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Different Demand Response Programs with its Implementation in Various Countries and the Role of TOU DR in the Context of Nepal

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Abstract

With the increasing trend of electricity consumption in worldwide it creates the cumbersome in reliable power system and necessitates the construction of new generator companies, transmission lines and other infrastructures. Despite on investing in new infrastructures to manage occasional peaks, utilities can use demand response concept to effectively handle demand during such peak time intervals and on doing so it enhance the grid stability. This assist on balancing the supply and demand for electricity, making the grid more resilient to fluctuations, and reducing the risk of blackouts. This paper delves into the diverse DR programs across the different countries and comparative analysis for finding the suitable DR method to make more reliable electric power network of Nepal.

Keywords: reliable power system, peak time interval, grid stability, risk of blackout

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(Aalami, Yousefi and Parsa Moghadam, 2008). 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(Anon., n.d.). 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(Anon., n.d.)."

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(Parvania and Fotuhi-Firuzabad, 2010). 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(Anon., n.d.). 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

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activities carried out by various Iso's are explained under the sub-headings of each countries DR implementation.

2. Classification of DR

Based on the price responsive nature of customers, motivation method, trigger criteria and way of shifting/switching the load by customer behavior, several papers divide the DR in mainly two parts that are Incentive Based DR (IBDR) and Price Based DR (PBDR)(Anon., n.d.). Those main two parts further categorized into several sub-groups as shown in the table below:

Table 1. Classification of DR programs

Classifiction of DR programs	
S.NO.	TYPES
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
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)

2.1 Incentive Based Demand Response (IBDR)

In this type of programs, the end customers are motivated by giving the direct payments to shift their load on peak hours and such prices are awarded to the customers in various ways. Those ways are clearly understood by the types of IBDR as below.

2.1.1 Direct Load control

The utilities or grid operators directly control the specific applications of participated end consumers such as washing machine, lighting, dish washer, heating system, motor pump, air conditioners etc. And such actions are triggered by the reliability events(Ali et al., 2022). There will be the facility of reduction in bill payment or some price awards to the consumer for agreeing on this, but the utility will not pre informed about the specific curtailment and customer may tend to lose their comfortless on consuming the electricity.

2.1.2 Interruptible /Curtailable Programs

This kind of DR program is suitable for the medium and large consumer where the utility request to curtail their specified load based on the agreement in between the customer and utilities. It is more likely as direct load control, but the main difference is in the case of penalty. If the customer does not follow the instructions of utilities, they need to pay penalty as specified in the contract which is not happening in direct load control program. The number and duration of each curtailment with the incentive and penalty amount mentioned in the agreement paper(Anon., n.d.).Those two programs are under the classical, type DR where the participating customers getting the payment as in the form of bill credit or discount rate on their payments.

2.1.3 Demand Bidding

These programs are also known by buyback DR. In this program demand customers bid the specified amount of load curtailment in the given price range in wholesale electricity market and if the price is less than market clearing price then the bid will be accepted(Anon., n.d.). The customers may need to face the penalties if they don't obey the specified amount of load reduction on the call of utilities/grid operator when the system contingencies arise.

2.1.4 Emergency DR

In this program the customers voluntarily reduced their load on the emergency call by the ISOs or utilities. Those load reductions are measured and paid the incentive to those customers based on the measured value during the emergency conditions(Aalami, Yousefi and Parsa Moghadam, 2008).

2.1.5 Capacity Market

The capacity market is like the demand bidding market, but the bidding is not happening in this type of market though the participant customers must commit the specified load reduction to the utilities and the utilities will give a day ahead notice of events to the customers(Anon., n.d.). Customers will be penalized if they don't do the pre-specified load reductions when the system contingencies arise.

2.1.6 Ancillary Services Market

In this program customers bid on the spot market price and if the bid accepted, they are paid on being standby as operating reserve and paid spot market energy price if the load curtailment is necessary(Wang, Wang and Tang, 2019). The participants are paid the spot market price for committing to be on standby.

2.2 Price Based Demand Response (PBDR)

On contrast to IBDR where consumers are encouraged to shift their load based on the corresponding incentive price, In PBDR customer participate in the program voluntarily to reduce/shift their peak demand in response to the electricity price signals. In this program customers check for the change in price and give emphasis on the adjustment of load by shifting their peak demand from peak hours to off peak or low peak hours as the electricity price will be higher during the high demand interval and less during the low demand interval(Anon., n.d.).so it can be safely said that PBDR is based on the dynamic pricing of electricity in which the tariff rates are not flat and rates are varying following the real time cost of electricity.

2.2.1 Time of Use (TOU)

This is a basic type of PBDR rate model in which the different slots of consumption time are allocated with various price rates. The simplest type of TOU is 2 block tariff structures where there will be high rate for peak hour's electricity consumption per unit and low electricity rate for off peak hour's electricity consumption(Aalami, Yousefi and Parsa Moghadam, 2008). Similarly, three block tariff structures are also available and if Time of use is modeled for 24 hours and updating on a day ahead basis then it becomes real time pricing. Some utilities also do the arrangements for seasonal tariff structures and such type also falls under TOU.

2.2.2 Critical Peak Pricing (CPP)

TOU method reflects for the longer-term electricity price costs like a year but for the short time interval which are critical to the power system Critical peak pricing method is applicable. The utilities or grid operators specifies the number of days per years where the critical condition in power system may occurred due to the unavailability of reserves /due to worst weather conditions/ and also specifies the number of period where the CPP applies. The pricing rate will be higher than normal flat rate for those hours and utilities communicates such events in very short notice, from several minutes to several hours before the CPP rate applies(Anon., n.d.). Extreme Day Pricing (EDP) and EDP CPP are two other types of CPP where once the high rate of price is applied for the EDP program, in all 24 hours of a day same rate will apply but in EDP CPP, the higher rate will be applied for the specified high peak hours and for the remaining hours of the day flat rate will be implemented like as in CPP.Those EDP and EDP CPP are applicable only for the extreme days only not the other days as in CPP.

2.2.3 Real Time Pricing (RTP)

In RTP, the energy price is updated by utilities and circulated to customers in very short notice and mainly on hourly basis. With this approach the customers are also directly exposed to the wholesale electricity prices or locational prices or zonal prices where the utilities specified the rate of electricity as per their generation and transmission costs and those day-ahead market prices are communicated before the actual power delivery(Ma and Venkatesh, 2022). The consumer prices are either as per the direct day-ahead prices or settled at the end of hours on the basis of hourly electricity prices which are averaged in 5-minute prices of that hours. This paper taken as the TOU type DR as PBDR and compared the effectiveness of this this with IBDR in industrial market.

3. Implementation in various 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). The table 3, 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(Martinez and Rudnick, 2012). The table 2 clearly depicts the various types of DR in different countries as:

Table 2. DR Implementation in various countries

S.No.	Implementation of DR Program		
1	USA	NYISO,2008	Demand side Ancillary service programs (DSASP), EDRP
		PJM	Day-ahead scheduling reserve market (DASR)
		ISO, new England,2005	Real time DR program
		ERCOT	Day ahead market (DAM), RTP and Ancillary service plans
		MISO	Emergency DR (EDR)program
2	CANADA	IESO, 2015.SASKPOWER,2023	Incentive based programs>Market Based>Demand bidding
3	SOUTH KOREA	KEPCO,2000	Demand Bidding
4	AUSTRALIA	AEMO/ARENA	Retailer DR program, mainly in south Australia
5	JAPAN	Aggregation coordinator /Enel X	Mixed DR
6	CHINA	CENSA,2014	Mixed type
7	UNITED KINGDOM	GRIDBEYONG	Capacity Market and ancillary service

3.1.1 DR Implementation in the USA

There are nine ISOs, five of which are RTOs, operating in North America. They manage the systems that serve two-thirds of the customers in the U.S. and over half the population of Canada. Over time, the distinction between ISOs and RTOs in the United States has become insignificant. Both organizations provide similar transmission services under a single tariff at a single rate, and they operate energy markets within their footprint(Liu, 2017). The major ISOs/RTOs are CAISO, ERCOT, ISO-NE, MISO, NYISO, PJM and SPP for carrying out the wholesale DR programs in the USA.

3.1.2 DR Implementation in the Canada

The major utilities across the Canada are IESO,AESO but there are separate sorts of DR programs implemented by own utilities of individual provinces such as hourly ahead dispatchable load, transitional demand response and emergency load reduction programs are launched by IESO whereas load curtailment programs, demand opportunity services, supplement reserve,59.5HZ load tripping, interruptible load remedial action scheme are primarily main DR programs carried out by AESO in Canada(Baboli, Moghaddam and Eghbal, 2011). This paper taken as the IBDR of Saskatchewan Province of Canada and PBDR of type TOU of IESO (Independent Electricity system operator) Ontario.

3.1.3 DR Implementation in the Australia

The availability and structure of DR programs can vary across different states and territories in Australia, and they are often managed by individual electricity retailers, distribution network companies, and sometimes by government agencies. In Australia, the concept underlying the ARENA (Australian Renewable Energy Agency) DR trial is straightforward. Instead of investing significant funds in expanding grid capacity, ARENA opts to compensate consumers, through energy retailers, with a smaller amount for actively reducing electricity consumption(Anon., 2024).

3.1.4 DR Implementation in the United Kingdom

The DR program in UK is evolving with the advent of two primary types: capacity market and grid balancing services offered by entities like the National Grid and other Independent System Operators (ISOs). When engaging individually without external technological, engineering, or market expertise, participants are required to possess 2MW of flexibility to join the capacity market or 1MW for participation in frequency response and other balancing services(Anon., n.d.). However, when participating as part of an aggregated portfolio, a common scenario when collaborating with a Demand Side Response (DSR) provider, the threshold is typically reduced to around 200kW, or even lower in some instances.

3.1.5 DR Implementation in the Japan

Japan, the DR programs have been initiated from 2012 as launching smart house and building standardization and business study committee where ADR server provides the services such as lower charge utilize RES, decrease of curtailment, avoiding imbalance, balancing P.Q.KW etc. based on the electricity/information flow in between resource aggregator(Ishii, n.d.). The minimum load for bidding is 5MW and there will be no limit for maximum under market-based demand bidding program.

3.1.6 DR Implementation in the China

Despite being currently limited in China's electricity market, DR is gaining significance within China's energy strategy and the ongoing wave of electricity reforms. CNESA (China Energy Storage Alliance) functions as a key integrated entity within the Beijing National Development and Reform Commission (NDRC), playing an active role in the city's DR pilot initiatives. In essence, DR entails power users altering their consumption behaviors in reaction to economic or administrative signals issued by the grid company. Three prevalent modes of DR are commonly employed today: 1) invitation DR, 2) real-time DR, and 3) economic DR(Anon., n.d.).

4. Results and Discussions

On taking the TOU DR programs on merging with the RTP the mathematical model for the new demand response $d(i)$will becomes as below equation 1 .The detailed derivation of the mathematical formulation is taken from literature (Pandey et al., 2022)where

$d_0(i)$=Initial Customer demand in i^{th} hour (MWhr)

$p_0(i)$ =Iinitial price of electricity before DR ($/MWhr)

$p(i)$ =RTP in i^{th} hour ($/MWhr)

$\alpha(i)$ = Incentive in ith hour ($/MWhr)

$\beta(i)$ =Customer income in i^{th} hour ($/MWhr)

$$d(i) = d_0(i)[\left\{1 + \frac{\varepsilon(i).[p(i) - p_0(i) + \alpha(i)]}{p_0(i)}\right\} + \left\{\sum_{i=1}^{24} \varepsilon(i,j).\frac{[p(j) - p_0(i) + \alpha(j)]}{p_0(j)}\right\}] \quad (Equation\ 1)$$

The IESO hourly electricity prices are taken and with the deterministic approach of price elasticity matrix the new demand data are formed. The test system taken for this research is 6-bus RBTS system in which the maximum demand of 185MW occurred on 51th week (Monday)(Azami and Fard, 2008), with this kind of DR programs the peak demand was reduced below than 185MW in different cases of various customers. The explanation on different categories of customers is analyzed in the context on Nepalese electrical power market and the result obtained with the assist of MATLAB and PSSE software.

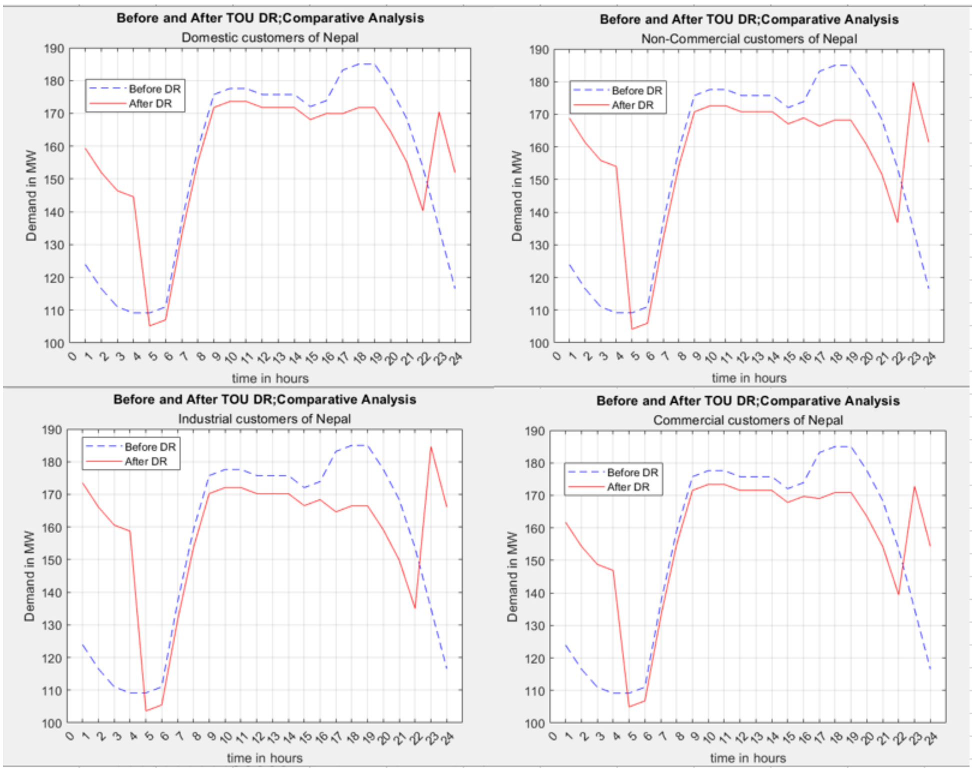

Figure 1. Changes in the peak demand after using TOU DR programs on various type customers of Nepal.

In the above graph it is resulted that the DR implementation is very effective for reducing the peak demand and to change the customer behaviors in responding with change in price. In all the cases the peak demand is reduced below than the previous high demand of 185MW. This kind of nature is more dominant in domestic consumer than the industrial consumers and hence the domestic consumer are highly motivated to do the PBDR while IBDR will be prominent for industrial consumers.

5. Conclusion

This paper introduces and classify DR, featuring the implementation of DR in different countries. Applying economic principles to electricity consumption, the deterministic approach of PEM serves as a foundation for formulating the level of DR achievable for each consumer type. The resultant DR models are seamlessly integrated into the standardized RBTS 6-bus system for comprehensive testing. Furthermore, the impact of DR on system reliability is systematically will be assessed in the future works(Ali et al., 2023). The approach for load flow after the DR implementation is successively tested by the PSSE and further effects of DR in nodal reliability will be carried out as future works. The conclusion drawn is that the role of DR on peak reduction and grid stability is very valuable and this type of programs in the countries across the world will reduce the necessity of tremendous investment on power system infrastructure by mitigating the well reliable condition of system.

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