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Implementation of various demand response programs across the countries and its impact on the bulk power system reliability

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Abstract

In recent decades, electricity power systems have seen the introduction of several demand-side participation strategies, including distributed generation, on-site storage, and demand response. The latter, now widely recognized as essential for ensuring a reliable power system, involves shifting loads to different time intervals to alleviate power scarcity during peak times, thereby aligning with fluctuating electricity prices. This study explores various demand response programs globally, tracing its origins back to the late 1980s, and ongoing research reflects a collective examination of its effectiveness and challenges in power market implementation. The paper aims to investigate demand response practices worldwide, develop a comprehensive model, and analyze its diverse effects on electric power networks. Additionally, it integrates the demand response model into a widely used power system network for research purposes. Throughout, peak demand is highlighted as critical, with a focus on evaluating power system reliability indices within a reduced peak network. The findings suggest improved system reliability, advocating tailored demand-side management approaches such as Incentive Based Demand Response (IBDR) for industrial applications and Price-Based Demand Response (PBDR) for domestic consumers, emphasizing the importance of consumer-specific solutions.

Keywords

Demand response, System reliability,Peak network,IBDR,PBDR

1. Introduction

The evolutionary deregulated electric power introduced the term demand side management (DSM) and later specific towards the demand response (DR) in late 1980s though there are major differences in between them [1]. The programs through which the activation of demand side is attempted can be considered as DSM, but such programs should include the energy efficiency, load management, saving and self-production whereas the DR mainly focuses on the load management part of DSM by changing the customer behaviors in response with the change in electricity prices [2]. The electric power research institute (EPRI) has defined the DSM as follows "DSM is the planning, implementation and monitoring of those utilities activities designed to influence customer use of electricity in ways that will produce desired change in utilities' load shape, i.e. Time pattern and magnitude of utilities' load pattern. Utility programs falling under the umbrella of DSM include load management, new uses, and strategic conservation. Electrification, customer generation and adjustments in market share [2]."

The concept of DR is evolved from the word spot price in late 1980s. DR can be defined as "the changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time. Further, DR can also be defined as the incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" by the US department of energy (DoE) and categorized as price based and Incentive based programs [3]. DR include all intentional modifications to consumption patterns of electricity of end use customers that are intended to alter the timing, level of instantaneous demand, or the total electricity consumption [4]. This paper presents the overview of demand response beginning from its classifications and definitions. Next section deals with the different practices in major seven countries across the world. The main organizations in the electricity market are ISO and RTO and corresponding major activities carried out by various ISO's are explained under the sub-headings of each countries DR implementation.

1.1 Classification of DR

In strategic plan of International Energy Agency (IEA), for 2004-2009 years, DR (analysis and implementation) is dedicated to United State of America however the Demand side management (DSM) was introduced by EPRI (Electric power research institute) in 1980s. Federal Energy Regulatory Commission (FERC) reported the results of DR investigations and implementations in US utilities and Power Markers [?]. In the mentioned report, DR is divided into two basic categories and several subgroups as shown in Table 1.

Direct Load Control (DLC) DR programs are initiatives that allow utilities or grid operators to directly control or manage specific appliances or equipment in consumers' homes or businesses to curtail electricity consumption during peak demand periods or grid emergencies. These programs are a part of DR efforts aimed at optimizing electricity use and improving grid reliability. For instance, the remotely controlled equipment is air-conditioners and water heaters. This is the most usual DR programs; in which utilities can remotely shut down participant's load on a short notice [?]. Like Direct Load Control programs customers participating in

Table 1: Classification of DR Programs

Sr.No.	Types of DR programs
A.	Incentive Based Programs(IBP)
A.1	Classical
A.1.1	Direct Control
A.1.2	Interruptible/Curtailable Programs
A.2	Market Based
A.2.1	Demand Bidding
A.2.2	Emergency DR
A.2.3	Capacity Market
A.2.4	Ancillary Services Market
B.	Price Based Programs(PBP)
B.1	Time of Use(TOU)
B.2	Critical Peak Pricing(CPP)
B.3	Extreme Day CPP(ED-CPP)
B.4	Extreme Day Pricing(EDP)
B.5	Real Time Pricing(RTP)

Interruptible/Curtailable Programs will receive incentive upfront payments or rate discount. The participants are asked to reduce their load to predefined values. Participants who are not responding might face penalties depending on the program terms and conditions [?].

Demand bidding, under the market-based DR program are also called the buyback programs in which customers bids specific reduction of load in the electricity wholesale market[5]. If the bidding price is less than the market price, then the bidding is accepted, and consumer should curtail their load by the amount as specified in the bid else they need to pay penalty but, in the emergency, DR programs consumers are paid the incentives on an emergency measured load reduction conditions[5].

Further, Capacity Market Programs are offered to customers who can commit to providing pre-specified load reductions when system contingencies arise due to assorted reasons. (Equipment failures, line outages, generator outages, load changes, natural disasters, cyber security incidents and human errors etc.) [5]. Participants usually receive a day-ahead notice of events and are penalized when not responding to load reduction call. Ancillary services market programs allow customers to bid load curtailment in the spot market as operating reserve. When bids are accepted, participants are paid the spot market price for committing to be on standby and are paid spot market energy price if load curtailment is required[5].

1.2 Composite system reliability

There is a growing concern about the reliability of power systems under a market environment, especially after the blackouts in North America and Europe in 2003. Bulk power system operators primarily rely on adjustments in generation output (MW movements up or down) to keep the system reliability [3].

Composite system reliability in electrical power systems refers to the overall reliability of a complex system that consists of multiple interconnected components, such as generators, transformers, transmission lines, and distribution systems. The reliability of the entire power system is crucial because any failure or outage in one component can affect the overall performance and functionality of the entire system.

The reliability of a composite power system is assessed based on the probability that the system will continue to operate successfully without any failures over a specified period. This assessment considers the reliability of individual components, their interactions, and the redundancy built into the system to handle potential failures.

In this paper RBTS-6 bus system is taken where by implementing the DR program the peak demand is trying to reduce below 185MW. The concept of price elasticity is used for calculating the new demand pattern of customer for 24 –hours and similar will apply for all the 8760 hours (i.e. for a year). Different reliability indices such as LOLE,ENS,AENS calculated in considering two cases ,one without taking DR program and another with implementing DR program.

1.3 Implementation of DR across the countries

The specific implementation of DR can vary depending on the type of facility, its energy usage patterns, and the regulatory environment in various regions. The concept of DR and its initial implementations date back to the early 20th century, but it gained more prominence and structure over the years(Martinez and Rudnick, 2012). Table 2 depicts the implementation of DR programs in various countries by different ISOs/RTOs and demand service providers. The first organized DR programs can be traced to various regions and utilities in USA. The other major countries which effectively implemented DR and gaining benefits from this are Canada, Japan, Australia, United Kingdom where there is still researching about the benefits and implementation about DR in china, France and other countries[6]. Table 2 clearly depicts the various types of DR in different countries.

2. Methodology

The overall approach of this paper is to find the new demand pattern based on the real time pricing (RTP) and time of use (TOU) pricing due to which the peak demand for a system is reduced for that time interval and new less demand will be the peak for another hours. In general TOU deals with the blocks of time and if TOU is specified in Real time then it becomes real time pricing (RTP). Following algorithm will be followed for this study:

- Identification of the pricing methods such as real time pricing (RTP), Time of use (TOU) pricing, CPP (Critical peak pricing) method.
- Collection of electricity price data and demand data for the particular system area.
- Modeling of the price elasticity matrix for the calculation of new demand pattern.
- Finding the new peak from the newly demand array and with the help of such maximum demand value, reliability evaluation is carried out.
- Performing load flow the reference 6-bus RBTS with the new load data and once the power flow success furnish the load loss report for the various contingencies.

Table 2: Implementatino of DR across different countries

S.N.	Countries	Organization	Types of DR Programs
1.	USA	NYISO,2008	Demand side Ancillary service programs (DSASP)
1.1		PJM	Day -ahed scheduling reserve market(DASR)
1.2		ISO,new England,2005	Real Time DR programs
1.3		ERCOT	day ahead market (DAM), RTP and ancillary service
1.4		MISO	Emergency DR (EDR) program
2.	Canada	IESO, 2015,SASKPOWER,2023	IBP,Market Based,Demand Bidding
3.	South Korea	KEPCO,2000	Demand Bidding
4.	Australia	AEMO/ARENA	Retailer DR programs mainly in spoyh austalia
5.	Japan	Aggregation cordinator/ENEL X	MIXED dr
6.	China	CENSA, 2014	
7.	SAARC Countries	Government bodies	Considered DSM as DR and planning for DR approach

- Performing techno-economic comparison of both before and after demand response implementation.
- Drawing the conclusions and recommendations.

on considering both self-elasticity and cross elasticity the final model will be prepared for both single time periods and multi time periods and the final mathematical model will be like as follows:

$$d(i) = d_0(i)[1 + e(i)[p(i) - p_0(i) + a(i)/p_0(i)] + \sum_{n=1}^{24} e(i,j).[p(i) - p_0(i) + a(i)/p_0(i)]$$

where,
$d(i)$ = is the new demand data
$d_0(i)$ = textinitial demand data
$e(i)$ = self elasticity coefficient
$e(i,j)$ = cross elasticity coefficient
$p(i)$ = price after DR implementation
$p_0(i)$ = initial price before DR implementation
$a(i)$ = incentive given for DR users

3. Result and Discussion

After the calculation of new demand pattern based on the various approaches of the PEM,the following results came in various cases. In all the cases before the demand response program implementation our system peak load is 185 MW (selected peak day 24 hours data out of 8760 demand values of the year). From the formed table of 8760 RBTS load data, this paper select the 51st week, 2nd weekday, 24 hours data.

On analysis the above data and with our definition of demand response, the PBDR is suitable for the domestic customer category who can shift their load based on the blocks of time price or hourly price basis. This kind of DR might be difficult for the industrial sector where the chunks of minimum load requirement occurred for the specific purpose and hence IBDR is more suitable for the industrial sector in Nepal where the major industries are of cement factory.

The above Peak demand is proportionate in the 185MW of 6-BUS RBTS system and analyzed the TOU based RTP DR programs and as this will be the temporal variation and without having the historical each individual class peak demand it will not furnish the accurate result[7]. Hence, we are considering the 185MW as the peak for each class customers and based on the variation on elasticity the new demand will be various for different consumers with evaluated indices are as shown below

- Before DR implementation,EENS(MWhr/yr) is 442.682
- After DR implementation,EENS(MWhr/yr) is 427.237

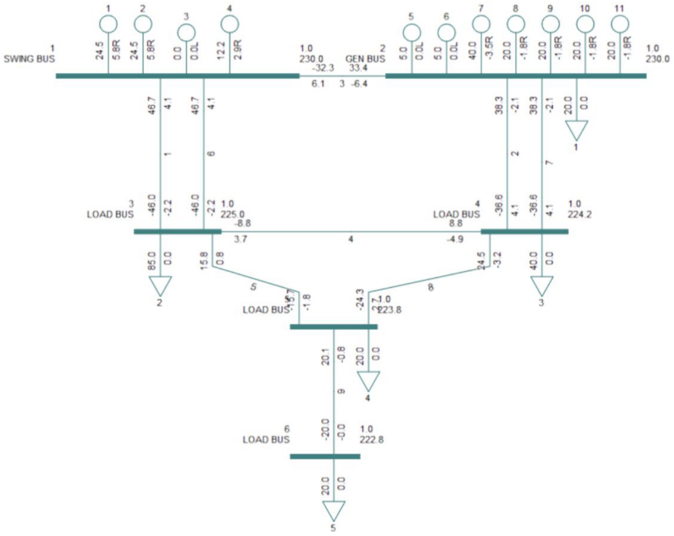


Figure 1: RBTS-6 bus PSSE model before DR implementation

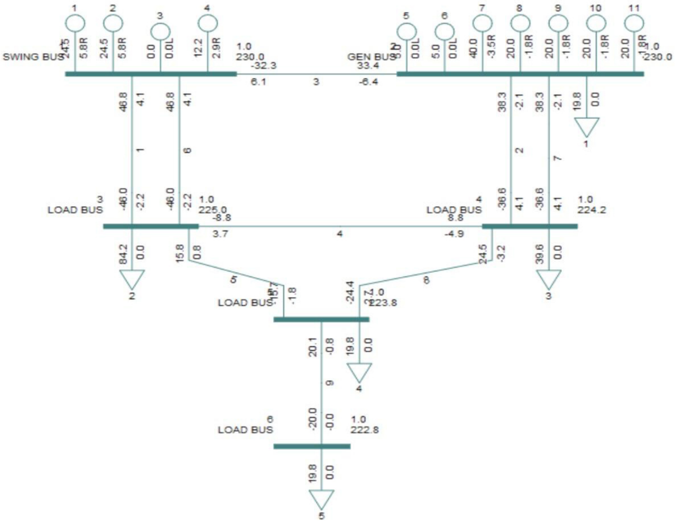
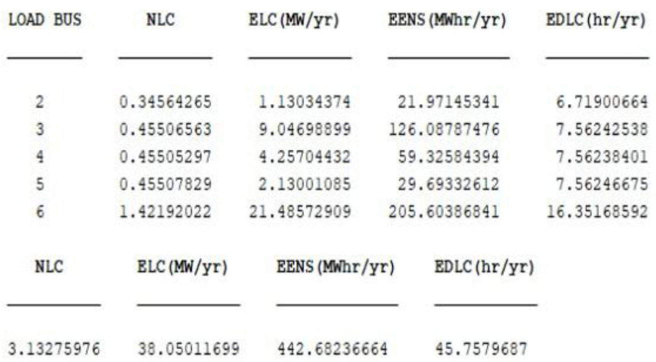


Figure 2: RBTS-6 bus PSSE model after DR implementation



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LOAD BUS      NLC          ELC(MW/yr)    EENS(MWhr/yr)    EDLC(hr/yr)
________   __________    ___________    _____________    ___________

   2       0.34564265     1.13034374     21.97145341      6.71900664
   3       0.45506563     9.04698899    126.08787476      7.56242538
   4       0.45505297     4.25704432     59.32584394      7.56238401
   5       0.45507829     2.13001085     29.69332612      7.56246675
   6       1.42192022    21.48572909    205.60386841     16.35168592

    NLC         ELC(MW/yr)     EENS(MWhr/yr)    EDLC(hr/yr)
__________    ___________    _____________    ___________

3.13275976    38.05011699    442.68236664     45.7579687
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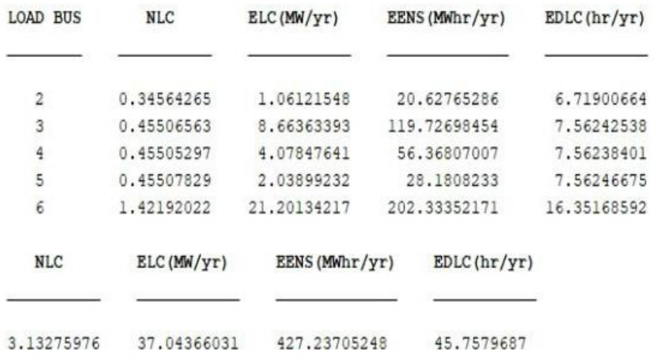
Figure 3: Reliability Indices Evaluation before DR implementation



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LOAD BUS      NLC          ELC(MW/yr)    EENS(MWhr/yr)    EDLC(hr/yr)
________   __________    ___________    _____________    ___________

   2       0.34564265     1.06121548     20.62765286      6.71900664
   3       0.45506563     8.66363393    119.72698454      7.56242538
   4       0.45505297     4.07847641     56.36807007      7.56238401
   5       0.45507829     2.03899232      28.1808233      7.56246675
   6       1.42192022    21.20134217    202.33352171     16.35168592

    NLC         ELC(MW/yr)     EENS(MWhr/yr)    EDLC(hr/yr)
__________    ___________    _____________    ___________

3.13275976    37.04366031    427.23705248     45.7579687
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Figure 4: Reliability Indices Evaluation after DR implementation

4. Conclusion

This paper introduces and formulates a model for electricity demand response, featuring the development of extensive price elasticity matrices tailored to different consumer categories. Applying economic principles to electricity consumption, these matrices serve as a foundation for quantifying the level of demand response achievable for each consumer type. The resultant demand response models are seamlessly integrated into the standardized RBTS 6-bus system for comprehensive testing. Furthermore, the impact of demand response on system reliability is systematically assessed. Simulation results unequivocally indicate that demand response programs contribute to the enhancement of both overall system reliability and nodal reliability within a deregulated power system. These findings underscore the effectiveness of demand response initiatives in fortifying the reliability of power systems operating under deregulated frameworks.

5. Future Works

Demand Response (DR) is emerging as a pivotal element in multi-objective demand-side management strategies. The evolution of advanced communication and control techniques within the grid heralds substantial advantages for both electric utilities and consumers through the implementation of DR. A prospective area of research lies in the seamless integration of Demand Response with volt/var control, promising remarkable benefits. A noteworthy extension of this research work involves showcasing a real-time demonstration of a volt/var control algorithm that leverages both the DR model and distribution operation model. The optimization of peak demand curtailment is best achieved through the synergistic integration of DR with a volt/var control algorithm. The rapid expansion of advanced metering infrastructure and distribution automation measures is poised to effectively coordinate DR with various demand-side management events at the distribution level. Addressing the pressing need for a coordinated distribution management system, which encompasses distribution automation, demand response, volt/var control, and fault location, isolation, and restoration, is imperative for the contemporary distribution grid. This research paper serves as a foundational platform for such ambitious projects in the realm of enhancing grid efficiency and reliability.

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