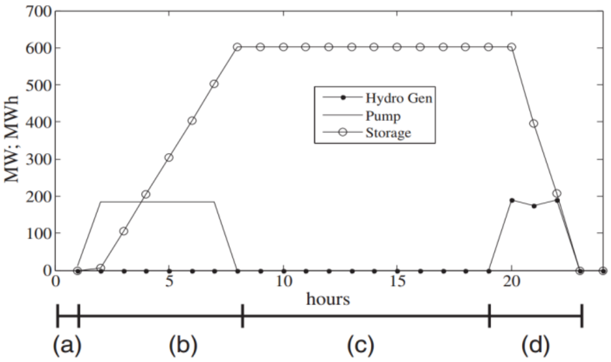

Figure 3: Typical operation of a water storage unit [1]

Operational Strategy (OS): This operation is conducted to minimize the difference between contracted power and generated electrical energy. This is done by storing energy during periods when the real wind power is higher than the forecast and by using hydro generation for filling wind power gaps.

Day ahead strategy takes into consideration the hour by hour wind power data and co-ordinate both plants to maximize the revenue. The two methods are used to coordinate the wind and pump-hydro plant by optimize the objective function. In the first method Bacterial Foraging Optimization Algorithm (BFOA) which is a newcomer to the family of nature-inspired optimization algorithms optimization strategy is used to optimization the objective function to maximize the profit. On other hand in second method interior-point algorithm is used to optimization the objective function to maximize the profit. The Objective function used in this paper is the combination of product of total power supplied to grid multiplied by the hourly prices and pumping cost. Here the cost of pumping is negligible. Equation 1 [15] represents the mathematical formulation of objective function.

$$\max EV = \max \sum_{i=1}^{n} [p_i \cdot (P_{Gi} + P_{Hi} + d_i) - T_s - c_{pump} \cdot P_{Ps} - c_{hydro} \cdot P_{Hi}]$$

(1)

T_i is the regulation price which is dependent upon the imbalance in prices as shown in equation 2.

$$T_i = \begin{cases} d_i(p_i - p_i^+) & if \ d_i \geq 0 \\ -d_i(p_i^- - p_i) & if \ d_i < 0 \end{cases} \qquad (2)$$

(2)

Here is the positive imbalance price and is the negative imbalance price. The objective function is bound by some technical constraints which are tabulated in below table [15].

$$P_{Wi} = P_{Gi} + P_{Pi}$$
$$d_i = P_{Wi} - (P_{Gi} + P_{Pi} + P_{DLi})$$
$$d_i(p_i - p_i^+) \leq T_{s,i}$$
$$-d_i(p_i^- - p_i) \leq T_{s,i}$$
$$T_{s,i} \geq 0$$

$$E_i = E_{i-1} + t[\eta_P \cdot P_{Pi} - \frac{P_{Hi}}{\eta_H}]$$
$$P_{Hi} \leq \eta_H \cdot [\frac{E_i}{t} + \eta_P \cdot P_{Pi}]$$
$$0 \leq E_i \leq E^M$$
$$0 \leq P_{Hi} \leq P_H^M$$
$$0 \leq P_{Pi} \leq P_P^M$$
$$0 \leq P_{DLi} \leq P_G^M$$
$$0 \leq P_{Gi} \leq P_G^M$$

The high uncertainty in speed of wind increases the deviation in contracted and generated energy. The operational management strategy (OS) aims to minimize this deviation, in order to reduce the system's regulation costs. The OS algorithm performs a new optimization for every hour (i, the market time interval) with a sliding window approach and considering all periods from i = 1 to i = n, using as inputs the past state of the system(e.g. storage level), updated wind forecasts (WF) and the day-ahead bids. For each hour of the optimization, the inputs are defined as:

- Day-ahead bid: The bid found by the stochastic DA optimization for the period of operating hour, i.e. P_{Hi}+P_{Gi}.
- System's past state: corresponds to the level of energy present in the reservoir in the previous period

(E_{i-1}), except for the first hour of optimization, where it is defined as the initial amount of energy present in the reservoir (E_{begin}).

- Updated wind power forecasts: These are received at each period i and evaluate point predictions from the period i to period i+4 (very short-term horizon).

Since the objective of this strategy is to minimize the deviation in the power generation. So the power deviation variable (d) is formulated as:

$$d_i = (\widetilde{P_{Hi}} + \widetilde{P_{Gi}}) - (P_{Gi} + P_{Pi} + P_{DLi}) \quad (2)$$

Here are the powers generated from the day ahead strategy. The next day power deviation will be reduced in equation 3 is minimized which changes the regulation cost, the objective function of this strategy will be

$$\min \sum_{i=1}^{n} T_i \quad (3)$$

Subject to

$$T_i = \begin{cases} d_i \ if \ d_i \geq 0 \\ -d_i \ if \ d_i < 0 \end{cases}$$

Other technical constraints will remain same as were with the previous case.

First the bacterial foraging optimization is used in both strategy planning cases, in day ahead strategy it maximize the revenue and in second case it decrease the imbalance.

Bacteria Foraging Optimization Algorithm (BFOA) [26] is a new comer to the family of nature-inspired optimization algorithms. In this algorithm the application of group foraging strategy of a*E.coli* bacteria is used for optimization the function. Bacteria search for food in a manner to maximize energy obtained per unit time. Individual bacteria can communicate with neighbors by sending signals. This bacterium decides foraging after seeing two previous factors. The process of bacteria of moving small steps while searching for food is called chemotaxis and this behavior of BFOA of chemotactic movement of virtual bacteria in the problem search space.

During foraging of the actual bacteria, movement is done by a set of tensile flagella. The two basic steps at the time of foraging, tumble and swim of *E.coli* bacterium is helped by flagella. When they rotate the flagella in the clockwise direction, each flagellum pulls on the cell. That cause in the moving of flagella independently. Thus bacteria tumble lesser in harmful place but it tumbles more to find the food gradient. The movement of flagella in anti-clockwise direction helps the bacteria to swim at a very fast rate. As explained above the bacteria undergo chemotaxis, where they want to move towards a food gradient and avoid noxious environment. Figure 4 shows how clockwise and anticlockwise movement of bacteria takes place in a nutrient solution.

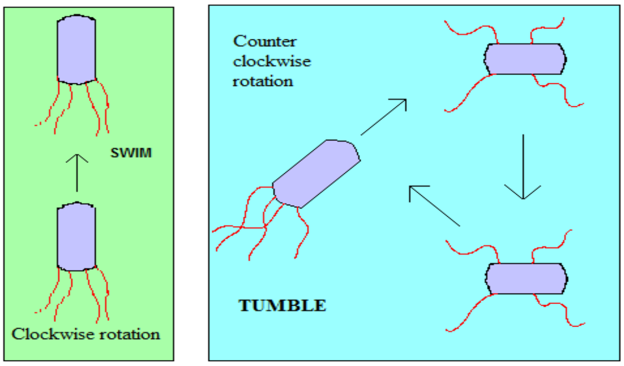

Fig.4 Swim and tumble of a bacterium [25]

When they get sufficient food, they are increased their size and in presence of suitable environment they break in the middle to from an exact same of itself. This phenomenon is called reproduction in BFOA. Due to the sudden change in or attack environmental, the chemotactic progress may be destroyed and a number of bacteria may move to some other places or some other may be introduced in the swarm of concern. This constitutes the event of elimination-dispersal in the actual bacterial population, where all the bacteria in a region are killed or a group is dispersed into a new part of the environment.

Thus search for food of E.Coli can be divided into four steps: Chemotactic, Swarming, Reproduction and Killing/ Dispersion.

Mathematically these can be represented step by step as:

Chemotactic:

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + c(i)\frac{\Delta(i)}{\sqrt{\Delta^t(i)\Delta(i)}}$$

Where represents *i*-th bacterium at *j*th chemotactic, *k*-th reproductive and *l*-th elimination-dispersal step. *C*(*i*) is the size of the step taken in the random direction specified by the tumble (run length unit).

Swarming

$J(i, j, k, l) = J(i, j, k, l) + J_{cc}(\theta(j, k, l), P(j, k, l)$

where $J(i, j, k, l)$ is the fitness function.

On other hand in second method the stochastic DA optimization the chosen optimization algorithm was the interior-point method, since its characteristics force the algorithm to find the optimal solution by traversing the interior of the feasible region [15][16]. Despite the efficiency, speed and ability to perform well in large-scale problems, several hours were needed to find the optimal solution. To suppress this limitation the gradient and Hessian matrix of the objective function were provided as inputs of the interior-point algorithm. These matrices are computed for each objective function of the DA optimization.

4. Results

The data used in this paper is collected from the Illionis state electricity website of 2006. One day data of 2006 is used for testing purpose. We have implemented the algorithm in MATLAB which provides a wide range of toolbox to make the analysis easier. Scripting is done in MATLAB and results are plotted. Below discussed are results of one day of December 2006. Wind data for 24 hrs is available on the state website and it is given in the form of predicted and actual wind power. Since co-ordination of wind hydro plant requires that at lower prices pump plant should be activated for storing the energy in the reservoir and high price hours hydro generation should be started and thus stored energy is used for generation. We have considered here that once pumping is stopped, the reservoir level will not decay until generation is started. Figure 5 shows the hydro-pump storage unit optimized by BFO.

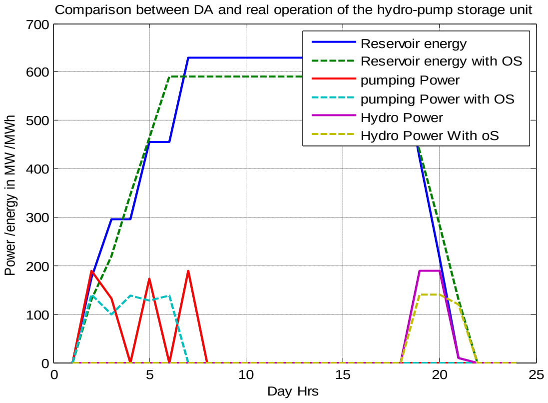

Figure 5: Operation of the hydro-pump storage unit defined by the stochastic day-ahead optimization and optimal strategy planning coordinated by BFO.

Graph clearly shows that when pumping action is off, reservoir energy reached at maximum level and when hydro generation starts, the energy stored in reservoir decays and hydro generation stops when energy is decayed to minimum level. The use of optimal management strategy plan is to reduce the imbalance in the energy.

The coordination by interior-point method is shown in figure 6.

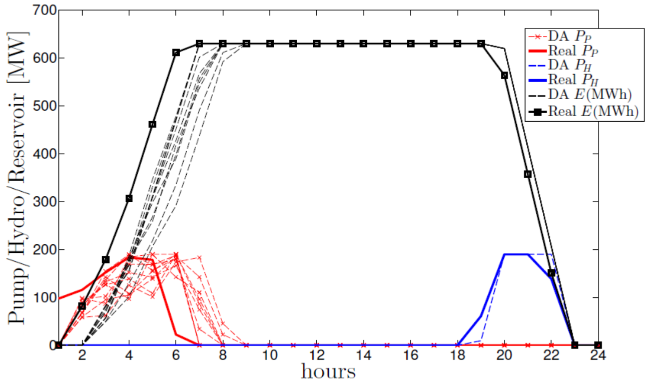

Figure 6: DA and real operation of the hydro-pump storage unit by interior-point method.

The results show that in the BFO algorithm pump-hydro unit generate and store the energy by according to price. The plant will operate from no load to full load according to spot piece.

On other hand in the interior-point method pump-hydro unit generate and store the energy on full load plant or otherwise it is off that is on no load. In this method the plant will not operate below the full load. Thus we can conclude that the BFO algorithm method is more suitable than the interior-point method.

5. Conclusion

In our work wind and pump-hydro power plants are coordinated to maximize the profit. An objective function considering the power delivered to grid multiplied with spot price is used. In this pumping efficiency and hydro plant efficiency and cost is also included. The technical constraints are also defined for the objective function. The output of this objective function which is mathematically formulated in equation 1 and 2 is maximized and minimized respectively using bacterial foraging optimization (BFO) and interior-point method. Two type of bidding strategies are used: stochastic day ahead strategy and operational management strategy. First one maximizes the revenue and with collaboration with second minimizes the imbalance. The data for forecasted wind power and spot piece have been taken from Illionis electricity market.

Results show the comparison of both strategies. If pump is activated at less price hrs and hydro power is generated at higher prices hrs then revenue will be maximized. Figure 5 shows the result for BFO and figure 6 shows the results of interior-point method. Pump and hydro power generation is activated at desired hrs which is achieved by bacterial foraging optimization and interior-point method.

The results shows BFO algorithm pump-hydro units generate and store the energy by according to the price variation. The plant will operate from no load to full load according to spot piece. On other hand the interior-point method pump-hydro unit generate and store the energy on full load plant or otherwise it is off that is on no load. In this method the plant will not operate below the full load. Thus we can conclude that the BFO algorithm method is more suitable than the interior-point method.

References

[1] F. Li and B. Kuri, "Generation Scheduling in a System with Wind Power," *IEEE Transmission And Distribution Con!, China, Aug.2005.*

[2] Julio Usaola, "An integrated approach for optimal coordination of wind power and hydro pumping storage." *Electric Power System Research, 2013.*

[3] Virender Singh, "Simulation and Analysis of Integrated Wind Power with Small Hydroelectric Hybrid Power System for Transient Stability."*Advanced Research in Electrical and Electronic Engineering, 2013.*

[4] SHENG Siqing, "A New Unit Commitment Model Considering Wind Power and Pumped Storage Power Station." *IEEE Workshop on Electronics, Computer and Applications, 2013.*

[5] Md. Rahimul Hasan Asif, "Dynamic Modeling and Analysis of a Remote Hybrid Power System with Pumped Hydro Storage." *International Journal of Energy Science (IJES) Volume 3 Issue 5, October 2013.*

[6] ArildHelseth, "A model for optimal scheduling of hydro thermal systems including pumped-storage and wind power." *IET Generation, Transmission & Distribution, 2013.*

[7] A. Kazemi, "Linear Programming Application in Unit Commitment of Wind Farms with Considering Uncertainties." *International Journal of Electrical,*

Computer, Electronics and Communication Engineering Vol:7, No:2, 2013.

[8] A. K. Barisal, "Scheduling of Pumped Storage Hydrothermal System with Evolutionary Programming." *Journal of Clean Energy Technologies, Vol. 1, No. 4, October 2013.*

[9] Wei SONG, "Optimization model of the Joint operation of Pumped-Storage Hydro Plant and Wind Farm: Considering the Imbalances of Wind Power Output." *Przegląd Elektrotechniczny, ISSN 0033-2097, R.89 NR 3B/2013.*

[10] Mohammad E. Khodayar, "Enhancing the Dispatchability of Variable Wind Generation by Coordination With Pumped-Storage Hydro Units in Stochastic Power Systems." *IEEE Transactions On Power Systems, VOL. 28, NO. 3, AUGUST 2013*.

[11] Dongmei Zhao, "An Optimal Dynamic Generation Scheduling for a Wind-Thermal Power System." *Energy and Power Engineering, 2013, 5, 1016-1021.*

[12] Hongxing Yang, "Technical feasibility study on a standalone hybrid solar-wind systemwith pumped hydro storage for a remote island in Hong Kong." *Renewable Energy 69, 2013.*

[13] H. Siahkali, "Wind Farm and Pumped Storage Integrated in Generation Scheduling Using PSO."*IEEE Trans. on Power Systems, Vol. 2 1, No.4, 2012.*

[14] Ruiwei Jiang, "Robust Unit Commitment with Wind Power and Pumped Storage Hydro." *IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 27, NO. 2, MAY 2012.*

[15] R.J. Bessa, "Operational Strategies for the Optimized Coordination of Wind Farms and Hydro-Pump Units." *8th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion MEDPOWER 2012.*

[16] M. Mokhtary, "Fuzzy Modeling of Uncertainties in Generation Scheduling Integrating Wind Farms and Pumped Storage Plants" *IEEE TRANSACTIONS ON POWER SYSTEMS, 2011.*

[17] V.Trashlieva, "Optimal Control For Daily Scheduling Of Combined Turbo And Hydro Power Generation." *Journal of Clean Energy Technologies, Vol. 2, No. 1, 2011.*

[18] Juhua Liu, "Wind Integration in Power Systems: Operational Challenges and Possible Solutions." *Proceedings of the IEEE |,Vol. 99, No. 1, January 2011.*

[19] M. Vakilian, "Electricity generation scheduling with large-scale wind farms usingparticle swarm optimization." *Electric Power Systems Research 79, 2009.*

[20] Feng Gao, "Wind Generation Scheduling with Pump Storage Unit by Collocation Method." IEEE, 978-1-4244-4241-6/09, 2009.

[21] Javier García-González, "Stochastic Joint Optimization of Wind Generation and Pumped-Storage Units in an Electricity Market." *IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 23, NO. 2, MAY 2008.*

[22] Gemma Allen, "Modelling Of A Wind-Pumped Hydro Scheme Within The Irish Liberalised Electricity Market." *ESBNG,, 2008.*

[23] Pierre Pinson, "From Probabilistic Forecasts to Statistical Scenarios of Short-term Wind Power Production."*Wind Energy ,2008.*

[24] Edgardo D, "On the Optimization of the Daily Operation of a Wind-Hydro Power Plant." *IEEE transactions on power systems, vol. 19, no. 3, August 2003.*

[25] Jorge Miguel Pérola Filipe "Optimization Strategies for Pump-hydro Storage and Wind Farm Coordination Including Wind Power Uncertainty" *FREE ELECTRONIC LIBRARY, July 2014*

[26] Swagatam Das, "Bacterial Foraging Optimization Algorithm: Theoretical Foundations, Analysis, and Applications." *Foundations of Computational Intelligence Volume 3 Studies in Computational Intelligence Volume 203, 2009, pp 23-55*

[27] Rivas Guzman, "Value of pumped-storage hydro for wind power integration in the British Columbia hydroelectric system" *UBC place of mind, Hydrovision International Conference, July 2010 www.esios.ree.es*