Optimal Operation of Smart Grids in an Open Energy Market Environment

John G. Vlachogiannis*   Kwang Y. Lee**

**Industrial and Energy Informatics (IEI) Lab., R.S. Lianokladiou, Lamia, 35100, Greece
(e-mail: vlachogiannis@gmail.com)
**Department Electrical and Computer Engineering, Baylor University, Waco, TX 76798, USA
(e-mail: Kwang_Y_Lee@Baylor.edu)*

Abstract: The control architecture for well functioning open electricity market of smart grids is introduced. The novel concept is that it establishes near real-time market operators for smart grids. In the proposed market model, traders, producers, brokers and end-users are incorporated. It develops near real-time active and reactive power dispatch policies based on optimal operation of players. In realizing electricity markets, one usually refers to active power markets, neglecting ancillary services such as reactive power and voltage control, which usually leads to sequential activities that may lead to inefficiencies because active and reactive powers are coupled. In this paper, a unified model to combine active and reactive allocation procedures based on a market approach as a way to ensure optimal operation. The resulting optimization problems can be solved by modern heuristic approaches that allow one to compute active and reactive nodal marginal prices at its final iteration.

Keywords: Optimal power dispatch, unified real and reactive power dispatch, market operators, real-time market.

1. INTRODUCTION

For a long time in the past, electricity power industry was characterized as vertically integrated, monopolistic, but regulated industry (Vlachogiannis, 2000). However, as the industry operates with market principles, the new paradigms emerging are introduction of unbundling, competition, and deregulation. After two decades of trials, it is now possible to recognize that there are a number of common features to all these movements despite the differences found in specific implementations. At first, vertically integrated utilities were unbundled to generation companies, transmission providers and distribution entities. Then, the eligibility level was progressively evolved and distribution companies were decoupled to wiring distribution providers and retailers.

These changes in the power industry have a primary goal, which is to increase efficiency, reduce the electricity rate, improve generation supply service, and insure the choice for the consumers (National Grid Company Settlements, 1991). Balancing of electricity supply and demand is the most important mechanism in the power system. Power company is responsible to always supply the amount of electricity the consumer demands when they want. Integrated tariffs were also separated to better follow this new structure in terms of pricing the services provided by different agents, to allocate costs adequately and to eliminate cross-subsidies. Apart from these new corporative and tariff structures, operational planning was also greatly modified since the supply and the demand relate themselves by day-ahead markets and by Bilateral Contracts and the operational planning functions are now typically split between a Market Operator and a System Operator (Gomes and Saraiva, 2008).

In spite of creating the market environment for competition, it should be recognized that electricity is not an easily marketable product or, in other words, it is far from being a true commodity. It cannot be stored in large quantities, it must be produced at the same time when it is consumed. Physical laws govern power system operation and there is a network that often prevents the implementation of optimal operation strategies. Furthermore, in realizing electricity markets, one usually refers to active power markets, neglecting ancillary services such as reactive power and voltage control. The reason behind not addressing reactive power is because it cannot be easily priced as active power and, and there is a notion that its price is negligible when compared to the one of active power. However, active and reactive powers are intricately coupled and joint economic dispatch of active and reactive powers brings about further reduction on operation cost (Lee, Park and Ortiz, 1985; Vlachogiannis and Lee, 2008). Gomes and Saraiva (2008) observed how they are inherently coupled, namely:

- the operation of synchronous generators is determined by PQ characteristics. A reactive power requirement issued by the System Operator may be unfeasible, given the active power already scheduled by the Market Operator. If the active output is reduced, the income of that generator will decrease regarding the value expected from the daily market, leading to what is known as an opportunity cost;

- secondly, active and reactive powers are coupled through the ac power flow equations and both of them lead to the line flows contributing to the transmission loss;

- finally, reactive power is closely linked with voltage control in ensuring the secure operation of power systems. More costly bids originally not accepted in the day-ahead market may have to be used to enforce branch limits or to alleviate voltage constraints.

This paper introduces basic architecture for well functioning open electricity market of smart grids. The novel concept is that it establishes near real-time Market Operators for smart grids (next called simply MO-SG). In the proposed market model for smart-grids, Traders, Producers (GENCO), Brokers and End-Users (next called simply players) are incorporated. It will develop near real-time active and reactive power dispatch policies based on optimal operation of players. In order to assign near real-time active/reactive power dispatches, the smart grid should have the IT ability to accept near real-time bids by players. In realizing electricity markets one usually refers to active power markets paying less attention to ancillary services, namely to reactive power and voltage control. In current structures of power systems the main reactive power sources are capacitor banks and synchronous generators. This usually leads to sequential activities that may lead to inefficiencies because active and reactive powers are coupled, given the PQ characteristics of synchronous generators, the power flow equations and other physical and operating constraints (Gomes and Saraiva, 2008). In smart grids new reactive power sources will be incorporated such as storage systems (*e.g.,* electric vehicles' charging/discharging posts and battery swap stations (Vlachogiannis, 2009) in order to support the conventional reactive power sources and cure above mentioned inefficiencies. These sources are also end-user players which can offer reactive power bids (amount, prices) for providing adequate loading margins (Sode-Yome, Mithulanathan and Lee, 2006).

2. MARKET MODEL FOR SMART GRIDS

The proposed near real-time market model for smart grids is portrayed in Fig. 1. When the electricity market is liberalized, electricity becomes a commodity like, for instance, grain or oil. At the outset, there is – as in all other markets – a wholesale market and a retail market and there are the three usual players: the producers, the retailers and the end users. However, for electricity, a more advanced trading pattern quickly develops. New players enter the scene: the traders and the brokers. A trader is a player who owns the electricity during the trading process. For example, the trader may buy electricity from a producer (GENCO) and subsequently sell it to a retailer. The trader may also choose to buy electricity from one retailer and sell it to another retailer, and so forth: there are many routes from the producer to the end user. The brokers play the same part in the electricity market as the estate agent in the property market. The broker does not own the commodity – he acts as an intermediary. A retailer may, for example, ask the broker to find a producer who will sell a given amount of electricity at a given time.

The procedure of the proposed market model is as follows: At instant t=0 all players offer bids (P, Q, p, q), namely real, and reactive power in kW and kVAr respectively, as well as corresponding prices (p) \$/kW and (q) \$/kVAr. The introduced MO-SG makes the clearance until instant-t_1. The MO-SG can be realized as microprocessor incorporated in the smart grids objecting to maximization of social welfare (Singh *et al.*, 2010). Specifically, the MO-SG orders selling bids by the ascending order of its price and buying bids in descending order of the corresponding price so that they are built with the aggregated generation and demand curves. The intersection of these two curves leads to the clearing quantity and to the clearing price, interpreted as the short-term marginal price (for real and reactive power) of the generation system of smart grid. This problem can be modeled by maximizing objective functions corresponding to the social welfare functions, and it represents the surplus between the aggregated real and reactive power demand and the respective real and reactive generation curves (Fig. 2). The objective functions are subjected to limits on the demand and on the generation and to demand/supply balance (Gomes and Saraiva, 2008).

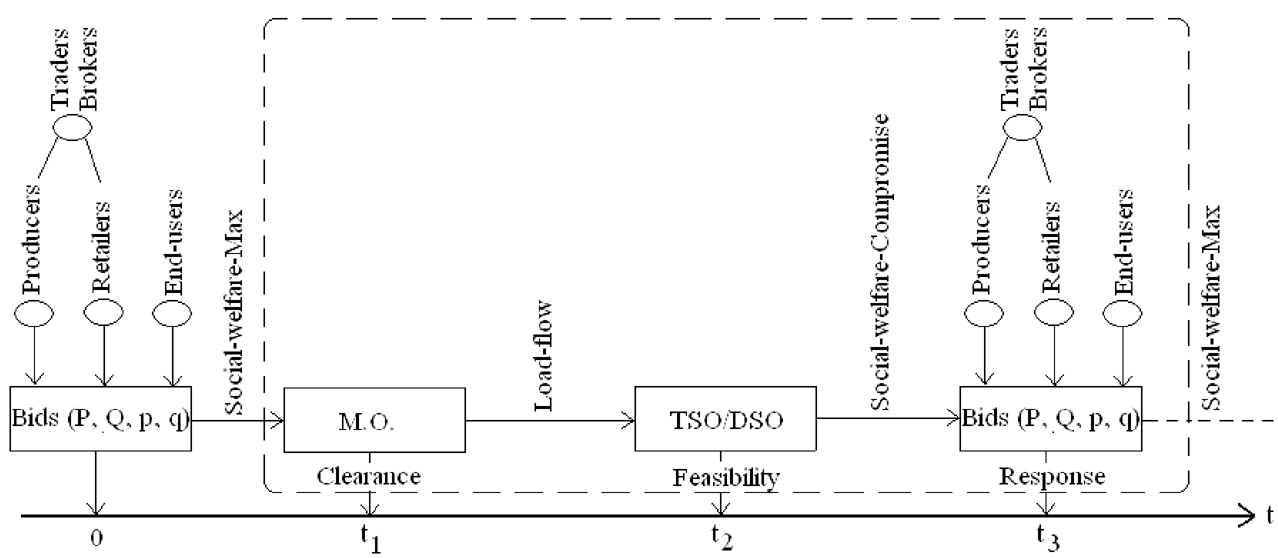

Fig. 1. Market model for smart grids.

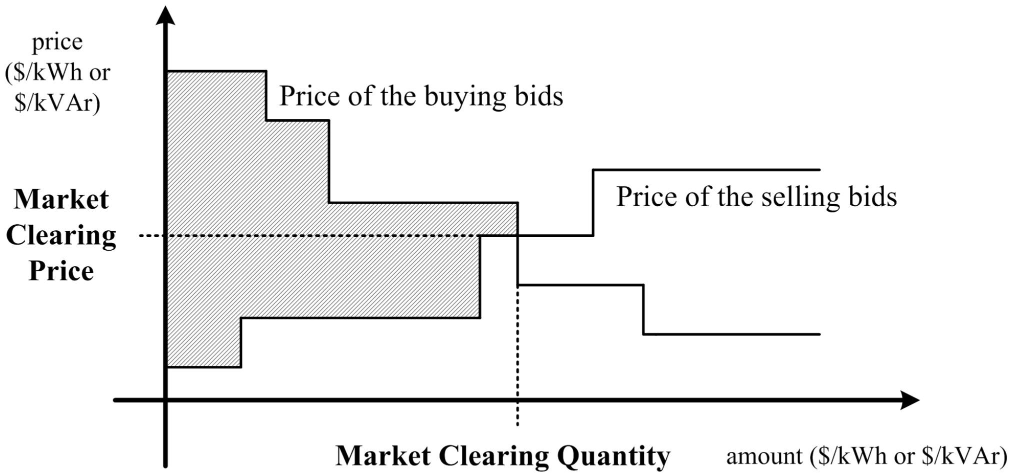

Fig. 2. Matching process in a uniform price auction (Gomesa and Saraiva, 2008).

Then, until instant-t_2, the system operator (transmission, TSO or distribution, DSO - it is related to the scale of smart grid) performs load flow solution. It verifies, or not, that the MO-SG dispatch solution is technically feasible.

If the MO-SG solution is not feasible, the offered bids are re-adjusted. For example, the scheduled bids are delimited in P-Q plan of the synchronous generators embedded in the smart grids. In the case that reactive power sources cannot cover the total reactive power demand, reserve reactive power sources in the smart grid are activated, *e.g.,* storage systems such as battery swap stations (modelled as end-users). This procedure should be finalized until instant-t_3.

The overall procedure of the proposed market model is integrated during a time which varies from the scale of smart grid. However, it should be few minutes (*e.g.,* t_3=5 min for medium scale smart grids). The resulting optimization problems will be solved by modern heuristic approaches such as PSO (Park, Jeong, Shin and Lee, 2010) and quantum-inspired evolutionary program (Vlachogiannis and Lee, 2008), that allow one to compute active and reactive nodal marginal prices at its final iteration. As a further research, the proposed market model will be incorporated in the operation of various smart grids (Vlachogiannis, 2009) to illustrate its applicability.

3. CONCLUSIONS

This paper introduces the first rational market model for optimal operation of smart grids. It defines, in addition to real power bids, reactive power bids. All players, namely, traders, producers (conventional and renewable ones), brokers and end-users, participate in the proposed market operation. They offer bids in a near real-time and therefore an advanced IT system should support the procedure. In the proposed IT system, agent technologies will be incorporated.

REFERENCES

Gomes, M. H. R., and Saraiva, J. T. (2008). Active/reactive bid based dispatch models to be used in electricity markets. *Electric Power Systems Research,* 78, 106-121.

Lee, K. Y., Park Y. M. and Ortiz, J. L. (1985), A United Approach to Optimal Real and Reactive Power Dispatch. IEEE Transaction on Power Apparatus and Systems, l04, l147-l153.

National Grid Company Settlements: “An introduction to the initial pool rules”, Nottingham, 1991

Park, J.-B., Jeong, Y.-W. Shin, J.-R. and Lee, K. Y. (2010). An Improved Particle Swarm Optimization for Nonconvex Economic Dispatch Problems. IEEE Transactions on Power Systems, 25(1) 156- 166.

Singh, K., Padhy, N. P. and Sharma, J. D. (2010). Social Welfare Maximization Considering Reactive Power and Congestion Management in the Deregulated Environment. Electric Power Components and Systems, 38:50–71.

Sode-Yome, A., Mithulanathan, N. and Lee, K. Y. (2006). A Maxumum Loading Margin Method for Static Voltage Stability in Power Systems. IEEE Transactions on Power Systems, 21 (2), 799-808.

Vlachogiannis J. G. and Lee, K. Y. (2008). Quantum-Inspired Evolutionary Algorithm for Real and Reactive Power Dispatch. IEEE Transactions on Power Systems, 23 (4) 1627-1636.

Vlachogiannis, J. G. (2009). Probabilistic constrained load flow considering integration of wind power generation and electric vehicles. IEEE Transactions on Power Systems, 24 (4), 1808-1817.

Vlachogiannis, J. G. (2000). FACTS applications in load flow studies effect on the steady-state analysis of the Hellenic transmission system. Electric Power Systems Research, 55 (3), 181-191.