Impact of wind farm integration on Market Clearing Price

OLUROTIM OLAKUNLE AWODIJI[1], UDAGA INYILA[2], DAUDA ISHAYA[3]
[1]*Department of Electrical and Electronics Engineering, University of Jos, Plateau State, Nigeria*
[2]*National Power Training Institute of Nigeria*
[3]*National Weather Forecasting and Climate Research Centre, Nigerian Meteorological Agency*

Abstract- The variability of the wind power output due to weather changes and the prediction inaccuracy could have an impact on the market clearing price of the day ahead market. Therefore, investigation into the impact of variable wind power integration on the market clearing price at different time intervals of the day, with varied load demand and how it affects the market operations of the power systems, particularly the price, then becomes necessary. The Plexos® market modelling software was used in this work to examine the impact of wind energy integration on the market clearing price for the specified day. Different scenarios were considered with and without wind energy. Also, the duration of the wind energy contribution was extended to cover a longer period by varying the dynamic property of the software. The results obtained show that the market clearing price (MCP) is reduced by the availability of wind for the particular period of the day.

Indexed Terms- Competitive, Market clearing price, wind energy.

I. INTRODUCTION

With the deregulation of the power market and the increasing penetration of renewable energy, the power system operations have changed significantly. In a deregulated environment, electricity is supplied in a competitive market, and the pricing methods play an important role [1]. The Gencos and the Discos rely on price forecast information to prepare their corresponding bidding strategies. However, the market clearing price in a deregulated market with high renewable energy penetration is very volatile. The accurate prediction of MCP with intermittent renewable energy is a difficult task with many associated uncertainties [2].

Wind and solar energy are the two major sources of renewable energy that are commonly integrated into the grid. Some of the characteristics of variable generations that present a challenge to the market design are the greater variability and uncertainties associated with the plant output [3][4]. Intermittent resources can suddenly cease supply to the grid with limited predictability when the sun stops shining or wind suddenly stops blowing at the point location [5][6]. This situation poses a risk of disruption to grid-supplied electric service. In a deregulated power system, the impacts of renewable generation and penetration are not only on the physical operations but also on economic operations [7]. The expected competitiveness in a deregulated market with high penetration of renewable energy can only be feasible with the right tools to determine the market clearing price for a day-ahead market that satisfies all conditions and guarantees a return on investment [8].

II. MODELLING TECHNIQUE

PLEXOS models a power system through a two-step simulation. The first step uses the simulation core to model the “business logic,” and the second step involves optimization using the solver. PLEXOS has three phases in the simulation core: the long-term (LT) plan, mid-term (MT) schedule, and short-term (ST) schedule. The LT plan is typically used to solve the capacity expansion over a range of ten to thirty years.

The LT plan examines the expansion/retirement decisions for generating plant, DC transmission line, expanding capacity on existing transmission interfaces and taking up new physical generation contracts. The MT schedule algorithms are used to analyze random forced outages, distributed maintenance events, and constraints over more than one week, optimize hydro and long-term constraints, and model strategic behavior. The final phase is the ST schedule, which optimizes the dispatch by trading period and pre-computes forced outages. The big difference between the MT and ST schedules is the time intervals; the MT schedule uses a time step of years, months, weeks, or days, while the ST schedule uses weeks, days, hours, or minutes.

PLEXOS model
Energy Exemplar's PLEXOS for Power Systems version 6.208R03 was used. PLEXOS requires generating/transmission parameters such as maximum and minimum ramp up/down time, minimum stable level, start-up cost, forced outage rate, wind input data, operational and maintenance costs, and fuel costs to model the power system. These SEM .csv files contain the latest input parameter required to perform any modelling of the SEM in the year of validation. The ST schedule is selected as the focus of this work. The ST schedule is the most suitable as it is designed to emulate the dispatch and pricing of real market clearing engines. The ST schedule optimizes each of the 366 days in 2013 at 30-minute intervals. Both forced outage and maintenance are applied to the model.

III. SIMULATION RESULTS

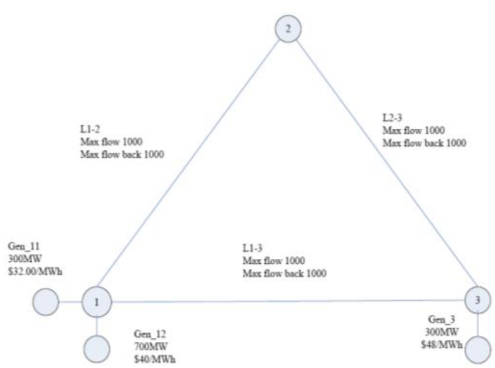

Fig.1 Base case test model diagram

The Test system consists of 3 generators, 3node and one load system. The Generator at node 3 was selected to be the slack bus. The purpose of the slack bus is to "balance the active power and reactive power in the system while performing load flow studies. The load would then be connected to the load bus, which is at node 2, and the transmission lines would have transmission constraints, such as maximum capacity for generation flow. The objective of this methodology was to model/mimic a real-world market as much as possible.

Case Study 1: Determination of MCP without wind power output integrated.

The two generators at node 1(Gen_11 and Gen_12) would have a constant power generator. The generator at node 3 (Gen_3), on the other hand, would vary in terms of the amount of power generated to account for any excess power in the system, transmission losses, and load demand variations. The load profile obtained from the input data set is shown below in Figure 1A and Figure 1B, respectively.

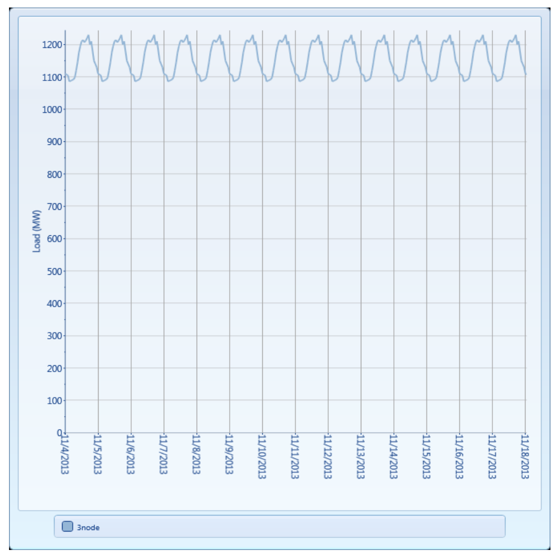

Fig.1A Load profile of case 2 for a week

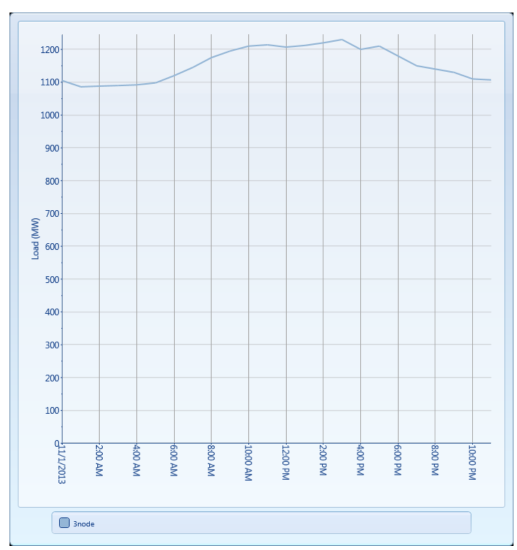

Fig.1 B. Load profile of case 1 for 24 hours

The amount of power generated in this case is shown in figure 2. G_11 and G_12 supply the base load for the system with a constant output as shown in the graph, while the G_3, which is connected to the slack bus for balancing purposes has a varied output.

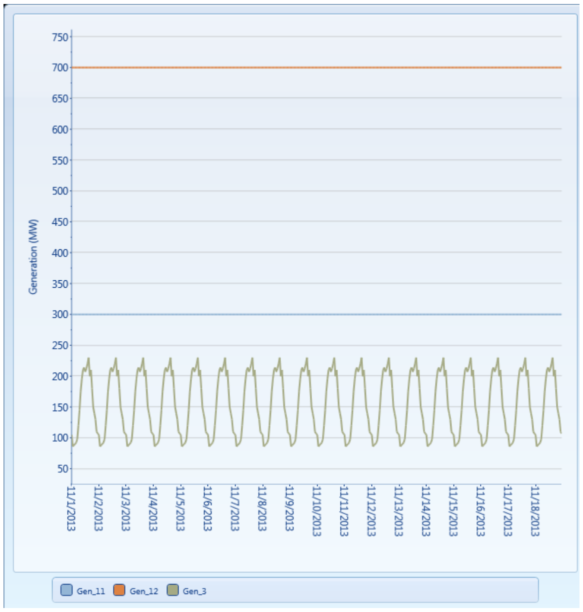

Fig.2: Power generated in case 1

The offer prices for generators G_11, G_12, and G_3 are $32/MWh, $40/MWh, and $48/MWh, respectively. These offer prices were calculated using the marginal price method, which is essentially the product of heat rate and fuel price, as shown in Figure 3.

These offer prices represent the cost at which each generator is willing to sell the power to the grid. The Merit Order of Generation, which arranges generation costs from the least expensive to the most expensive, is used. The result of this process is that a marginal unit is determined, which is, by definition, the last generator to offer generation that satisfies the market demand.

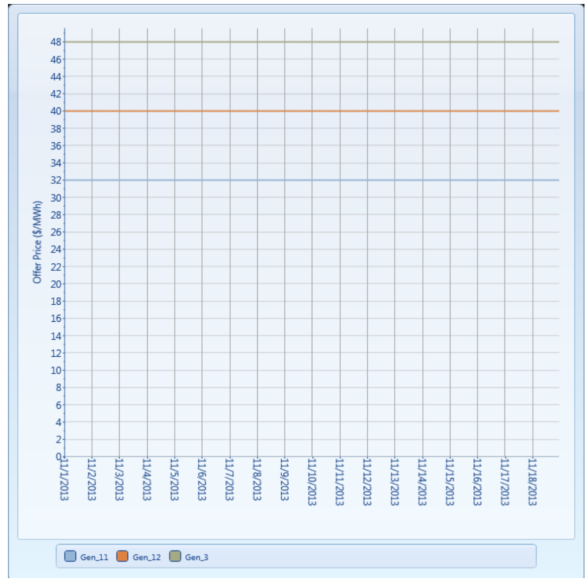

Fig 3: Generator offer prices (base case)

In this case, the generators all received a price of $48/MWh for their generation, as shown in Figure 4.

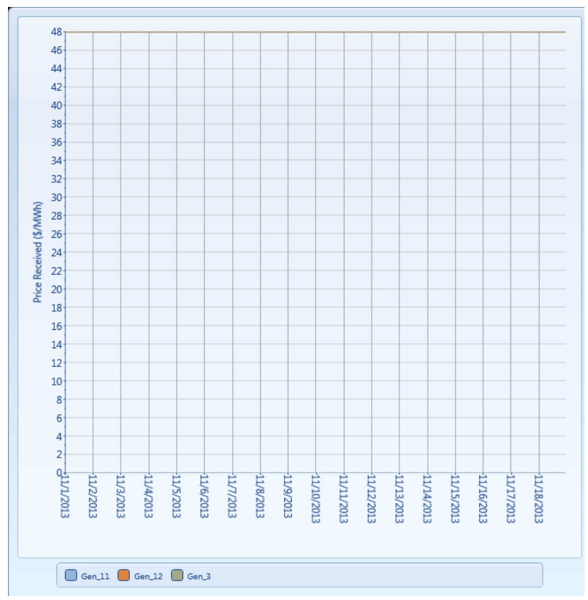

Fig.4: Price received by the generators

Case Study 2: Determination of MCP with wind power output integrated

Gen_11, in this case, is the wind generator. The three generators' output profile over the period is shown in Figure 5. The dynamic properties of the generators were altered with the integration of wind and the output power generated varies.

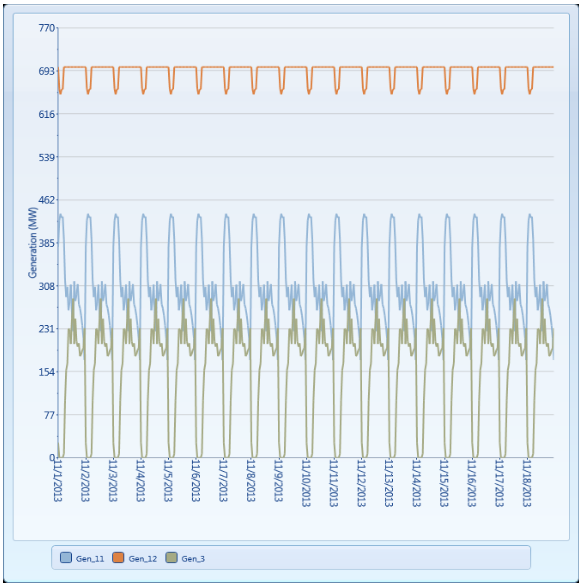

Fig. 5: Generator Output

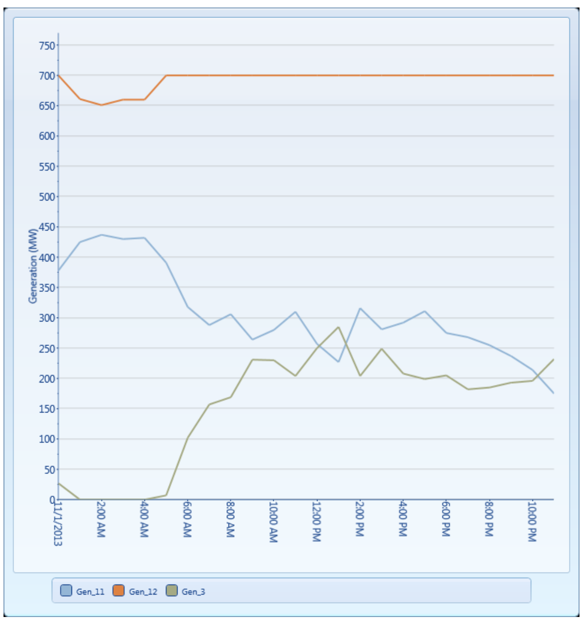

Fig. 6: Amount of power generated in 24 hours

From Figure 6, Gen_3 produced 0MW between the hours of 00:00 am and 05:00 am every day. Gen_11, which is the introduced wind generator, increases its output power at this same time because of the availability of wind.

Gen_11 receives 0$/MWh, as shown in Figure 7, since it is the wind generator.

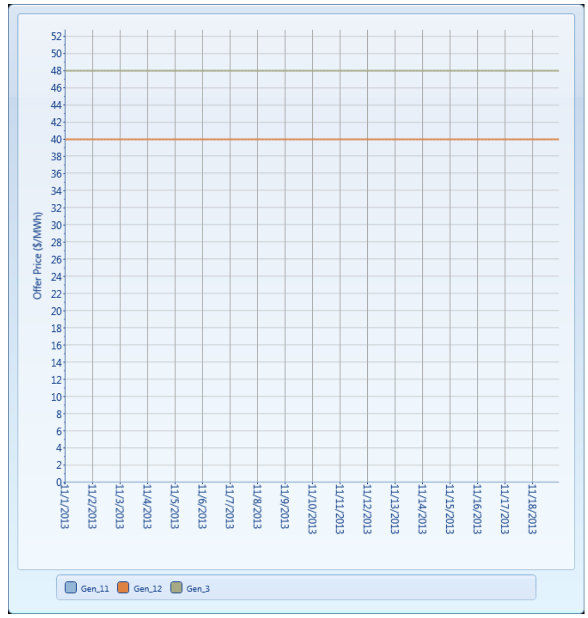

Fig 7: Generator offer prices

The offer prices for Gen_12 and Gen_3, \$40/MWh and \$48/MWh, respectively, remained unchanged.

The price received for the generators varied between \$40/MWh and \$48/MWh.

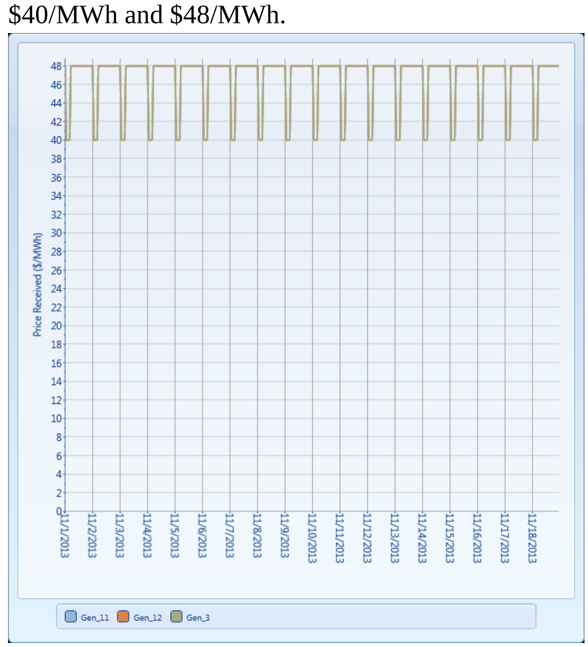

Fig 8: Price received by generators (case 2)

Case Study 3: Determination of MCP with high wind availability.

The wind availability was increased from 00:00 am to 11:00 am and the effect monitored as shown in Figure 9.

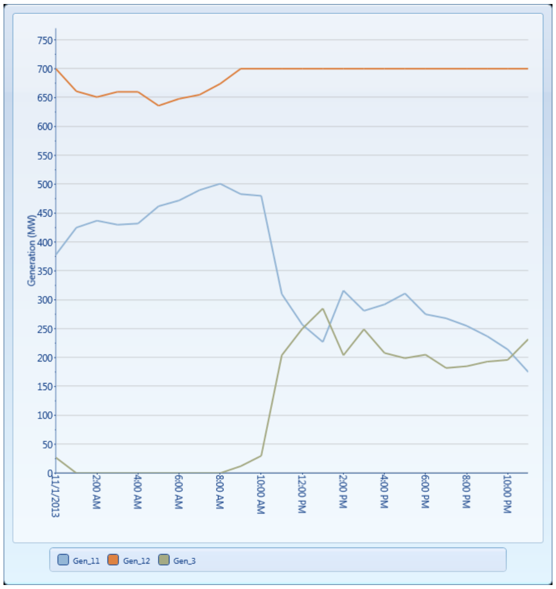

Fig 9: Amount of power generated in 24 hours

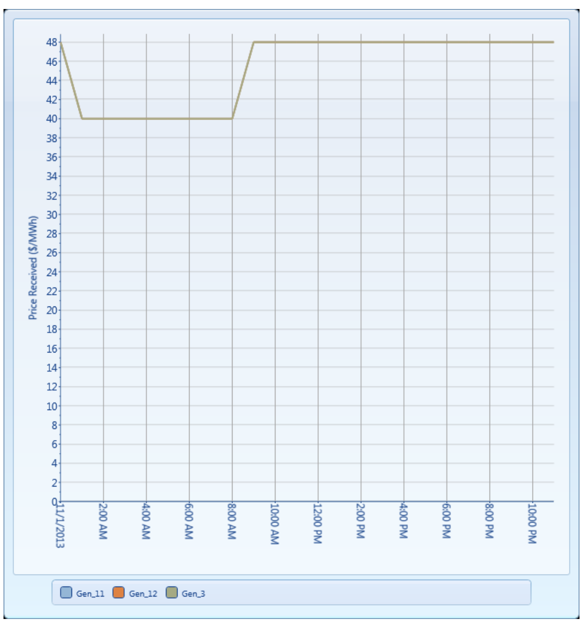

Fig.10: Price received by generators (case 3)

The result of this increase in time in which wind generation is high during the day results in an increase in the length of time that the generator's price received is equal to $40/MWh during the day, as shown in Figure 10.

Further increase in the amount of time in which wind generation is very high during the day leads to even longer time and can also lower wholesale market prices, which is shown in Figure 11.

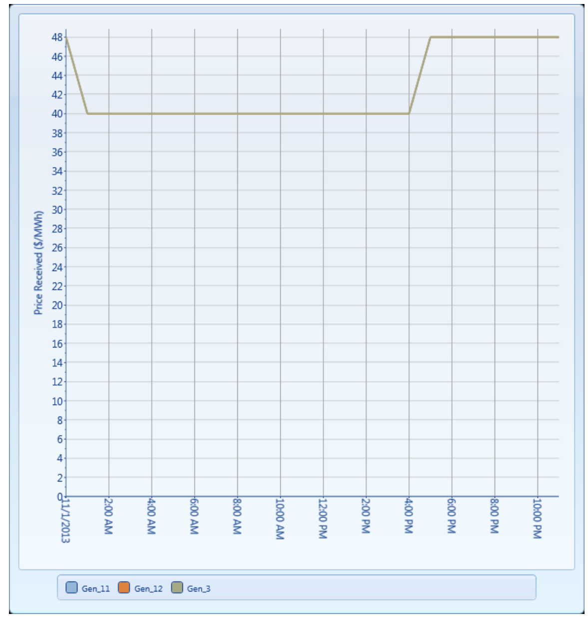

Fig.11: Price received by generators (case 3)

However, it is important to note that in real life wind generation will not be that high for very long durations of time. This part of the investigation was simply to prove and emphasize the point further that an increase in wind generation results in lower market prices.

CONCLUSION

From the results obtained using the test model case scenario, the wind power does indeed affect wholesale market clearing prices. This effect is mainly due to wind power's intermittent and unreliable nature and the low cost of electricity produced that is associated with wind generators.

It was found that the integration of wind power generators into the power systems can lead to lower wholesale market prices. This low price is because market clearing prices are based on the marginal costs of generators that form the merit order list. As a result, wind generators will always have an effect of reducing the market prices when wind generators are introduced into the market.

The presence of wind power in the energy market leads to constant price fluctuation and variations due to its unpredictable and intermittent nature. There is a positive correlation between the time when there is a high wind generation and when there are lower wholesale market prices.

REFERENCES

[1] D. Yang and Y. Chen. "Demand Response and Market Performance in Economics," *IEEE,* 2009.

[2] R. Garcia, A. Conejo and S. Gabriel" Electricity market near equilibrium under locational marginal pricing and minimum profit conditions" *European Journal of Operational Research, pp. 457-479,*2006.

[3] B.F. Hobbs, "Linear complimentary models of Nash-Cournot competition in bilateral and PoolCo power market" *IEEE Transaction on Power Systems, 16(2), 194-202,* 2001.

[4] C. Wang and S.M Shahidelpour, "Ramp-rate limits in unit commitment and economic dispatch incorporating rotor fatigue effect" *IEEE Transaction on Power Systems, 9(3) 1539-1545,* 1994

[5] P. Kunur, "Power System stability and control" McGraw Hill, 1993.

[6] S. Stof, "Power System Economics: Designing Markets for Electricity" Wiley-IEEE Press, 2002.

[7] H.P. Chao and H.G. Huntington, "Designing Competitive Electricity Markets" *Kuvert Academic Publisher,* Boston 1998.

[8] E.A. DeMeo, Grants, M.R. Milligan and M.J Shuenger, "Wind plant integration" *IEEE Powe and Energy Mag. Vol 3,* pp.3846, 2005

[9] R. Sioshansi and W. Short, "Evaluating the impacts of real-time pricing on the usage of wind generation" *IEEE Transaction Power Systems,* vol.24, no.2, pp.516-524, 2009.