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An Approach to Imbalance Power Management Using Demand Response in Electricity Balancing Market

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Abstract— Imbalance power management is a key operational task for a system operator. Imbalance power is produced from the difference in electrical energy supply and demand in the real operational time which deviates power system stability. In this paper, a balancing market model using demand response is developed to mitigate imbalance power. In context, a case study of balancing market model is investigated using flexible residential load along with nord pool spot market and imbalance data Therefore, the market model is simulated in MATLAB for five weeks. The simulation result is evaluated in order to determine imbalance reduction value, flexibility benefits and demand response value. Finally, the study is concluded with the propositions of future balancing market model contribution in imbalance reduction using demand response.

Keywords - demand response, electricity market, power system imbalance, residential appliances, consumers flexibility, aggregators, load shifting

I. Introduction

Imbalance power management is a key operational service for a secured power system by preserving same amount of energy in both supply and demand side in real operating time. The system imbalance means the difference between electrical energy supply and demand causes a deviation of system frequency in an interconnected grid [1]. The main reasons of this power imbalance due to technical outage of power plants, recent development of distributed energy generation, abrupt load variation and constraints in transmission network capacity [2]. Distributed energy generation (DER) is a small scale electricity production from renewable sources such as solar photovoltaics, wind turbine with limited storage facilities which makes the system generation uncertain to keep balancing. In European energy market, power transmission system from the generation has separated according to Electricity Directive makes this system balancing task difficult. The balancing market is final part of electricity market after day ahead, intra-day market to establish an organization management of system imbalance by doing financial transactions [1].

In an electricity market, day-ahead part decides the spot price for next day where both producers and retailers (consumers) submit hourly supply bids with volume and selling price and demand bids with volume and buying price before the trading start [3].Then, a regulated price is introduced in intra-day regulated market for those who can't supply their committed spot market volume in real time and this trading is responsible to keep both technical and financial balance in the market. Finally, the net imbalance from both producer and retailer is settled in balancing market after fixing the regulated price (down/up) as imbalance price in that hour. In the existing electricity market practice, imbalance management strategies are found at system generation side by producing more energy or reducing production from committed value to keep the system balance [4].

Now a days, demand response (DR) is a useful demand management technique means the changes in consumer's electricity usage from their regular consumption in response to any electricity price or incentive payments over time [5].Therefore, incentive and price based DR techniques are used to facilitate consumers to participate in demand response. The load shading, peak load shifting, emergency response, demand bidding and direct load control are considered as incentive based DR programs. In addition, the time of use (TOU) rate, critical peak pricing (CPP), real time pricing (RTP) are price based programs are used to regulate the peak demand by setting high peak price and low off-peak price for industrial or commercial customers [6]. The consumers can participate in DR by reducing their usage at high pricing period with a loss of comfort or using their own distributed generation. Furthermore, the recent development of smart appliances and IoT based smart energy management system have unexploited potential to participate in demand response [7].Therefore, the aggregated demand response potential is not considered as a solution of imbalance power management in an electricity market instead of traditional solution from production side [8].

This paper aims to develop an electricity balancing market model using residential load-shifting of demand response techniques. Then, a case study is presented and balancing market model is evaluated with imbalance reduction capacity, stakeholders (balance responsible players, consumers) benefits and demand response value. The case study of this paper is based on the electricity price and imbalance power data of Nordic electricity market which is operated by Sweden, Norway, Finland and Denmark. In section II, literature on European balancing market and imbalance management solution is presented. Section III

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represent the balancing market model. The implementation of market model with a case analysis is discussed in Section IV. Then, simulation results are evaluated in Section V. The article ends with the discussion of future work in section VI.

II. LITERATURE REVIEW

In this section imbalance power impact in European electricity market is discussed. A comprehensive study is presented on European balancing market scenario in 2030 [9]. The authors provide a model- based analysis of different balancing market in comparison with day-ahead market under different policy framework It estimates the future balancing market volume and revenue growth across European Union states and asses the benefit of cross-border participation and net imbalance integration in different EU internal market. There findings shows that, physical volume of imbalances are quite low despite increasing renewable electricity shares. Then, the financial aspects of balancing market has found as less impact in compare with day ahead market in near future.

The overview of the key decision factors for a balancing market design is presented in article [1]. In context, a design framework is presented with an elaborate discussion of balancing market challenges for European energy market. The authors have classified their designed market framework in three parts. At first, the balancing market architecture is briefly discussed with the functionality of balance service provider's and service operators, bidding process, imbalance cost and two types of balancing service like balancing energy and capacity. Then, the authors have discussed market performance criteria in three fundamental areas. The factors like availability of balancing resources, balance planning accuracy, balance quality are covered under security of supply criteria. The economic efficiency criteria in balancing market is set with the factors of cost allocation, utilization, price and operational efficiency. Then, the market facilitation criteria is set up with the factor of transparency and non-discrimination. Finally, the authors have set different balancing market design variables in four categories as general variables, balance planning variables, Balancing service provision variables and Balance settlement variables. Then, balancing market in Netherlands is analyzed as a case study under the above set criteria's and factors to evaluate with comprehensive real data. The schedule time unit, timing of balancing service market and imbalance price mechanism are found as the influential factors for balancing market operation. The authors are also identified few design challenges for the balancing market as agreement between stakeholders on key balancing market criteria and variables, initiated from power system and market conditions, understand the trends of future power system and market developments, strive for appropriate incentives to market participants, reduce uncertainties through in-depth analysis and monitoring of performance.

Next, the aggregator based demand response potential to minimize the imbalance caused by uncertainty of solar production is discussed in [10] .It asses the DR potential for residential and service sector loads to reduce individual imbalance of the aggregator. Therefore, a model predictive control (MPC) optimization model is applied and a comprehensive case study is done in Netherlands based on electricity market data, residential consumers load data and forecasted solar radiation data. The developed model is used only load shifting DR options where loads are classified as non-flexible, semi flexible and flexible. The authors have concluded with a result that, MPC model is able to reduce 30% aggregator's internal imbalance in a month. It is also mentioned, the imbalance minimization varies depending on the magnitude and types of error in forecasting solar radiation. Finally, thee imbalance cost is found as identical using DR in compare with current practices.

III. BALANCING MARKET MODEL

In this study, a balancing market model is developed using flexible load-shifting demand response technique for residential customers. The historical imbalance volume and price data is taken from Nord-Pool electricity market for the year 2016 [11].The flexible-load data of three hundred residential consumers is taken from Pecan Street (an end-user energy consumption database).Then, the balancing electricity market model using demand response is developed using MATLAB simulation software.

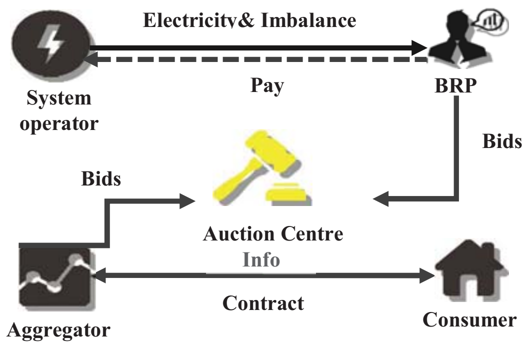

Fig. 1 . Balancing Market Model

Figure 1 shows the structure of the balanced market model. It will operate for one hour trading period. The balance responsible players (BRP) will submit the imbalance volume for next hour with supplying bids (both positive and negative) to auction centers [12]. On the other hand, aggregator will submit demand bids (both positive and negative) for flexible customers to change flexible consumption using an optimize load shifting model. Then, the auction center will analyze all BRP bids and declare the system as positively or negatively imbalanced for that hour and customer bids will be accepted based on this decision. The information will be shared between aggregator and consumers to change their flexibility using load-shifting demand response technique in real hour. Finally, auction centers will declare the system net imbalance after analyzing the all BRP imbalance volume, prices and submitted bids. The profits margin will be calculated for the customers and BRP by auction centers [13].

The next significant part in this model is to identify emergent flexible-loads to participate in DR. In context, different home appliances such as washing machine, dryer, dish washer electric heater power consumption profile is analyzed. The hourly consumption of washing machine is different in three cycles of operation wash, rinse and spin and the average 500W is considered for a full cycle operation. In opposite, dryers are consumed on average 2000 W for one hour cycle where it takes time to switch on heat tumble. Then, the dish washer average consumption is found as 800W in a cycle for 120 minutes and having three cycles of power at different temperature level. Dish washer is a flexible load having automated delay options to shift the whole load in flexible hours. Next, the average consumption of electric water heater is 2000 W which is used to keep the heating water inside the tank at a set temperature point and able to control directly in demand responses [6].Finally, the refrigerator average power consumption is 180 watt for one cycle is quite low for demand response participation. In this paper, laundry machine is considered as a flexible-load to participate in the load-shifting demand response in balancing market model.

IV. MODEL IMPLEMENTATION

In this section, the above discussed balancing market model is implemented to estimate the DR potential to manage imbalance power.

A. Generation of BRP Bids

The imbalance volume and price are two main factors to generate the bidding price that will always be less than imbalance price. The BRPs are penalized in balancing market for their imbalance at a certain cost. In this model, they will generate their own reference price at each hour. In this study, historical imbalance prices (Nord-pool-2016) are assumed as reference imbalance price at each hour. Then, risk factor will be in range from 0 - 1.This will be produced based on imbalance volume and companies own factors. Currently, BRP has to predict imbalance volume for next day to participate in spot market. In this model, volumes are taken from historical data (Nord-pool-2016). The company factor is the

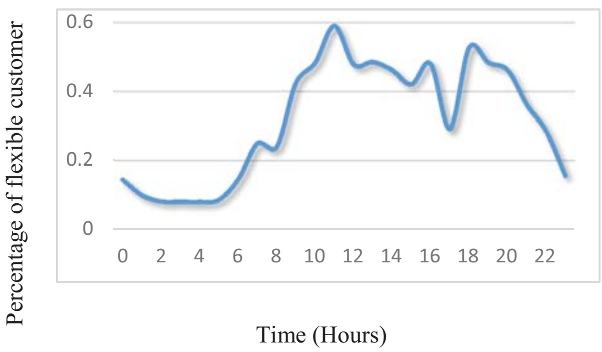

Fig. 2. Flexible customer's percentage with time

willingness and strategy to participate in the market. It will depend on the volume, weather and possibility to accept the bids, other constraints. The whole idea is represented in following (1) and (2)

$$\textit{Bidding price} = \textit{Imbalance price} * \textit{Risk factor} \tag{1}$$

$$\textit{Risk factor} = \frac{\textit{Imbalance volume} - \textit{Minimum volume}}{\textit{Maximum volume}} \pm \textit{company factor} \tag{2}$$

B. Generation of customer Bids

The customer bids will generate by aggregator at each hour after analyzing the willingness of flexible consumer participation in DR. The positive bidding will ensure the increase of consumption and negative bidding will shift the load in flexible time from regular plan. An automated load-shifting model will execute this mechanism in balancing market. Customer bidding price will depend on price behavior and flexibility can be represent by (3)

$$\textit{Customer Bidding price} = \textit{Price behavior} * \textit{flexibility} \tag{3}$$

The price behavior will depend on multiple factors such as day-ahead market spot price, forecasting weather data and customer flexibility volumes participated in DR. The flexibility factor will be defined by customer's willingness to participate in balancing market by selling their comfort using load-shifting DR program. In this mechanism, aggregator will set different prices for positive and negative bids with different flexibility factors. In reply, customers will confirm in which price they are interested to participate in the market. In this paper, four set of prices are presented to generate customer bids and randomly distributed to laundry users. Then, auction center will fix the real time balancing market price by crossing the BRP and customers generated bids at each hour [7].

C. Case Analysis

A balancing market model is implemented in MATAB based on above discussed bidding approach considering laundry-machines load data. Therefore, a 'flexibility curve' and 'flexibility table' is produced from 300 laundry-user data for simulation.

Considering customers behavior doing laundry once in a week, the consumption of 300 laundry user is distributed in order to observe customer responses to participate in demand response, with which the users 'flexibility curve' is generated. Figure 2 presents the percentages of flexible customers in a particular hour which means a certain amount of customers would like to select "available" for participating in the next-hour bidding market. In addition, random factors ranges from 0 – 1 are also added considering individual customer behavior. In reality, it will depend on consumer willingness, spot price, weather impact, market influence etc. The curve in figure 2 shows that, 60% consumers selecting "available" from 10 to 11 am to participate in DR but in the simulation, it will not be exactly 60% after adding the random factor (0 – 1).

After that, a 'flexibility table' is created according to the value of customer 'flexibility curve'. From this table, customers will select there flexible hours to sell their flexibility with a price preference and it can be updated at any time during the day. The price is defined in four-levels with 15%, 30%, 45%, and 60% of the spot price as reference. The

User	00	01	02	03	04	05	06	07	08	09	10	11	12	13
1		√	√		√							√	√	√
2				√	√				√	√				
3	√			√					√					
4		√												√
5			√					√			√		√	
6							√					√		
7	√			√	√				√					
Total	1.91%	1.32%	1.08%	1.07%	1.06%	1.14%	1.92%	3.29%	3.16%	5.58%	6.35%	7.76%	6.29%	6.38%

No. of flexible customer

Customer flexibility hour with price preference

Fig.3. Flexibility table for customers

price levels are also an influential parameter in the market model needed tuning in order to get the best performance. Figure 3 illustrates part of the flexibility table, in which different colors mean the different price levels. Therefore, consumer bids are generated based on the flexibility table and spot price considering other factors. Then, the aggregator sum up total volumes in respect with four bidding price and submit customer bids to auction center. Together with each hour's BRP bids, the data are organized with high price to low price for BRP and low price to high price for consumer.

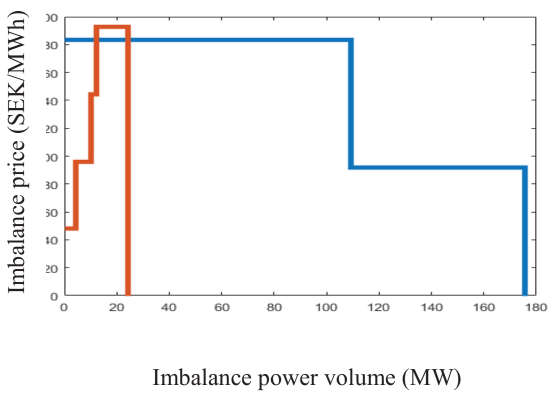

Fig. 4. Bidding price matching in balancing market

The auction system is able to find the matching point of the two stairs and check the accepted volumes and prices shown in figure 4. Blue stairs stand for BRP bids while the red stand for consumer bids. Hence, the volume before the first cross point could be reduced for the imbalance. In this case, the curve doesn't show the dynamic price matching in the market. Though the BRP data is scale down at a narrow range but still the consumer's volume for one flexible load was still very low for price matching**.** The simulation of the balancing market model is run for five-weeks as the consumer uses laundry once in a week is considered. Three BRP's are participated in the market bidding and 300 customers laundry load with an average consumption of 2 kW are taken into account to generate customer bids.

V. EVALUATION OF RESULTS

Section-V presents the results obtained from the balancing market model case analysis. The results are evaluated considering four identical factors such as imbalance reduction, customer flexibility, BRP & customers benefit and demand response value.

A. Imbalance Reduction

Table I. Weekly imbalance power reduction

Week	Imbalance BRP (kW)	Capacity (kW)	Reduced Volume	Customer sharing	BRP sharing
1	14795	600	426	71%	2.88%
2	14795	600	371	62%	2.51%
3	14795	600	522	87%	3.53%
4	14795	600	347	58%	2.35%
5	14795	600	394	66%	2.66%
Avg.	14795	600	412	69%	2.79%

In this market model, the total load-shifting capacity from laundry machine is 600 kW. The imbalance reduction in the balancing market depends on accepted BRP and customer bids at each hour. Table I shows that, imbalance reduced from both customer and BRP end for five weeks. It varies from week to week but the average 69% imbalance is reduced from customer participation whereas 2.79% is reduced from BRPs participation. This reduction capacity can be increased when flexible load-shifting volume and imbalance volume will be near values.

B. BRP and Consumers Benifits

The financial benifits of consumer custoemers and BRP is shown in Table II. The average profit of customers is 58 SEK (Swedish Krona)-the currency of sweden from this balancing market by trading in demand response with a avearge volume of 412 kW. In addition, the BRP can save 61 SEK which is only 1.2% of cost from the current imbalnce cost. In this study,the financial values are found very low but it can be increse with a large number of customer participaition with higher demand reponse volume.

Table II. Benefits for consumers and BRP in Swedish currency (SEK)

Week	Volume Reduced (kW)	Customer Benefits (SEK)	BRP Benefits (SEK)	Cost Imbalance (SEK)	Saving cost
1	426	58	62	5080	1.22%
2	372	54	49	5080	0.96%
3	522	67	78	5080	1.54%
4	347	51	56	5080	1.10%
5	394	59	61	5080	1.20%
Avg.	412	58	61	5080	1.20%

C. Consumer Flexibility

Table 3 shows the traded volume of consumer's flexible load participated in the balancing market for four price levels with different flexibility factors. Customer bids are submitted by aggregator with one single price and four price levels are being set depending on their willingness in trading price. The average bidding price is found highest 126 SEK in F30% flexibility at price level-2 whereas found lowest 68 SEK in F 60% flexibility at price level-4. The higher flexibility shows the high price and maximum risk to accept the bids in the market trade. In opposite, lower flexibility factor provides lower price at minimum risk and better chance to accept bids in the market. The spot price is considered to observe the price behavior. In this model, all four price-level bids are accepted as the value deviation from BRP bids are very high quite large with consumer bids.

Table III. Weekly accepted customer bids

Week Running	Accepted Volume [kW]	Price1 F15%	Price2 F30%	Price3 F45%	Price4 F60%
1	426	106	168	92	60
2	372	104	108	102	58
3	522	102	102	200	118
4	347	116	137	52	42
5	394	134	118	82	60
Average	412	113	126	106	68

D. Demand Response value

The demand reponse techniques provides financial benifts for electricty customers and technical benifts for power system operator.In this market model, load shifting price based DR technique are applied to mitigate imbalnce power in the system.The customers financial benefits are presented inTable 2.The benefits will be significant when high volume of consumers load will participate in market model on dynamic spot and imbalnce price.In that case, the balancing market model can be represented as real time pricing (RTP) DR method [14]. The assesment technical benfit for system operator by keeping frequency 50 Hz for stable operation need to further study.

VI. CONCLUSION

This paper proposed a balancing market model using demand response techniques to mitigate imbalance power. In context, laundry machine is considered to develop the market model as flexible load along with Nord-pool market spot and imbalance price and volume data. Therefore, the market model is simulated for five weeks and results are evaluated by identifying imbalance reduction value, key stakeholder benefits and demand response value. It shows that, in this balancing market model, the resulted values are not impressive as it can make a significant impact. It will be more effective when the customer participation of other all flexible appliances like air conditioner, electric heater, and dish washer, industrial and commercial loads will enhance the demand response techniques in real implementation. The other factors like seasonal demand, weather data, and end-user distributed production from renewable need to consider to make an efficient model using demand response. The pattern analysis of consumer's participation and occupant behavior will also be an important factor for a comprehensive model.

Power industry is passing a transitional phase to integrate modern techniques into existing systems. The distributed renewable energy, development of smart grids, energy storage, vehicle charging, and consumer participation in demand side management are need to investigate with different technical solutions. Load automation and control will be the next challenge where smart communication is enhanced. This paper provides a balancing market conceptual model with a small scale implementation and ends up with few propositions. First, system imbalance can be managed by using consumer participation in demand response. Next, the household customers have potential along with industry and commercial load to make a significant impact by participating in demand response. The aggregator based demand management will be a feasible solution to implement balancing market. Finally, all market players including BRP, Service operator, consumer, and aggregator will be technically and financial benefits from balancing market model need to study separately in future.

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