Transmission Congestion Management Considering EV Parking Lots and Demand Response Programs

AMIN MOHSENZADEH
Department of Electrical and Computer Engineering
Wichita State University
Wichita, USA
Axmohenzadeh@shockers.wichita.edu

Abstract— Transmission congestions are one of the key elements affecting spike price and local market power. Reducing the demand and increasing the generation in distribution network may lead to reliving the congestion of a transmission line. Plug-in Hybrid Electrical Vehicle (PHEVs) parking lots and Emergency Demand Response Programs (EDRP) are considered as two main options to manage the demand of a transmission bus. In this paper, a novel approach is proposed to determine the optimal capacity of EDRP and PHEV parking lots to relieve transmission congestion in a least-cost manner. The behavior of EDRP participants and available size of the parking lot are modeled. Genetic Algorithm (GA) with binary variables is employed to solve the non-linear optimization problem. Simulation is carried out on a 14-bus transmission network. Results demonstrate the optimal contribution of parking lots and EDRP has a significant effect on mitigating congestion and decreasing the cost of the system.

KeyWords—Congestion management, EDRP, parking lot, Shift factor, Transmission system

1. Introduction

Congestion in transmission systems is one of the critical issues for secure and reliable system operations [1]. Transmission congestion occurs when there is inadequate transmission capacity to meet the demands of all customers and overloads in transmission lines or transformers are appeared [2]. In order to supply local demands, more expensive generating units have to be brought on-line. This situation can create "market power" for some of the market participants and may lead to electricity price spikes in restructured power systems [2]. In recent years, many studies have been carried out to develop congestion management in a restructured electricity market. In [1] a model for the optimal planning of Distributed Generation (DG) for congestion management in the restructured electricity market is proposed. Also, a cost/worth analysis approach for optimal sizing of DGs to mitigate congestion and increase the security of the system is introduced in [2]. A computational method for power dispatch considering transmission congestion is discussed in [3]. In [4], optimal rescheduling of generation and transmission switching is proposed to reduce line loading in a congested transmission system. Due to increasing electric vehicles in the power system, PHEVs parking lots utilization has been extended to improve reliability, loss, and security of network [5]. Charging and discharging ability of PHEVs persuaded utilities to employ parking lot as a useful energy resource in transmission network and power energy market [6]. O'Connell et al. calculated a dynamic day ahead tariff to EV operators bidding into the day-ahead market [7]. In [8] EVs can stop their charging or even inject energy to the grid aiming for congestion management issues.

Another approach for congestion management is finding volunteer customer to curtail their consumption when a transmission line is congested. Determining how much each load should be reduced depends on various factors such as the elasticity of loads, required incentive, and contribution of each demand to flow of the congested line[9]. Applying Demand Response (DR) programs to manage transmission congestion are discussed in [10, 11] at which other resources were not considered. Authors of [12, 13] have implemented DR program along with parking lots to improve the reliability and voltage of network regardless of transmission issues

In this paper, a novel method is presented to determine the optimal capacity of parking lots and EDRP to meet transmission capacity limits and mitigates transmission

Part of this material is based upon work supported by the National Science Foundation under Award No. EPS-0903806, Wichita State University Research/Creative Projects Award (URCA) and matching support from the State of Kansas through the Kansas Board of Regents

congestion in a least-cost manner. Also, the available capacities of EDRP and parking lot during congestion and required incentive for participating in these programs are mathematically formulated.

This paper is organized as follows: In section II DR Program is discussed and elasticity of customers is formulated. In section III available capacity of PHEVs parking lot is modeled. Shift factor and LMP are calculated in section IV. In the section V problem formulation and methodology are presented. In part VI the effectiveness of proposed congestion management model is evaluated, and the conclusion of this paper is given in section VII.

2. Demand response programs

Due to the relationship between the demand of a bus and flow of a transmission line, DR as a load shaping tool may bring significant opportunities such as reducing demand and preventing congestion for utilities [14].

2.1. Emergency demand response programs

Large power users sign up to take part in the EDRP to reduce power usage through shutting down a part of their loads. The participants are paid by an Independent System Operator (ISO) for reducing energy consumption when asked to do so by the ISO. [15]. Elasticity is defined as demand sensitivity with respect to the energy price and incentive [16].

$$E=\frac{\partial D}{\partial \rho}=\frac{\rho_0}{D_0}\frac{dD}{d\rho} \tag{1}$$

In (2) EDRP is economically modeled in response to network electricity price and incentive of ISO in emergency cases.

$$d(i)=\left[d_0(i)+\sum_{j=1}^{24}E(i,i)\frac{d_0(i)\left[\rho(i)-\rho_0(i)+A(j)\right]}{\rho_0(i)}\right]\times \left[\sum_{\substack{j=1\\ j\neq i}}^{24}E(i,j)\frac{\left[\rho(j)-\rho_0(j)+A(j)\right]}{\rho_0(j)}\right] \tag{2}$$

d (i) denotes customer demand changes in 24 hours, which affects and decrease the main demand. d_0 denotes load participation factor. *E (i, i)* denotes self-elasticity of each DR programs price in 24 hours interval. *E (i,j)* denotes cross elasticity of each DR programs prices in 24 hours interval. A (j) in \$/MWh is the incentive which is paid in the j-th hour. ρ_0 and $\rho(i,j)$ denote base default price.

The elasticity of load could be related to the curtailment ratio. On the other words, by increasing the amount of curtailment, the flexibility of customers could be decreased, and utility should pay more incentive to satisfy participants.

3. Modeling PHEVs parking lot

PHEVs are equipped by powerful batteries which can be charged and discharged for many times. This significant aspect enables vehicles to participate in various energy markets [12]. Parking lot revenue is achieved by selling power to the grid during peak hours or contingencies. PHEVs are modeled based on historical driving data and arrival/departure time[17]. Equation (3) shows the relationship between the available capacity at each hour and statistic values such as SOCs, Battery capacity, charging level and number of EV in a parking lot at each hour. In this paper, according to data of [13], the available capacity of parking lots at each hour can be calculated.

$$P_{EV,\max}^{t}=\sum_{n=1}^{N}\frac{SOC_n\ BC_n}{CL\ t_{dis}} \tag{3}$$

Where $P_{EV,\ max}$ states maximum capacity of parking *i* at *t* (MW), N is the number of EVs in parking in location of *i* at time *t*, t_{dis} is discharge time of an EV with initial SOC of n-th EV, BC_n is the battery capacity of EV, and CL is power discharge rate of EV.

Due to the financial and technical importance of relieving the congested line, an incentive should be paid to the parking lots' owners to inject required power to the system during contingencies.

Equation (4) determines how much incentive should be paid to parking lots' owners to inject power to the system.

$$In_{EV,i}=\frac{\lambda_{Congestion,i}\times P_{EV,i}^{t}}{P_{EDRP,i}^{t}+P_{EV,i}^{t}} \tag{4}$$

Where $In_{EV,i}$ is incentive of parking owner in bus *i* (\$/MWh), $\lambda_{Congestion}$ is LMP of bus *i* during congestion, and $P_{EV,i}$ is injected energy of parking lot *i* at time *t* (MW), and P_{EDRP} represents reduced demand by EDRP program in location *i* at time *t* (MW).

4. Local marginal pricing

In this paper, the shift factor is used to calculate the LMP of the power transmission network during congestion. In addition, the shift factor is one of the significant indexes to find the contribution of each bus to the flow of a congested line.

4.1. Sensitivity analysis

When a transmission line of a system is congested, the impact of each transaction between two buses on the congested lines could be different [18]. Transmission line relief (TLR) and shift factor (SF) are known as the significant indexes to measure the contribution of the flow on a transmission line to demand of a bus. SF is an incremental amount of power flow on constraint j when an additional unit of power is injected at bus *i* and withdrawn at the reference bus [18].

$$SF_i=\frac{\partial P_l^T}{\partial P_i} \tag{5}$$

Where SF is the shift factor of bus i, P^T states the flow of line l th, and P is a load of the bus in the location of i.

4.2. Locational marginal price calculation

LMP is the marginal cost of supplying the next increment of electric energy at a specific bus considering the generation marginal cost and the physical aspects of the transmission system [19]. In this paper, transmission losses are ignored and the difference in LMP would appear when lines are congested [20]. The LMP at bus i can be calculated as follows:

$$\lambda_i = \lambda_{Energy,i} + \lambda_{Congestion,i} \tag{6}$$

Where λ states LMP of bus i , λ_{Energy} and $\lambda_{congestion}$ represent the energy and congestion cost, respectively. Also, the congestion cost at bus i can be calculated as follows:

$$\lambda_{Congestion,i} = \lambda_i - \sum_{k}^{NC} \mu_k \ SF_{i,k} \tag{7}$$

Where NC represents the total number of transmission constraints, μ_k is the shadow price of transmission constraint(S/MWh) which is associated with the binding constraint, and $SF_{i,k}$ is the shift factor of i to transmission constraint k.

As can be seen in (7), the LMP of congestion consists of two terms: (1) SF, and (2) shadow price. Shadow price of a transmission constraint is the significant system cost to relieve a marginal MW of congestion.

5. Problem Formulation

In this session, the problem is mathematically formulated in an objective function according to its constraints as follow:

5.1. Objective function

In this paper, utilities have two options to manage the consumption and local generation in their area: (1) reducing loads by implementing EDRP, and (2) increasing the local generation by injecting the stored power of PHEV to the system. The primary purpose of this paper is to minimize the objective function considering the constraints of the system.

$$Min\left[\sum_{t=1}^{T}\sum_{k=1}^{nbus}(P_{net,i}\lambda_k) + \sum_{t=1}^{T}\sum_{i=1}^{n}P_{_{EV,i}}^{t}\ In_{EV,i} + P_{EDRP,i}^{t}\ In_{EDRP,i}\right] \tag{8}$$

Where P_{net} represents consumption of bus i (MW), λ_k states energy cost of bus i at time t ($/MWh), $P_{EV,i}$ is injected energy of parking lot i at time t (MW), $IN_{EV,i}$ is the incentive applied in location i at time t to EVs' owners ($/MWh), $P_{EDRP,i}$ represents reduced demand by EDRP program in location i at time t (MW) and In_{EDRP} is the incentive applied in location i at time t to customers ($/MWh)

5.2. Constraints

$$0 \le P_{EV,i}^{t} \ \le P_{_{EVi,\max}}^{t} \tag{9}$$

$$0 \le P_{EDRP,i} \le C_{EDRP\max,i} \tag{10}$$

$$P_{ij,\min} \le P_{ij} \le P_{ij,\max} \tag{11}$$

$C_{Pmax,i}$ is the maximum capacity of parking i at time t, $C_{DRmax,I}$ is the maximum capacity of customers in location i at time t. Equation (11) and (12) state the voltage of buses V_i and power of lines P_{ij} should be in allowed range.

5.3. Methodology

In this paper, DCOPF is used to calculate the power flow of lines and obtain the congested line due to its accuracy and rapidity. Also, DCOPF is used to calculate the shift factors of buses by changing the demand of a bus and monitoring the flow of the congested line. Congestion cost can be calculated based on SF and shadow price. For determining the energy cost of a bus, in this paper assumed that every generator bids at its marginal costs. This simple bidding criterion is used for simplicity because it does not affect the process. The available capacity of the parking lot in each bus and bidding curves of customers to participate in EDRP are calculated based on (3) and (2), respectively. In order to converge the problem and reduce the calculation time, we used GA as an optimization tool to find optimal sizes for parking lots and DR programs. The values should be checked to satisfy the constraints. Due to the proposed combination, the incentive for parking lots and EDRP participants are determined according to (2) and (4). The objective function is obtained for each proposed capacities. Finally, after 2000 iterations of GA, $P_{EV,i}$ and P_{EDRP} of buses are determined.

6. Simulation result

Fig. 1 depicts a test case to study the proposed approach. The parameters and power flows of the 14-bus power system are shown in Table I. Characteristics of generators are illustrated in Table II. shadow price of the system has been considered 2500$/MW [21]. The marginal cost of the system before congestion is 13.54 $/MWh.

To evaluate the impact of the proposed method, the generator 4 is failed and congestion at line 2-4 at peak hour has occurred.

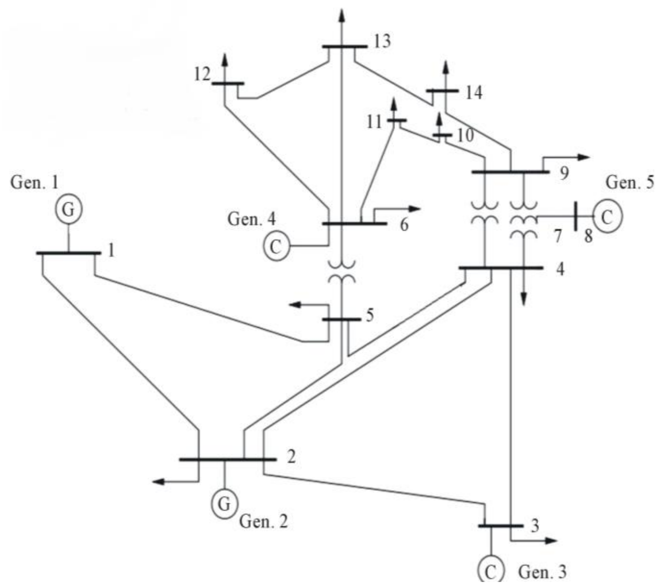

Figure. 1 IEEE 14 bus test system

TABLE I. FIVE-BUS POWER SYSTEM DATA

Line	R(p.u)	X(p.u)	Line	R(p.u)	X(p.u)
1-2	0.05	0.2	5-6	0.08	0.3
1-5	0.08	0.3	6-11	0.05	0.25
2-3	0.05	0.25	6-12	0.05	0.1
2-4	0.05	0.1	6-13	0.1	0.3
2-5	0.1	0.3	9-10	0.12	0.26
3-4	0.07	0.15	9-14	0.05	0.25
4-5	0.12	0.26	4-5	0.05	0.1
4-8	0.05	0.25	10-11	0.05	0.25
4-9	0.05	0.1	13-14	0.05	0.1

TABLE II. GENERATOR COST CHARACTRISTICS

Generator	A ($/MWh)^2	B ($/MWh)	C ($/h)	P_{max} (MW)	P_{min} (MW)
G1	.013	10	0	200	0
G2	.018	20	0	200	0
G3	0.18	12	0	150	0
G4	.015	15	0	250	0
G5	.021	20	0	300	0

Shift factor of buses has been computed according to (5) which shown in Table III. In this case, buses 3, 4, and 5 with higher SF have been considered as candidate buses for implementing the congestion management approaches. The LMP of buses under congestion is shown in Table IV.

As mentioned before, by increasing the curtailment ratio, willingness of customers to participate in this program will be decreased. On the other words, the elasticity of loads is due to the amount of reduction. In this paper, the elasticity of curtailing 2% to 4% of demand in peak hour is changed from 0.004 to 0.006, respectively. The proposed incentive for EDRP in each bus is illustrated in Fig. 2 to Fig. 4. Since the initial demand of bus 4 is less than bus 3 and 5, incentive rate of bus 4 is more than two other buses. Therefore, the ISO should pay more incentive for curtailing 1 MW (2% of demand in bus 4) compared to the same amount in bus 3 (about 1% of initial demand).

The optimal capacity of EDRP and parking, lots by minimizing the objective function, has been illustrated in Fig. 5 and Fig. 6.

TABLE III. SHIFT FACTOR

Bus	1	2	3	4	5
SF	-0.005	0.021	0.035	0.026	.023

TABLE IV. MARKET CLEARING RESULTS DURING CONGESTION

Bus	3	4	5
LMP_{Energy}($/MWh)	418	544	456
$LMP_{Congestion}$($/MWh)	1428	2261	1642
LMP($/MWh)	1846	2805	2098

Fig. 6 shows the contribution of EDRP and parking lots to mitigate the congested line. Totally 5.2 MW power has been implemented in this case. Blue and red charts represent PHEV parking lot and EDRP, respectively. The total capacity of each bus demonstrates bus 4 with higher SF has more potential to alleviate the congested line compared to buses 3 and 5. As can be seen, in bus 4 the contribution of EDRP is significantly less than the parking lot, because the incentive rate of EDRP is considerably raised in higher capacity. On the other hand, the limited parking capacity in bus 5, leads to utilize more capacity of EDRP to achieve the required demand.

Fig. 7 illustrates the amount of incentive for each bus. Blue and red charts represent PHEV parking lot and EDRP, respectively. Due to the limited capacity of the parking lot in bus 5, ISO has to pay more incentive for implementing the EDRP program.

The LMP of the system after implementing this approach has been decreased to 14.67 $/MW.

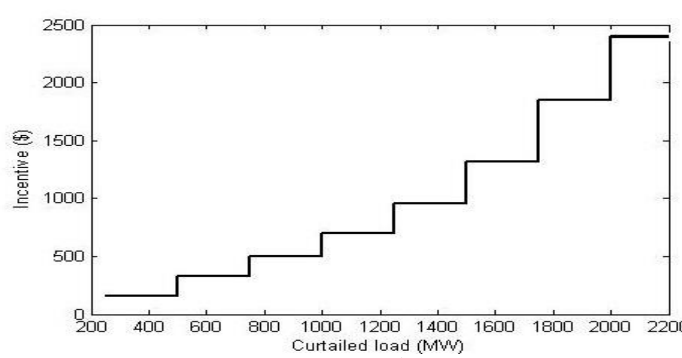

Figure 2. The proposed incentive of bus 3 in EDRP

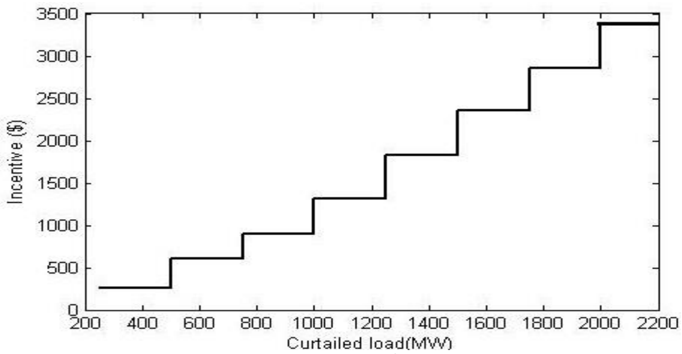

Figure 3. The proposed incentive of bus 4 in EDRP

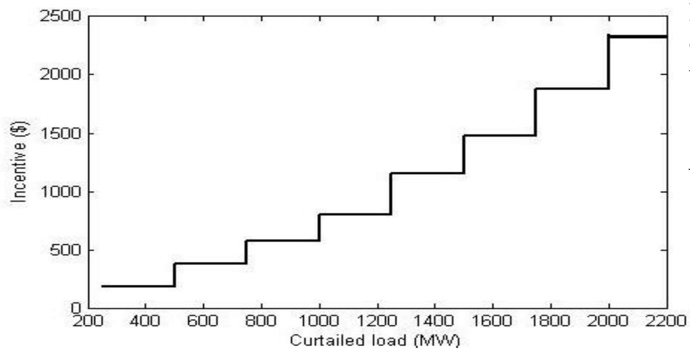

Figure 4 Proposed incentive of bus 5 in EDRP

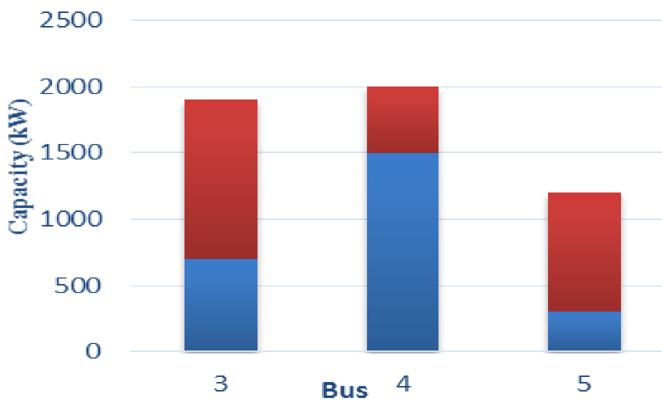

Figure 5. Optimal capacity of EDRP and parking lot

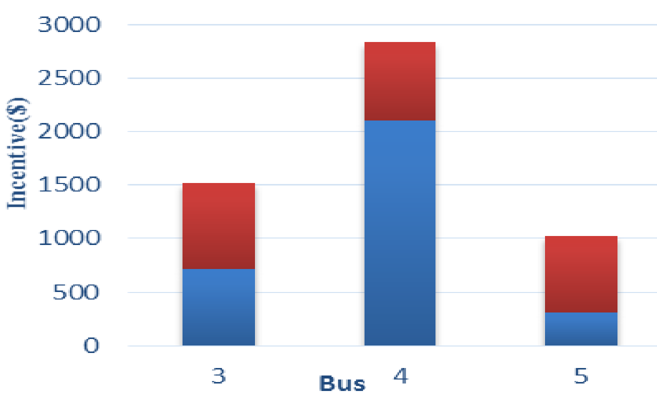

Figure 6. Incentive paid for EDRP and parking lot to each bus

7. Conclusion

This paper proposed an efficient approach for alleviating congestion in the power system in a least-cost manner by utilizing EDRP and parking lots. This method considers economic factors such as congestion shadow price, an incentive for parking lots and participants of EDRP to calculate the cost of each program. The results proved the total cost of the system has been decreased and transmission congestion relieved by implementing the proposed approach. Also, the results illustrated when the capacity of parking is not adequate, ISO should pay more incentive to EDRP participants to achieve the required demand in a bus. Furthermore, the elasticity of demand has a significant impact on the incentive cost and contribution of EDRP to mitigate the congested line.

References

[1] M. Afkousi-Paqaleh, A. Noory, and M. Rashidinejad, "Transmission congestion management using distributed generation considering load uncertainty," in *Power and Energy Engineering Conference (APPEEC), Asia-Pacific*, 2010, pp. 1-4.

[2] M. Afkousi-Paqaleh, M. Rashidinejad, and K. Lee, "Optimal placement and sizing of distributed resources for congestion management considering the cost/benefit analysis," in *Power and Energy Society General Meeting, 2010 IEEE*, 2010, pp. 1-7.

[3] P. Panyakaew and P. Damrongkulkamjorn, "Optimal generation dispatch considering transmission congestion in electricity market with step-bidding prices," in *Transmission and Distribution Conference and Exposition (T&D), IEEE PES*, 2012, pp. 1-7.

[4] Z. X. Chen and J. Shu, "Congestion management based on particle swarm optimization," in *Power Engineering Conference, 2005. IPEC 2005. The 7th International*, 2005, pp. 1019-1023.

[5] M. H. Amini and A. Islam, "Allocation of electric vehicles' parking lots in distribution network," in *Innovative Smart Grid Technologies Conference (ISGT), 2014 IEEE PES*, 2014, pp. 1-5.

[6] H. Ahmadi and M. P. Moghadam, "Effects of EV-parking lots on transmission lines

congestion and price in the electricity market," in *Integration of Renewables into the Distribution Grid, CIRED 2012 Workshop*, 2012, pp. 1-4.

[7] N. O'Connell, Q. Wu, J. Østergaard, A. H. Nielsen, S. T. Cha, and Y. Ding, "Day-ahead tariffs for the alleviation of distribution grid congestion from electric vehicles," *Electric Power Systems Research*, vol. 92, pp. 106-114, 2012.

[8] M. Lopez, S. Martin, J. Aguado, and S. De la Torre, "V2G strategies for congestion management in microgrids with high penetration of electric vehicles," *Electric Power Systems Research*, vol. 104, pp. 28-34, 2013.

[9] S. PARNANDI and K. SCHODER, "Regular paper Power Market Analysis Tool for Congestion Management."

[10] A. Yousefi, T. Nguyen, H. Zareipour, and O. Malik, "Congestion management using demand response and FACTS devices," *International Journal of Electrical Power & Energy Systems*, vol. 37, pp. 78-85, 2012.

[11] W. Liu, Q. Wu, F. Wen, and J. Ostergaard, "Day-ahead congestion management in distribution systems through household demand response and distribution congestion prices," *Smart Grid, IEEE Transactions on*, vol. 5, pp. 2739-2747, 2014.

[12] S. Pazouki, A. Mohsenzadeh, and M.-R. Haghifam, "Optimal planning of parking lots and DLC programs of Demand Response for enhancing distribution networks reliability," in *PES General Meeting| Conference & Exposition, 2014 IEEE*, 2014, pp. 1-5.

[13] A. Mohsenzadeh, S. Pazouki, M.-R. Haghifam, and C. Pang, "Optimal planning of parking lots and demand response programs in distribution network considering power loss and voltage profile," in *Innovative Smart Grid Technologies Conference (ISGT), 2015 IEEE Power & Energy Society*, 2015, pp. 1-5.

[14] F. Staff, "Assessment of demand response and advanced metering," *Federal Energy Regulatory Commission, Docket AD-06-2-000*, 2006.

[15] P. Cappers, C. Goldman, and D. Kathan, "Demand response in US electricity markets: Empirical evidence," *Energy*, vol. 35, pp. 1526-1535, 2010.

[16] P. T. Baboli, M. Eghbal, M. P. Moghaddam, and H. Aalami, "Customer behavior based demand response model," in *Power and Energy Society General Meeting, 2012 IEEE*, 2012, pp. 1-7.

[17] M. H. Amini and M. P. Moghaddam, "Probabilistic modeling of electric vehicles' parking lots charging demand," in *Electrical Engineering (ICEE), 21st Iranian Conference on*, 2013, pp. 1-4.

[18] R. Baldick, "Shift factors in ERCOT congestion pricing," *University of Texas*, 2003.

[19] M. Shahidehpour, H. Yamin, and Z. Li, *Frontmatter and Index*: Wiley Online Library, 2002.

[20] Y. Fu and Z. Li, "Different models and properties on LMP calculations," in *Power Engineering Society General Meeting, 2006. IEEE*, 2006, p. 11 pp.

[21] J. Yu, S. Teng, B. Whittle, and Y. Ren, "A study on congestion management improvement in ERCOT market," in *Power Engineering Society General Meeting, 2006. IEEE*, 2006, p. 6 pp.