ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY

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Regulatory context of smart grids in Europe and Brazil: current state and trends

Third ELECON Workshop

University of Grenoble Alps - G2ELAB (Grenoble Electrical Engineering Laboratory)

November 17-18, 2015.

State of the art of current demand response experiences

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Abstract

In recent years the energy consumption, decentralized feed-in, storage of renewable energies and the power system complexity have grown rapidly worldwide. Hence, some power grids are already working at their stability limits. Consequently, the risk of power system instability has greatly increased during energy consumption peaks. Therefore, the demand response utilization in order to protect electrical networks from critical situations and to avoid building extra power plants etc. is becoming a very relevant issue in the network operation.
In this paper the demand response methodology for reduction or shift of energy consumption, its advantages and possible application areas are introduced. In addition, main present and past demand response programs, which have been implemented in the EU, especially in Germany, are identified and described. Finally, the potential of controllable loads in the distribution power systems on the example of Germany are illustrated.
Keywords: demand response; controllable load

1. Demand response

According to the Federal Energy Regulatory Commission [1], [2], Demand Response (DR) is defined as "*Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*". Therefore, DR means decreasing the load energy consumption or its shifting to other period of time during demand peaks.

The electricity price can be reduced by using demand response, which can help to decrease the energy demand in power grids during the day. Furthermore, building extra power plants, which are operated just during energy consumption peaks, and some blackouts, which occur if there is not enough generation to cover high energy demand, can be avoided with the help of DR. In addition, by utilization of DR more renewable energy sources can be installed in the electrical power grids. DR has not only the already mentioned advantages but also can reduce carbon emission in order to decrease environment pollution.

There are different types of DR: emergency DR, economic DR and ancillary services DR. Emergency DR is used in order to avoid dangerous situations and instabilities in the power systems, e.g. blackouts, which can occur because of the lack of the generation while electrical consumption peaks. Economic DR allows electricity customers to reduce their energy demand and in this way decrease the electricity costs. Ancillary services DR includes different services, which provide the secure transmission power grid operation, and are usually used for generators [2].

2. Demand response programs

Demand response programs are created to involve electricity customers in the DR process. Therefore, such programs help customers to reduce or shift the energy consumption during the highest energy demand peaks. Thereby, some dangerous and unexpected events, which occur in the electrical network because of overloading, can be prevented. [3]

DR programs are advantageous for both: networks operators and energy customers. On the one hand, the customers get some financial incentives, they pay less for electricity. On the other hand the power networks operators can keep the system stable during periods of a high energy demand using DR. In addition, they can avoid building extra power plants, which are only utilized to cover the energy consumption peaks.

2.1. Demand response programs in Europe

Europe has an enormous potential of the demand response utilization because there are already different technologies and electrical equipment which provide the ability to implement the DR methodology in its different regions. In recent years, European energy market is developing und changing very fast because of using new regulation methods. In the past there were political barriers in the European Union which did not give many possibilities to use the capacity of demand resources. Nevertheless, European countries has recently begun to change their politic and laws in order to utilize DR in the power grids more often. Particularly, there are some countries in Europe, e.g. the United Kingdom, France, Italy, Spain and Ireland, which are very interested in the DR utilization in the energy market. [4]

2.1.1. Demand response programs in the United Kingdom

The United Kingdom (UK) has a large energy market for the DR utilization. The UK was planned to take some nuclear and coal power plants out of operation between 2008 and 2016 in order to reduce gas supply and install more renewable energy sources into its power grid [5].

2.1.1.1. The National Grid Short Term Operating Reserves program [5]

The National Grid Short Term Operating Reserves (STOR) program was created to shed some electrical loads during the time periods of dangerous events, which could make the power grid instable. The customers are paid if they disconnect their loads from the electrical network during critical time periods. In this way the power operator can easily keep the power grid stable and avoid rolling blackouts.

The DR needs to be used in the UK in very diffident days and various periods of time. Hence, the National Grid divides a year into six parts which consist of so-called working days (including Saturdays) and non-working days (Sundays and Holidays). In addition, critical periods are determined in every day if the DR is necessary.

The customers are allowed to take part in the STOR program if their capacity is minimum 3 MW. This can strongly reduce the number of participants in this DR program because plenty of them do not have enough capacity. Nevertheless, the customers can combine their facilities to participate in the STOR program. However, this process causes extra cost for them.

2.1.1.2. Triad Management [6]

So-called Triads in the UK are time periods of electricity consumption peaks. Triads last three and a half hour per day, usually between 4 and 7 pm, in the winter. During this period the domestic consumption is the highest. Besides, the industry could have a demand peak during this period too.

Triads programs give the customers an ability to shift their energy consumption from demand peak periods to another time period or reduce it. In this way, the customers can usually save around 12 % of the electricity bill.

2.1.2. Demand response programs in France

France is also very interested in the DR mechanism. There are many customers, e.g. private customers and small companies, whose energy consumption could be reduced or shifted to other periods of time during energy demand peaks.

2.1.2.1. Electricite´ de France’s Tempo tariff

Electricite´ de France’s Tempo tariff is a DR program where the electricity prices for end-customers vary depending on the weather. Around 350,000 private customers and 100,000 small companies use this program [7]. Taking into account whether conditions the electricity price is shown using color system.

The system is shown if the current hour is a peak hour or not [8]. Therefore, customers can connect or disconnect their heating systems or water circuits automatically or manually.

Hence, using the Electricite´ de France’s Tempo tariff the energy demand was reduced for around 15 % in so-called ‘‘white’’ days and 45 % in ‘‘red’’ days [7]. In this way, customers could usually save around 10 % of their electricity bill.

2.1.3. Demand response programs in Ireland

In Ireland there are plenty of large and small different providers of smart technologies in the energy consumption. Many of them deal with the DR management and offer electricity customers various methods in order to use the DR. These providers are very active in DR policy of Ireland and interested in the joint work with electrical network operators.

2.1.3.1. Demand Response Aggregators of Ireland

Several smart technology provider companies, such as EnerNOC, Electric Ireland, Energy Trading Ireland etc. (Fig. 1), created an association Demand Response Aggregators of Ireland (DRAI) in 2015. According to [9] the DRAI was founded to *“provide a single voice on policy and regulatory matters of common interest”*. In addition, *“the purpose of Demand Side Participation in the Single Electricity Market (SEM) aims to improve system security while reducing costs to the consumer and reducing generation related emissions”*.

Fig. 1: Members of the DRAI association [9]

One of the DRAI members is a biggest smart technology provider company in Ireland, EnerNOC. It provides energy intelligence software (EIS) for the DR and different deliver custom services for commercial, institutional, and industrial customers.

EnerNOC's energy intelligence software (EIS) includes data analysis, energy management tools, customer management portal etc. The EIS evaluates an energy demand and provides detailed information for its clients. This enables customers to analyse their own energy consumption and helps them to find the best way for a reduction of their electricity costs. [10]

2.1.4. Demand response programs in Italy

Italy is the leading country in the smart metering in the European Union. It has the highest utilization of smart meters in households in Europe with more than 90 %.

2.1.4.1. Advanced Metering Infrastructure

According to [2], a smart meter is an electronic device which saves the information about the electricity consumption at least every hour or even more frequently and send it to a service program for control and billing. Hence, a smart meter provides a connection between the meter and the control system and makes possible to collect more data about the energy demand.

In Italy, the Advanced Metering Infrastructure (AMI) is currently executed by using two different methods. The first method is the traditional one. This solution is integrated into Distribution System Operators (DSO). The second one is customer-specific where DSOs work with smart meters to improve the energy management planning. More than 32 million of smart meters were installed in Italy during ENEL Automated Meter Management (AMM) program, which was named Telegestore. It started in 2001. [11]

2.1.4.2. Load Shedding Programs

Load Shedding (LS) is the disconnection of loads for the load control in the electrical network. The load curtailment is done by automatic devices, e.g. network protection, if a frequency measurement reaches a previously set threshold. This remedial action leads to a power outage for consumers who are affected by LS. The LS is used by the network operator in critical situations. Hence, Load Shedding Programs release automatic LS only in case of emergency [12].

Participants of Load Shedding Programs can be removed from the power grid in the short term. There

are two types of LS programs depending on time: real-time and 15 min programs. Participants must utilize special units for the LS. Therefore, they receive financial compensation according to the market price. The LS capacity in Italy is around 13 MW [8].

2.1.4.3. Interruptible Programs

Participants of Interruptible Programs must reduce their energy demand to pre-agreed value. The difference between Interruptible Programs and above mentioned Load Shedding Programs is that participants of first programs can be penalized if they do not decrease their energy consumption in time.

The Interruptible Programs in Italy are used only in large industries and that helps to save around 6.5 % of energy peaks [12]. Compensations for the customers, who participate in these programs, were determined until 2007 by the energy agency [13]. They are calculated depending on the economic situation in the country. In 2007 the compensation for the Interruptible Programs participants was a fixed sum which was chosen without any analysis of the energy market. As a result, this compensation was almost three times higher than the electricity costs which were saved by using the Interruptible Programs. Nowadays, the compensation is calculated taking into account the benefit for the Italian Transmission System Operator (TSO).

2.1.5. Demand response programs in Spain

Because of the growing utilization of the wind power in Spain, the interest in the DR use has been increasing in recent years [14]. There are two types of DR programs: system-led and price-led programs in Spain [8].

2.1.5.1. System-led programs [12]

System-led programs are a classic way to manage DR in the power system. It has been more than 20 years since large industry consumers started to choose special tariffs. The TSO in Spain, named Red Eléctrica de España, can require the system-led program participants to reduce their electrical consumption during critical events or time of demand peaks etc. from 45 min to 12 h. However, the TSO is obligated to inform its clients in this situation in advance. The duration and the value of energy consumption reduction must be previously defined by the TSO for every system-led program participant. Depending on this, the industry consumers receive different compensation amounts for their participation. Nevertheless, every load curtailment must be explained to end-users. In 2002 the Spanish TSO, Red Eléctrica de España, created a new Interruption Flexible Management Program in order to consider market aspects in system-led programs.

2.1.5.2. Price-led programs [12]

Price-led programs were created in Spain in order to take into account the economic situation and aspects of the Demand Response (DR) utilization. The purpose of these programs is to make consumers reduce or shift their electrical consumption in time periods of energy demand peaks. This is achieved by varying the electricity price. The TSO is entitled to choose time periods of the highest energy demand and according to this increase prices of electricity for its consumers.

2.1.6. Demand response programs in other countries of the EU

Other countries of the EU such as Sweden, Austria, Belgium, Denmark, Finland, Greece, Ireland, Luxembourg, the Netherlands, and Portugal are interested in the DR utilization as well. They created different research projects, in order to analyze a possible influence of the DR on the power grid in their countries, and programs for a real DR utilization.

The Advanced Metering Infrastructure (AMI) is currently being used. in Sweden. Swedish DSO has a successfully experience in the DR program implementation [15].

Because of the growing use of renewable sources, the power grid in Belgium often utilizes DR. In 2013, a fully automatic load shedding was implanted by some electricity users in Belgium.

2.2. Demand response in Germany

Germany utilizes already now a huge amount of renewable energy in its power grid, more than 80GW. In the nearest future this number will just increase. According to Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMUB) in Germany, the renewable energy use should reach around 30 % of the power supply in 2020 [16].

However, such fast installation of renewable energy sources leads to different challenges in the

electrical network. One of them is accruement of strong fluctuations in the generation. Still the generation and load must be balanced when renewable sources dominate. In this case, the use of the Demand Response (DR) could be a good method to keep the power grid stable.

2.2.1. Operating reserve for the frequency control in Germany

The operating reserve is an energy capacity in the power grid which can be used by the network operator to keep the balance between the power generation and demand in case of energy fluctuations. Therefore, short-term power adjustments of controllable power plants can be realized. Power plants, which can be run up very fast, and pumped-storage power plants can be utilized for this purpose. Alternatively, electricity customers can be disconnected from the power grid. Usually, these methods are only possible for a limited time.

2.2.1.1. Frequency control in the European Union

To keep the frequency stability, the frequency control, which includes three main control types (primary, secondary and tertiary), is utilized in Europe.

Primary control: The primary control is used to compensate imbalances between the physical power generation and demand in order to restore the stable frequency in the power grid. The available power reserve for the primary control is dependent on the size of the electrical network and its topology. In the European wide area synchronous grid (UCTE) approximately 3000 MW of active power is available for the primary control [17]. Each network operator of the interconnected system must provide during 30 seconds 2 % of its current generation as a primary control reserve. In addition, not every power plant, e.g. wind farms, photovoltaic systems, etc., can be involved in the primary control. Independent of the fluctuation area in the European power system the current frequency changes in the entire electrical network.

Secondary control: The secondary control must restore the balance between the physical power generation and demand as well as the primary control. In opposite to the primary control, the secondary control observes only the situation in the respective control area including the power exchange with other control areas. By monitoring the power network frequency it must be ensured that the secondary and primary control always work in the same direction. Both control types can start at the same time. According to the requirements of the UCTE, the secondary control process must replace the primary control after maximal 15 minutes. Therefore, the primary control is available again.

Tertiary control: The tertiary control (minute reserve) is an economic optimization. Since 2012, the minutes reserve is retrieved automatically from the Merit Order List Server (MOLS) [18]. The available minutes reserve power must be completely provided during 15 minutes. Conventional power plants or other generation units, and controllable loads can be used in this process.

2.2.2. Load shedding in Germany

By the nominal frequency of 50 Hz the generation and consumption are balanced including power grid losses. Deviations from the nominal frequency between 49.8 and 50.2 Hz are usually compensated by primary, secondary and tertiary control operating reserves. If a fault exceeds the maximum primary control reserve, the frequency can sink or rise above the tolerance limits. In the case of an underfrequency in Germany, with the value of 49 Hz, the automatic load shedding is activated using so-called 5-step plan (Table 1) to restore the power system balance.

The basis for the selection of the automatic load shedding volume is an annual peak load, which is measured as a vertical load at transfer points to the transmission network. Only in agreement with the responsible transmission network operator (TSO) the distribution network operators (DSOs) can install frequency relays and parameterize them in such way that the required percentage of this reference load can be cut off according to the 5-step plan.

Table 1: 5-step plan according to Transmission Code [19]

Stages	**Measure**
Stage 1: 49,8 Hz	Alarm, storage pump shedding
Stage 2: 49,0 Hz	Load shedding 10 - 15 % of the network load

Stage 3: 48,7 Hz	Load shedding 10 - 15 % of the network load
Stage 4: 48,4 Hz	Load shedding 15 - 20 % of the network load
Stage 5: 47,5 Hz	Power plant cut-off

2.2.3. Secondary and tertiary ancillary services in Germany

In Germany ancillary services in the Demand Response (DR) include three types: primary, secondary and tertiary. Primary ancillary service in the DR is closed to the frequency control in the power grid and includes the already mentioned load shedding measure which is used to keep the balance between the power demand and generation. The secondary and tertiary services are related to operating reserves which are used for the secondary and tertiary control of the network frequency.

The secondary and tertiary reserves in the electrical network normally need around 2500 MW each in both directions to use the DR. Germany is a unique country for this purpose. On one hand, the energy demand must be reduced if there is not enough generation, on the other hand, the demand must be increased if there is too high generation from renewable sources.

Hence, Germany has a big potential for the DR which is not used very often. The German government is only starting to interest in possibilities of the DR utilization. In addition, electricity customers must apply for a permission by electric supply providers in order to take part in the DR. Furthermore, the contracted demand could be easily exceeded if customers provide the negative DR. In this case they must pay fees. Finally, the utilization of natural gas power plants in the ancillary services slows the DR implementation in the German power grid. [20]

Nevertheless, provider of the DR services e.g. EnerNOC [10] are already very active in the German energy market. Hence, the DR utilization in Germany should strongly increase in the near future.

3. The potential of controllable loads in the distribution power systems on the example of Germany

The flexibility of electrical loads and their transformation into an active power grid element will have a high importance for future power systems because of an increasing number of decentralized generation plants. The shift of part of the electrical consumption from one period to another can help to integrate optimally the high number of weather-related energy infeed from wind and photovoltaic into the electrical network. Thereby, technical and economic boundary conditions which influence the usable potential must be taken into account.

Before the DR utilization in the network planning and especially in the network operation, analyses of each load which takes part in the DR must be done in order to reach a high accuracy of demand shifting to ensure the network security.

The important prerequisite for the DR use is a high degree of the consumer acceptance because an active or passive change in the energy consumption of customer leads to a necessary adaptation of the usual consumption pattern [21]. To provide these consumption processes following DR criteria have to be taken into account [22]:

- Interruptibility of a process
- Reactivation of a process
- Relocatability of a process.

3.1. Consumer technology overview

3.1.1. Household

There are two typical types of household appliances such as refrigerators and washing machines with a high market penetration. Nevertheless, they cannot be used in the DR because of their working principle. Refrigeration systems have a very periodic behavior. Their power consumption is dependent on the interior temperature and cooling level which is chosen by each user. In addition, the turning-on of a refrigeration system is still dependent on factors of the direct temperature compensation with the environment e.g. opening the interior space and the insulation quality. To reduce the power consumption of a refrigeration system the temperature can be changed on condition that the functionality of the appliance is not limited.

The power consumption of a typical washing machine is dependent on the washing program status and because of this, washing machines have non-periodical behavior as well as refrigeration systems. Therefore, the working process of a washing machine should not be interrupted in order to avoid a higher energy consumption.

In recent years the utilization of electrical systems has been increased in the area of private heating rebuild. In particular, the heat pump use has an increasingly important role because of government funding. In today's households oil-fired heating systems are still underrepresented compared to fossil-fueled systems. However, the utilization of electrical heating systems should grow significantly before 2030. Around 1.48 million of heat pumps until 2020 and around 3.5 million until 2030 will be installed in Germany [23]. In combination with a sufficient thermal storage there is a significant DR potential in the area of the electrical heating [22].

The consumers with thermal storage capacity (group 1) and with a non-interruptible start process, which can be shifted, (Group 2) are able to shift the energy consumption without significant limitations (Fig. 2).

The identified household appliances which can be used for the DR can be classified as program-driven (with thermal storage, group 1) and task-driven (start at a defined time, group 2) [24] (Fig. 2). This group of household appliances amounts approximately 54 % of the total energy consumption. The remaining share is so-called user-driven household appliances e.g. lighting and multi-media systems, which are unsuitable for the DR utilization according to the selected criteria and a direct feedback by the load change on the consumer.

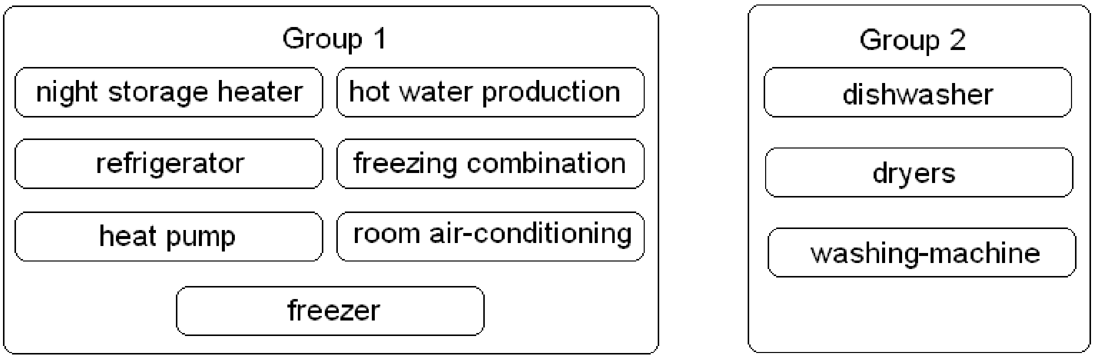

Fig. 2: Household loads which can be used in the DR

3.1.2. Industry, commerce und service

The second consumer group includes Industry, Commerce and Service (ICS) which power consumption is about 24 % of the gross electricity demand in Germany. The main applications of ICS [25]:

- Marketing
- Office companies
- Catering industry
- Manufacturing operation
- Schools, universities
- Agriculture
- Baths
- Hospitals
- Building industry
- Textile+ Clothing+ Forwarding companies
- Baking industry
- Butcher's shops
- Airports
- Horticulture
- Laundries
- Rest food industry.

The large share of the gross electricity consumption is used for lighting (approximately 40 %) which is not suitable for energy demand shifting. The proportions between the ICS types vary from 10 % in the baking industry to about 65 % in educational institutions. The importance of communication as a further application area within the scope of the DR increases. The energy share has increased to more over 35 % especially in communication and data processing in office companies. The average share is already about 17 % [25].

There are four processes types (applications) of the DR:

- Process refrigeration/air conditioning
- Process heating

- Mechanical energy (excl. compressors for air conditioners)
- Electrical heating.

The electrical supply of refrigeration in the process technology or air conditioning represents about 10 % of the gross electricity demand in the ICS area (status of 2010) [25]. Cold stores e.g. offer a possibility of energy demand shifting due to the inherent storage capability because of the enclosed air and the closing walls as well as the stored products. DR can be also utilized in food retailing because of increasing of frozen products sales. The number of refrigeration units increases, which are already equipped as composite systems with a higher power consumption and extra storage [26]. The average duration of their use is 14 h to 18 h per day, what enables a load shifting over a long period.

The area of the electrical heat supply is becoming important mainly in the process heating, but also in the space heating (around 8.5 % of the gross electricity consumption, status of 2010) [25]. A driving force in this process is the growing fuel costs and government funding for suitable heating systems. If the systems are equipped with a sufficient daily storage (charging time 8 h) [26], a shift of the recharge over several hours is technically realizable. However, the potential of these loads is strongly dependent on the user consumption behavior. The storage can overheat in summer but the needs cannot be completely covered in winter. This should be considered by planning the DR utilization.

3.1.3. Electromobility

The transport represents approximately 28 % of the final energy demand in Germany and thus a significant number in terms of CO_2 emissions reduction and fuel requirement [27]. This is a driving force in the development of electric vehicles (electric vehicles and hybrids) which can lead to a significant increase of the net electricity consumption mainly regional at medium and low voltage levels. Because of a possibility to load the electric storage as well as to feed energy back into the power grid, there is great potential for the DR use. Until 2030 the expected number of electric vehicles varies around 10 million based on different studies.

Electric vehicles are in an early stage of its development. Their market maturity is linked to two main parameters. The available battery technology provides a limited distance typically from 100 to 120 km depending on the use of further consumers and the vertical profile of the driving distance. Furthermore, the low maintenance costs cannot compensate the high investment costs for the battery system during the service life of an electric vehicle compared to a conventional vehicle [28].

The mentioned economic aspect is a basis for the development of new commercial models which can generate additional compensations for the vehicle battery use as a decentralized energy storage in the power grid [29]. This process is called vehicle-to-grid concept [30]. According to this approach, the saved electric energy should fed into the electrical network during periods of a low renewable generation in order to keep the power network stability.

According to different studies, there will be 1Mio. electric vehicles in 2020 and 10Mio - in 2030 in Germany. Whereby, electric vehicles will be probably used only as a second car [31]. Hence, their kilometrage will be typically 15,000 km/year. This corresponds to an annual energy consumption of about 3,000 kWh by an average consumption of 20 kWh per 100 km. Consequently, Germany's gross electricity demand will increase by about 5 % compared to 2010 (600 TWh). Assuming an average charging capacity of 3.7 kW in 2020 and 7.3 kW in 2030 the maximum power consumption will be 3.7 GW resp. 73 GW. Therefore, the battery storages of electric vehicles can be used as short-term storages with a high aggregate power consumption.

3.2. Interpretation of the results

The analysis of different loads in the household and ICS show that there are significant DR potentials by today's energy consumption in the electrical network even now. In particular, the thermal processes, which are characterized by mostly continuous operation and their storage capacity, are very important for the DR use. In the ICS area the systems which provide the process refrigeration (such as cold stores) and heating (as steam) have the largest DR potential which is maximum 10 GW.

The further development of possible load shifting is characterized by the increasing electrification of providing of the heat energy and air conditioning as well as by the expected increase of the electric vehicles number. The load capacity for shifting will be 34.7 GW in the household and 11.5 GW in the ICS area until 2030. The industrial energy consumption will increase only a little compared to 2010 because of an energy efficiency rise and a hesitant expansion of heat pumps and room air-conditioning systems.

4. Conclusion

Because of a high energy consumption, growing power grid complexity and renewable energy utilization the demand response (DR) use is becoming a very important issue for the power grid operation. Critical situations in the electrical network which accrue because of the imbalance between the power generation and energy demand, further building of extra power plants which are operated just during energy consumption peaks can be avoided by using DR. Moreover, DR can also reduce carbon emission in order to decrease environment pollution.

Therefore, different demand response programs have been created worldwide in order to implement DR methods in the power network operation. The European Union has a huge potential in the DR utilization. Hence, it is also becoming very active in the process of the DR implementation. Several European countries such as the United Kingdom, France, Italy, Spain and Ireland have already started and are going to organize many DR programs.

In addition, Germany is a unique country in the EU which has a very big potential for the DR use. It already utilizes a huge amount of renewable energy and its amount will just increase. However, this process causes strong fluctuations in the generation. The DR can be a good method to avoid such fluctuations. Unfortunately, DR is still not used very often in Germany. But this situation can be changed very fast in the nearest future because German network operators are becoming very interested in the DR utilization.

Acknowledgements

The research leading to these results has received funding from the People Program (Marie Curie Actions) of the European Union's Seventh Framework Program FP7/2007 - 2013/ under project ELECON−Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912. The author acknowledges the support and efforts of colleagues from LABSPOT (Departamento de Engenharia Elétrica, UFSC, Florianópolis), especially Prof. Antonio J.A. Simões Costa, Prof. Jacqueline G. Rolim and Daniel Tenfen.

In addition, the author would also like to convey thanks to André Richter (OvGU Magdeburg) and the staff around the ELECON project for giving the opportunity to visit Brazil and gain a lot of new experience.

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