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Methods of Demand Site Management and Demand Response

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Review Article

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ABSTRACT

Electrical power system is one of the most complex and advanced systems in the world. The energy management of such a system from the point of generation and distribution has been optimized but the demand side has only received attention in the last decade. This has led to the implementation of demand side management (DSM) which involves a number of different methods to improve the power system at the demand side. DSM ranges from increasing load efficiency by using better materials to implementing smart energy tariffs for different consumption patterns, up to using sophisticated systems to control distributed energy sources. This paper gives an overview of the DSM and discusses in detail the different ways of implementing the DSM in the electrical power system.

INTRODUCTION

The traditional method of supplying electricity to the consumer involved using a limited number of power plants to supply the electricity demand of the consumers. This method worked well till the last decade when volatile renewable energy sources [1] and electro-mobility concepts entered the electricity market. These methods have made the supply of electricity bi-directional and require new sophisticated methods of control to monitor the generation and consumption of electricity [2]. The concept of changing the static nature of the electric load into a dynamic form has been around for a long time but this concept was not implemented until the advent of affordable global communication networks and embedded systems which have allowed a certain degree of “smart” to be implemented in the electrical loads. The development of demand side management has also been driven by the increasing demand of electricity despite increases in efficiency of electrical loads.

The increasing generation capacity can keep up with the increasing load. However, the main problem being faced now a days is the gird capacity which is reaching its upper limits. This is due to large renewable energy projects such as offshore wind farms in the Northern Sea [3] that are putting a strain on the existing grid system. Due to these reasons intelligent demand side management (DSM) is needed to increase the capacity of the existing grid. DSM includes everything that is done on the demand side of the power system. This can include such simple things as increasing efficiency of a light bulb by replacing an incandescent light bulb with fluorescent light bulb to using sophisticated controllers to dynamically change the load. DSM can be broadly categorized into 4 different categories.

Energy efficiency (EE), Demand response (DE), Spinning reserve (SR), and Virtual power plants (VPP) are the four effective methods for demand side management and demand response. The effect of these methods on the consumer process can be seen graphically in the **(Figure 1)** below. The “process” can be defined as a manufacturing process, pump power or even the well-being of the consumer. These 4 different methods are discussed in detail in the following sections.

Energy efficiency

The energy efficiency of buildings or industrial areas requires careful planning to find out the processes that need optimiza

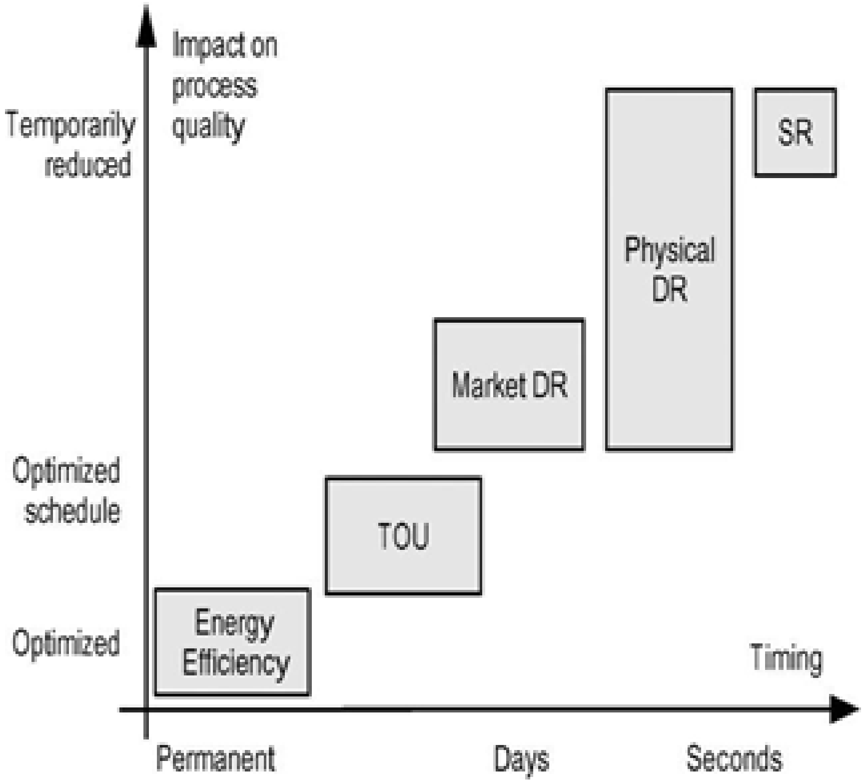

Figure 1: Categories of demand side management.

tion. These processes can be trivial things such as broken equipment, clogged A.C filters, inefficient light bulbs, etc. Too often, such processes are overlooked and as a consequence efficiency is not improved. To remedy this situation sensors at the consumer site have to be connected to a data base server which contain algorithms to take decisions based on the input signals from the sensors to improve the overall efficiency. To achieve this, one of the methods is to uses the internet to transport the data from the sensor sites to the consumer as well as the data base server. This method is shown graphically in the diagram below **(Figure 1)**.

Peak load versus baseline comparison

In this comparison the baseline power consumption is compared with the peak load consumption and the difference calculated. If the difference is not large then this could be due to consumption of standby power or installation of obsolete equipment

Weekly time series comparison

This method involves the comparing the electricity consumption per week and finding out if there are any anomalies. This could be due to people forgetting to turn off there lights over the weekend or leaving there air conditioning on.

Benchmarks series

This method involves the comparison of electricity consumption of a consumer with other consumers. This is especially effective for multisite consumers such as government buildings.

Process correlation

This involves comparing the electricity consumption with the ambient conditions such as temperature to see if the consumption correlates with the ambient conditions. Besides these traditional methods of computing the output to reduce loads, a smart algorithm or an experience controller can predict the electricity consumption patterns and use this information to reduce peak loads.

Demand response

The variation in electricity usage by end-use consumers from their regular consumption patterns in response to the change in electricity price overtime is known as demand response (DR) [4]. It further includes the entire pattern changes by end-use consumers that are proposed to alter the timing of the electricity consumption. DR gives an opportunity for consumers to take part in the operation of the electric grid by shifting or decreasing their electricity usage during peak time in response to some financial incentives. DR programs are used by electric operators and system planners as an option to balance the supply and demand. These programs are capable to decrease the electricity cost in wholesale market which leads to lower retail rates [5].

Demand response offers various methods to attract customers in real time based rates such as real time pricing, variable peak pricing, critical peak pricing, critical peak rebates and time-of-use pricing. DR is considered as a valuable resource option in electric power industry because of its potential impacts and capabilities of grid modernization efforts. Recently, a massive focus has been made on DR programs that are aimed to improve market liquidity, reduce electricity price, resolving transmission lines congestion, and security enhancement.

Finally, the demand response is mainly classified in to two categories; incentive based programs and price based programs **(Figure 2)**. Some literature papers have also named them as emergency and economic-based, or stability and economic-based programs [6].

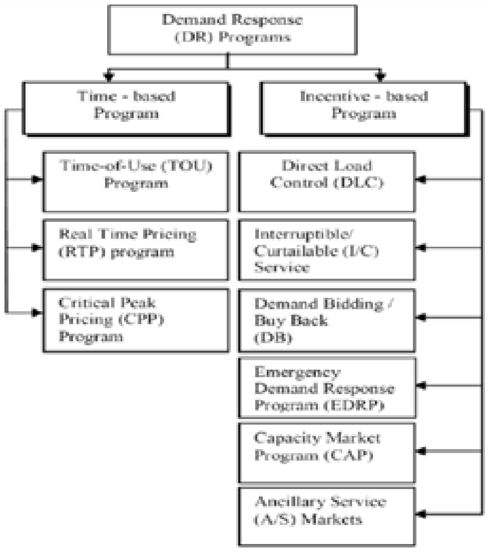

Figure 2: Categories of demand response programs.

Incentive-based programs

These programs offer payments to participating customers for load reduction during peak hours. These end-use customers reduce the demand level of distribution networks by limiting or adjusting production process and shifting load time to off-peak time. Thus, participating endues customer's to get bill credit or discount rates.

Interruptible/curtailable service: These programs provide participating customers upfront incentive payments and lower rates. The customers are asked to reduce load to pre-specified level during system contingencies. These programs are offered by utility/ load service entity and the interruption usually occurs during high energy demand periods [7]. Customers must curtail in 30-60 minutes time period when informed and participants who do not curtail when directed can face penalties depending on the terms and conditions.

Capacity market program: These programs offer customers to commit on providing predefined load reductions during system contingencies and in return customers are guaranteed with payments. These programs are typically offered by wholesale market providers and are usually called on a one day notice. Participating customers are penalized if they do not curtail load when directed. Capacity market program is fully demonstrated with eligibility criteria to make sure these reductions are achievable by the consumer [7].

Direct load control: These programs provide power companies the ability to remotely shut down consumer's electrical equipment such as water heaters and air conditioners during peak time to address local reliability contingencies. In return they get lower electric bills and other financial incentives [8]. DLC was first operated two decades ago and normally it occurs in system peak demand time. DLC is also operated to avoid peak time electricity purchases. These programs are voluntary so that consumers are not penalized if they don't accept the offer.

Ancillary services market program: These programs allow customers to bid load curtailment as an operating reserve in spot market. The participating customers are given market price if bids are accepted because of being on standby and are also paid spot market energy price if load curtailment is needed. The customers should adjust load rapidly whenever reliability event happens in order to participate in ancillary service markets [7].

Emergency demand response programs: These programs provide incentive payments to customers for load reductions during reliability triggered events. These programs are offered by load serving entity or electric utility and are most probably associated with Regional Transmission Organizations/ Independent System Operators (RTO/ISO) *12+. Customers won't get penalized if they do not curtail consumption because this program is voluntary so customers can stop paying and not curtail consumption when notified.

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Demand bidding/buyback programs: This is one of the latest types of incentive based demand response program. This program encourages customers to offer a price of load reduction at which they are ready to be curtailed, or to find out how much load will they curtail at given prices [8]. These programs are operated by (RTO/ISO) and integrated utilities.

Time based programs

These types of programs are generally based on dynamic pricing rates and time based rates, in which rates follow the real time cost of electricity. The ultimate objective is to promote DR by increasing price rates during peak time and decreasing price rates in off-peak time. These rates include Extreme Day Pricing (EDP), Real Time Pricing (RTP), Critical Peak Pricing (CPP), Extreme Day CPP (ED-CPP), and Time of Use (TOU) rate.

Time of use programs: This is the basic type of TBP and it has the most predominant time varying rates for residential customers. This program offers different rates of electricity price per unit in different blocks of time. It is basically designed to reflect the average cost of electricity in different time period [8]. TOU rate has two time blocks on-peak and off-peak and these rates are given to the customer in a particular season. On-peak hours charge a higher rate and off-peak hours charge lower rates and these rates usually apply during the night or some part of evening [7].

Real time pricing program: These program rates vary continuously in day time and directly reflect the wholesale price of electricity market. This program offers hourly price rates linked to hourly changes in real time cost of power. The connection between retail rates and wholesale prices offers price responsiveness in retailing market [8]. Various RTP programs are day-of versus day-a head pricing, mandatory versus voluntary, and one-part versus two-part pricing.

Critical peak pricing program: This program is comparatively new form of TOU rates which depends on high critical peak prices opposed to ordinary peak prices in TOU. The critical peak time period defines high specified per unit rate for usage during load time. These programs usually occur 6-10 hours in a season with relatively short time period notice. CPP is price based and happens in real time of extreme system conditions and makes it a reliability based DR [5].

Spinning reserve

The spinning reserve method of DSM involves supporting the traditional ancillary services by changing the loads on the demand side to maintain the frequency of the power system. Two of the schemes used to implement the SR concept are grid friendly controller [9] and Integral Resource Optimization Network (IRON) [10]. The difference between the two schemes is that the IRON system uses telecommunication systems (GSM/3G) to implement cooperative algorithms to automatically adjust the different loads so that one of the loads is not turned OFF most of the time. Grid friendly controller on the other hand controls a single load and does not have communication abilities between different loads.

The year wind speed profile graph shown below shows the fluctuation of wind speed throughout the year. As we can see the wind fluctuates quickly between peak speeds of above 20 m/s and speed below 5 m/s in a short period of time. Due to this behavior wind power is considered an intermittent source of renewable energy **(Figure 3)**.

The discrete wind histogram shows how many hours per year does the wind blow at a particular speed. The graph shows that most of the time the wind blows between the values of 5 m/s and 10 m/s. At this wind speed most wind turbines do not produce there rated power. Due to this reason the overall efficiency of wind turbines throughout low as compared to other ways of producing electricity **(Figure 4)**.

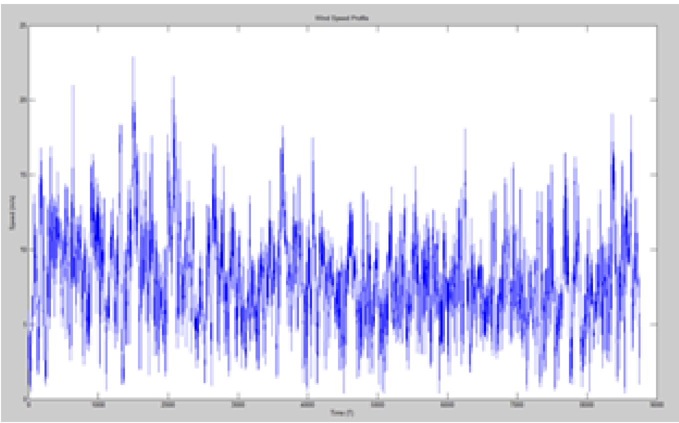

Figure 3: Yearly wind speed profile

Rayleigh statistic

The Rayleigh PDF given below shows the theoretical wind probability distribution of different wind speed given only the average wind speed of the sight. This method is very robust as it helps us in estimating wind distribution of a sight without actual wind data **(Figure 5).**

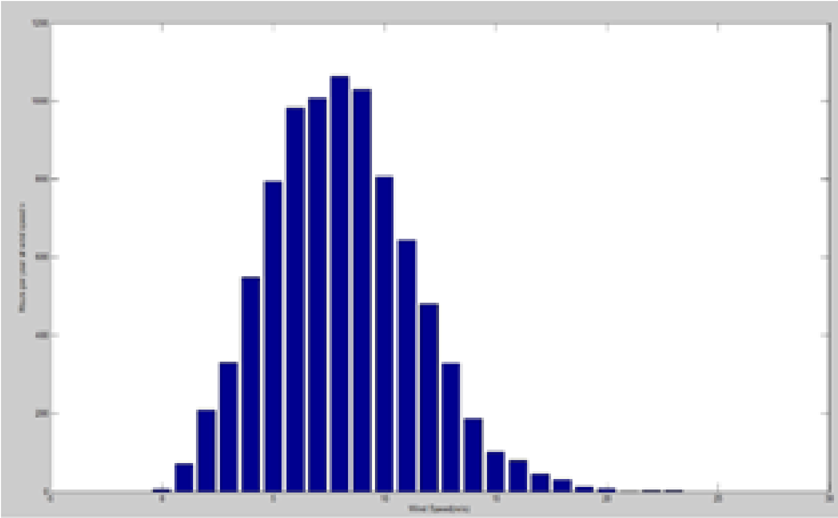

Figure 4: Note 1 year=365x24=8,760 hours.

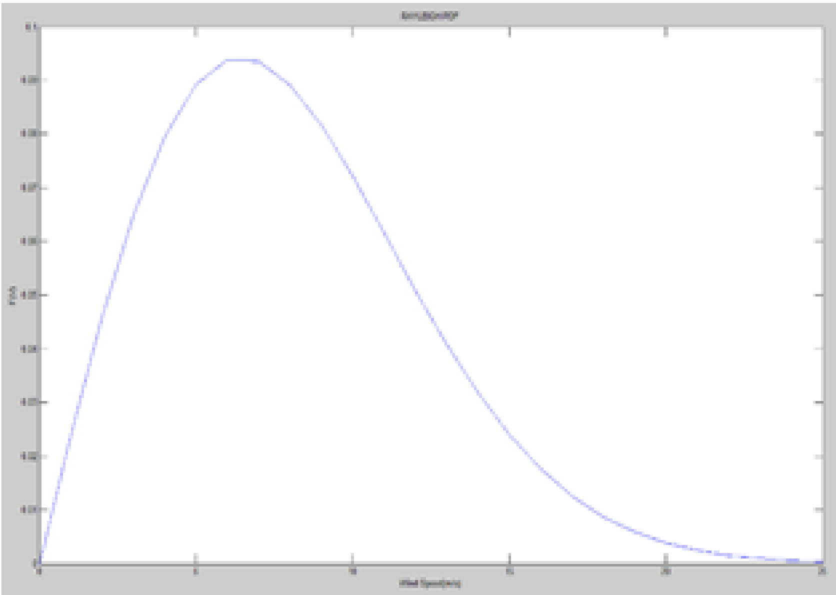

Figure 5: Rayleigh Probability Density Function.

The measured data PDF given shows the measured data probability distribution of wind speeds. This graph is not a smooth curve as the probability change suddenly between wind speeds.

The graph below shows the comparison between the Rayleigh PDF and measured data PDF. As we can see from the graph for most values Rayleigh PDF does follow the real PDF but deviates from the real PDF between wind speeds of 5 m/s and 10 m/s. This is because the real PDF depends on the real measured data as compared to Rayleigh PDF which only estimates the probability of a given wind speed based on average wind speed **(Figure 6)**.

Virtual power plants

Virtual Power plants (VPP) represent a family of small generation units on the demand side (mostly renewable energy sources) that are seen as a single power plant by the system operator [11]. This is achieved by linking the different distributed renewable sources to a single control center using modern SCADA standards such as IEC 61850 [12].

CONCLUSION

In conclusion this technical paper details the overview of the DSM including its four sub types. Firstly, the paper discusses the energy efficiency method of DSM including the different methods to implementing this method in the power system. Secondly, the paper discusses in detail the demand response part of the DSM. This part was further categorized into time-based program and incentive based programs which are different methods of implementing the DR program. Thirdly, the paper touches the spin

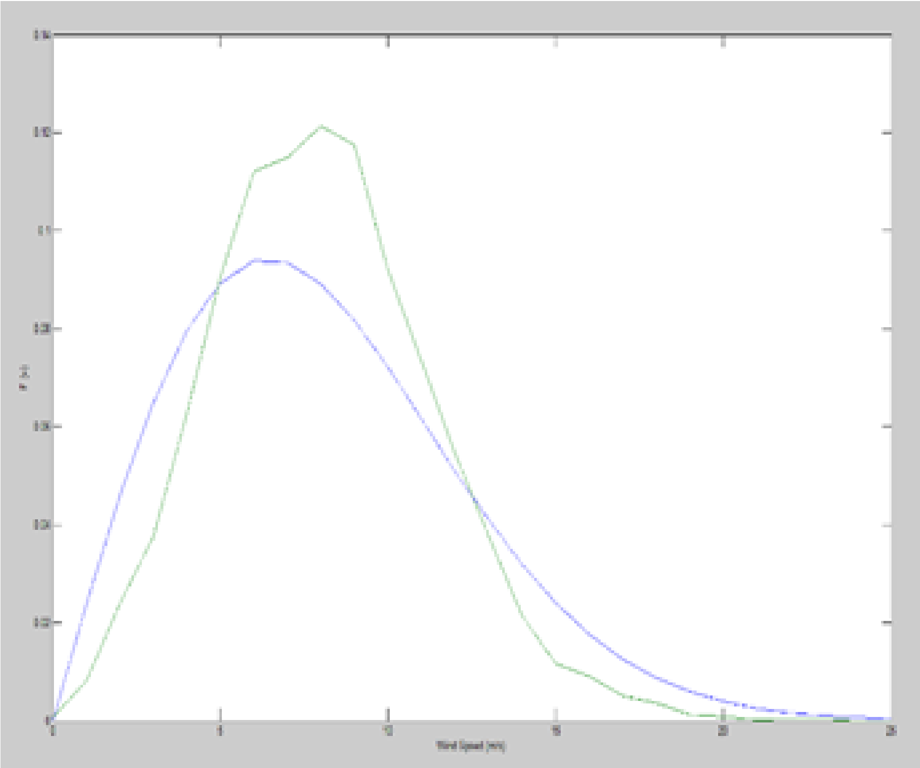

Figure 6: Comparison between the Rayleigh PDF and measured data PDF.

ning reserve concept of DSM which includes the concept of changing the load to stabilize the frequency of the grid system. Finally, the paper concludes with the idea of VPP which includes the concept of renewable energy sources which are grouped into a single power plant entity which can then stabilize the grid system.

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