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Implementation of Demand Response Programs in Various Countries and Its Impact on the Bulk Power System Reliability

by

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CERTIFICATE OF APPROVAL

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a dissertation entitled "**Implementation of Demand Response Programs in Various Countries and Its Impact on the Bulk Power System Reliability**", submitted by **Madhav Sapkota** in partial fulfillment of the requirement for the award of the degree of **Master of Science in Power System Engineering**.

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ABSTRACT

Over recent decades, electricity systems have adopted demand-side participation features, including distributed generation, storage, and DR, recognized globally as vital for reliable power supply. Despite increasing electricity demand requiring robust infrastructure, DR effectively mitigates peak power scarcity by load redistribution, aligning with price fluctuations. This thesis explores diverse DR programs, originating from the late 1980s, with ongoing global research on efficacy and challenges in power market implementation. Utilizing MATLAB for coding and PSSE for power flow solutions, the thesis has two main objectives: investigating DR practices worldwide and integrating a DR model into a widely used RBTS 6-bus system for analysis.

Peak demand assessment is pivotal, evaluating power system reliability indices within a reduced peak network context. The thesis introduces a comprehensive DR model, incorporating consumer behavior across scenarios and rationality levels, with Price Elasticity Matrices (PEMs) guiding DR calculation. Results indicate enhanced system reliability, supporting further demand management, especially through major DR programs. The thesis emphasizes tailored demand-side management approaches based on consumer categories, highlighting the importance of Incentive-based DR (IBDR) for industries and Price-based DR (PBDR) for domestic users.

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LIST OF ABBREVIATIONS

DSM	Demand side management
DR	Demand response
PSSE	Power system simulation for engineers
RBTS	Roy Blinton Test System
ISO	Independent system operator
RTO	Regional Transmission Operator
KV	Kilo Volt
KW	Kilo Watt
IBDR	Incentive based DR.
PBDR	Price based DR.
PEM	Price Elasticity matrix
MW	Mega Watt
NEA	Nepal Electricity Authority
Pu	Per-Unit
TOU	Time of use
TOD	Time of day
NLC	Number of load curtailment
EENS	Expected energy not supplied.
IESO	Independent Energy system operator
LMP	Locational marginal price
ADR	After demand response
BDR	Before demand response
IEA	International energy agency
EPRI	Electric power research institute
FERC	Federal energy regulatory commission
DLC	Direct Load Control

CHAPTER ONE: INTRODUCTION

1.1. Background

1.1.1. Definition

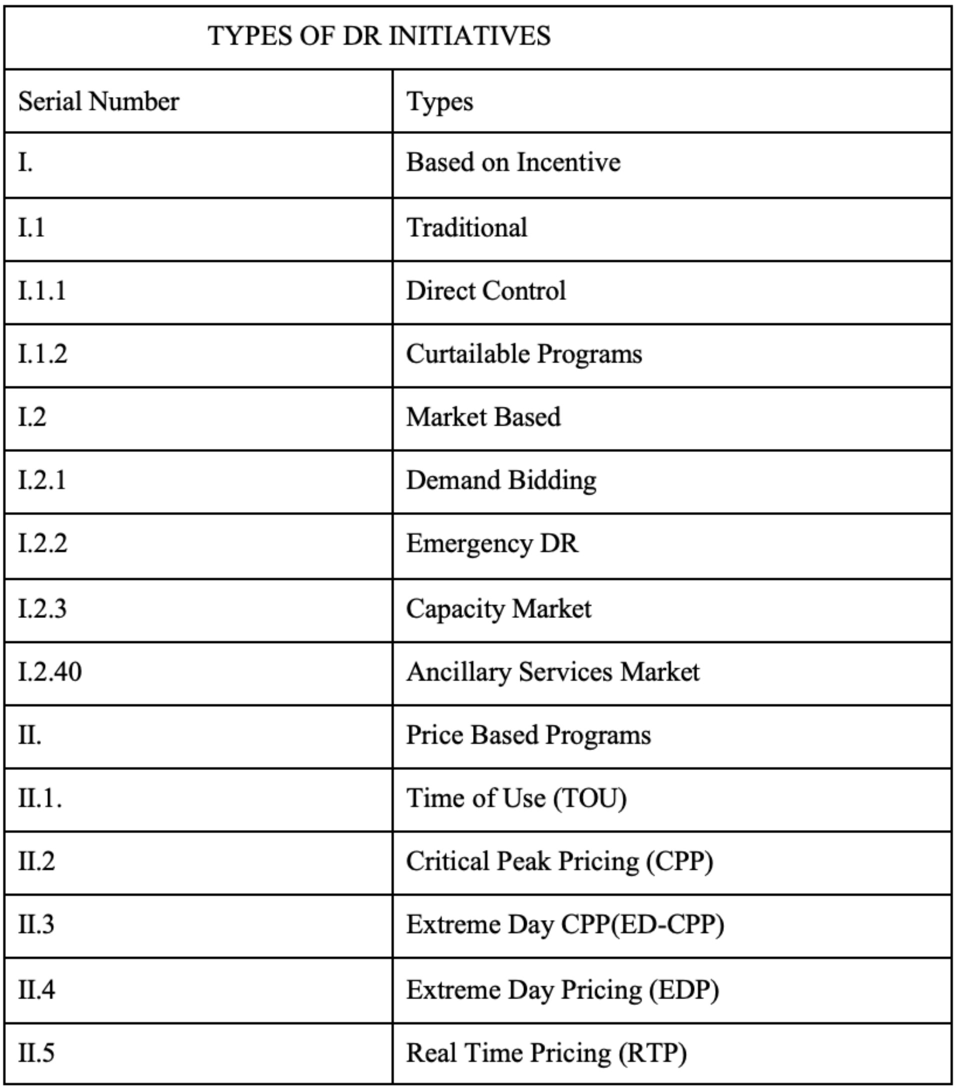
DR, originating from the term "spot price" in the late 1980s, can be defined in two distinct ways: firstly, according to the electricity price variation the end use customers alter their daily consumption pattern of electricity. Secondly, DR refers to motivational remission aimed at reducing electricity consumption during periods of high wholesale market prices or when system reliability is at risk [1]. DR encompasses all deliberate changes to electricity consumption patterns by end-use customers, with the goal of shifting the timing, amount of instantaneous demand, or total electricity consumption.

According to IEA (International Energy Agency), DR involves managing power grid demand by incentivizing customers to shift electricity usage to times when power is more abundant or demand is lower, often through pricing incentives. Alongside smart grids and energy storage, DR plays a crucial role in providing flexibility to cope with the variability of renewable energy sources and the increasing electricity demand from sectors like transportation and home heating in scenarios aiming for Net Zero Emissions by 2050 [2]. As solar PV and wind generation, which depend on weather conditions and time of day, expand, DR can help mitigate their impacts and potentially reduce the necessity for costly new transmission and distribution infrastructure [3]. Advancements in digital technologies enable automated DR through connected devices, tapping into distributed energy resources such as rooftop solar, electric vehicle batteries, and home energy storage systems. However, accelerating policy implementation and technology deployment is crucial to align DR capabilities with the goals of the Net Zero Scenario.

1.1.2. Classification of DR

According to the International Energy Agency's (IEA) strategic plan for the years 2004-2009, the focus on DR analysis and implementation was dedicated to the United States of America. Meanwhile, in 1980s EPRI (Electric Power Research Institute) introduced the term Demand Side Management (DSM). The Federal Energy Regulatory Commission (FERC) reported findings from DR investigations and implementations across US utilities and power markets [4]. In their report, DR is classified into two primary categories and several subgroups, detailed in Table 1.1.

Table 1.1 Classifications of DR Initiatives



TYPES OF DR INITIATIVES	
Serial Number	Types
I.	Based on Incentive
I.1	Traditional
I.1.1	Direct Control
I.1.2	Curtailable Programs
I.2	Market Based
I.2.1	Demand Bidding
I.2.2	Emergency DR
I.2.3	Capacity Market
I.2.40	Ancillary Services Market
II.	Price Based Programs
II.1.	Time of Use (TOU)
II.2	Critical Peak Pricing (CPP)
II.3	Extreme Day CPP(ED-CPP)
II.4	Extreme Day Pricing (EDP)
II.5	Real Time Pricing (RTP)

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 [5]. Participants in Interruptible/Curtailable Programs, as to Direct Load Control programs, receive upfront incentives or rate discounts. These programs require participants to reduce their electricity usage to predefined levels. Failure to comply with program terms and conditions may result in penalties for non-responsive participants [3].

Bidding on Demand, under the market-based DR program are also known as the buyback programs in which customers bids particular reduction of load in the electricity wholesale market. If the bidding price is lower than the market price, then the bidding is agreed, and consumer must curtail their load by the cost as mentioned 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 [6].

Additionally, these DR Programs are available to utilities such that they are committed to providing predefined load deduction during network contingencies caused by various factors such as equipment failures, line outages, generator outages, load changes, natural disasters, cybersecurity incidents, and human errors [1]. Contributors typically receive advance notice of events and may face penalties for failing to reduce their load as requested. Moreover, other initiatives enable utilities to bid their commitment into the spot market as part of operating reserves. If their bids are agreed, participants are compensated with the spot market price for being on standby and receive the spot market energy price if load curtailment is activated [7].

1.1.3. Customer classifications and peak variation

Different types of consumers, such as domestic, commercial, and industrial, have distinct power consumption patterns and peak demand characteristics [8]. Analyzing the percentage of sales attributed to each customer class can provide insights into the overall load profile and help in capacity planning for the power system.

Here's how you can generally relate the peak power of a system to different customer classes based on their percentage of sales:

1. **Domestic/Residential Customers**:

- Residential customers typically have a relatively constant but lower level of electricity consumption throughout the day.
- Their peak demand often occurs in the evening when people return home from work and use appliances and lighting.

2. **Commercial Customers:**

- Commercial customers, such as offices and retail establishments, may have more consistent power consumption throughout the day.
- Their peak demand might coincide with business hours, but it may not be as concentrated as residential peak demand.

3. **Industrial Customers:**

- Industrial customers usually have higher and more variable power demands, often with specific peak periods during production cycles.
- Their peak demand may be influenced by factors such as machinery operation, manufacturing processes, and production schedules.

By understanding the percentage of sales from each customer class, utilities and grid operators can estimate the distribution of peak demand across various times of the day and seasons. This information is essential for strategizing the capacity of power generation and distribution infrastructure to guarantee a dependable and steady electricity supply. It's worth noting that the specific relationship between percentage of sales and peak power may vary based on regional and local factors, economic activities, and technological advancements. Advanced metering and data analytics can also play a role in refining these relationships and optimizing the operation of the power system. As per NEA report [9] the customers classification and their percentage of number with percentage electricity consumption is depicted in the bar -chart below:

Figure 1.1 Customer Classification based on NEA annual report-2023

1.1.4. Composite system Reliability

There is a rising apprehension regarding the reliability of electricity systems under a market-driven approach, particularly in light of the blackouts that occurred in North America and Europe in 2003.Operators of large-scale power systems primarily rely on adjusting the output of electricity generation (increasing or decreasing megawatt outputs) to manage system reliability. These adjustments are crucial to align electricity supply with demand in real-time, ensuring stability and preventing overloads or blackouts. However, the complexity of modern power grids and the variability introduced by renewable energy sources present significant challenges to maintaining this equilibrium [10].

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 dependability of the entire power grid 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 [11]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[12].

1.2. Problem Statement

In an electrical power system, the maintaining the reliable power to all end consumer is very challenging and this challenge is increasing day by day on the introduction of various industries, electrical appliances and with the penetration of new energy resources also. DR programs can mitigate the reliability of electric power system and can enhance its certainty by addressing the customer’s response in accordance with changing electricity price in various time intervals. Instead of establishing the more generating companies with higher investment on infrastructure, there is a need of changing the user pattern of electricity and for implementing the same in real time it is necessary to increase the electricity price during high demand hour and lower the electricity price during off peak hours.

1.3. Objective and scope

The overall objective of this thesis is the implementing the Time of Use (TOU) DR programs in the country which assist on changing the customer behaviors towards the electricity consumption in response to the change in prices and trying to maintain the reliable power system. The sub-objectives are:

- To find the optimal demand in MW for each time interval (of 1 hour) for a day (24 hours) corresponding with the percentage change in electricity price.
- Peak demand shaving along with the consumer bill saving is another main objective of this Thesis.
- To improve the reliability of a composite power system, the focus is on lowering peak electricity demand over a day by employing Time-of-Use (TOU) based DR strategies.

1.4. Outline of Thesis

The thesis is structured into six chapters:

Chapter One provides a concise introduction to the importance and necessity of DR programs for enhancing the power system reliability indices, its classification and implementation of this in major 7 countries of the world, scope and objective of thesis and outline. Additionally, this chapter contains the brief description of composite system reliability and the role of DR programs for evaluating the reliability indices.

Chapter Two presents an overview of the literature review conducted for this thesis. Forecasting of next day demand pattern based on the time of use DR programs and role of price elasticity matrix for finding out the customer behavioral response in accordance with the price changes are also contained.

Chapter Three outlines the methodology employed in this thesis, including a detailed discussion of the approach for parallel operation of MATLAB and PSSE for power flow based on RBTS 6 bus systems.

Chapter Four gives slight overview of MATLAB and PSSE Software Tools used in this thesis. This chapter also includes RBTS 6-bus system data for the 24 hours demand and hourly electricity prices of IESO and 3-time intervals of Time of Day (TOD) energy rate structures in Nepal for the analysis of DR programs possibilities in Nepal.

Chapter Five delves into the findings of this thesis, where the outputs are thoroughly analyzed and discussed.

Chapter Six provides a summary of the thesis and emphasizes its contributions. The thesis concludes with a bibliography and included appendices.

CHAPTER TWO: LITERATURE REVIEW

2.1. DR model considering TOU and EDRP pricing.

DSM is a pivotal strategy essential for maximizing benefits for participants within the electricity marketplace. Authors in [6] examine the changing dynamics within the competitive electricity market, DSM takes on the form of DR. This study focuses on two specific DR programs: Time-Of-Use (TOU) and Emergency DR Program (EDRP). The investigation integrates the modeling of DR, incorporating both TOU and EDRP methods simultaneously. The models used incorporate single and multi-period load models, integrating the concept of load elasticity. This approach is applied specifically to the peak load situation in the Iranian Power Grid, aiming to establish optimal pricing for Time-of-Use (TOU) programs and optimal incentives for a combined TOU and Emergency Demand Response Program (EDRP) strategy.

2.2. Role of market price indices for the Measurement of DR

Authors [13] analyze wholesale DR dynamics in Ontario's electricity market, using detailed data from generators and market levels. They calculate hourly market metrics like the Lerner Index and Residual Supplier Index, integrating them into a Cournot competition model to estimate price elasticity of demand during peak hours across days, seasons, and years. Results show small yet statistically significant price elasticities, varying by time period. For instance, in 2007, elasticity ranges from -0.021 to -0.133, and in 2008, from -0.013 to -0.053. The study considers 2006's extreme weather and 2009's economic crisis and low gas prices, finding higher elasticities during economic downturns. Comparing winter and summer demand hours from 2006 to 2009, they find lower price responsiveness in summer. Using these findings, the study forecasts that modest transmission investments and increased trade could substantially lower market prices. Additionally, the authors discuss applying their methodology to estimate coefficients of PEM for other commodities like gasoline and crude oil.

2.3. A bi-level decision framework for IBDR in distribution systems

In an expanding retail electricity market, DR is increasingly pivotal for enhancing economic and operational efficiency. This study proposes Incentive-Based Demand Response (IBDR), referred to in [14], which introduces a bi-level decision framework involving multiple DR providers (DRPs) within a competitive retail environment. The framework is structured as a multi-leader-multi-follower game, where DRPs act as strategic stakeholders optimizing costs. At the upper level, they optimize the load serving entity's costs collectively, while at the lower level, each DRP, representing aggregated customers, optimizes its individual costs.

The strategic interactions of DRPs are formalized by applying a normal Stackelberg game within a game-theoretic framework. The study validates the consistency of this game through variation inequalities, presenting it as a nonlinear problem that incorporates AC network constraints. To model this multi-layer, multi-follower scenario comprehensively, a linear problem with linear constraints is formulated as a mathematical program, simultaneously solving to most DR Providers. The diagonalization approach is applied as a computational approach. Numerical analyses are detailed, demonstrating the model's applicability and scalability. Testing is practiced on IEEE 33-bus and Distributed Indian-108 bus systems, showcasing the feasibility of the outlined methodology [14].

2.4. DR scheduling by stochastic SCUC

The emergence of advanced communication system for demand-supply system has empowered ISOs to harness marginal offered by DR in ancillary service markets [15]. Presently, numerous system operators have instituted initiatives to effectively deploy DR reserves in electricity markets. This paper introduces a stochastic model designed for the optimal scheduling of DR reserves within wholesale electricity markets. The demand-side reserve is sourced from DR providers (DRPs), entities entrusted with aggregating and overseeing customer responses. The model employs a mixed-integer representation to depict DRP-provided reserves and incorporates an associated cost function. Modeled on making the two steps SMIP approach, the formula addresses for the unit commitment and economic dispatch in the base case during the first stage. As there is a two-stage integer programming model, Subsequently, the

second stage delves into ensuring security assurance under various system scenarios. This model not only schedules reserves supplied by DRPs but also determines the commitment states of generating units, along with their scheduled energy and spinning reserves throughout the scheduling horizon. The proposed approach is empirically validated through application to two test systems, elucidating the tangible advantages of integrating demand-side reserves into electricity markets.

2.5. PSSE-34 version Program Operation Manual (POM)

This manual is useful to do the load flow of 6-bus RBTS system and to create the loss of load report. In the manual [16] provided by PSSE The sub file, .con file and .mon file are useful for the necessary contingency arises and, in this paper, we are evaluating the reliability indices for the maximum no of contingencies before and after the DR implementation.

2.6. Price elasticity matrix of demand in power system considering DR program

Price-based DR influences customer behavior in power consumption by leveraging pricing mechanisms in the power market. Understanding the regular patterns in customer power consumption in response to price changes is crucial for DR research, as it impacts price setting in the power market and the economic outcomes for market entities. Price elasticity of demand, a standard economic measure, assesses how the quantity demanded of a good or service changes in response to price variations. In the context of power consumption, this responsiveness is captured through the Price Elasticity Matrix of Demand (PEMD).

Recent studies [17] have explored applications of PEMD, typically relying on traditional models or empirical coefficients to calculate elasticity values [7], [18]. However, these approaches often overlook the structural and characteristic variations within PEMD across different price policies and types of electricity loads. This oversight can introduce forecasting errors in power consumption predictions using traditional models. To address these challenges, the authors propose a modified PEMD framework. This framework aims to enhance the accuracy of demand forecasting under DR programs by capturing the nuanced relationships between price policies, load types, and consumer responses. By refining the understanding of PEMD's structure and characteristics, the study contributes to more reliable predictions of power consumption patterns in dynamic market environments.

2.7. DR Implementation across the Globe

The way DR is implemented depends on factors like facility type, energy consumption methods, and policies landscapes in different areas. The idea and early deployments of DR date back to the early 20th century, evolving with increased organization and structure over the years [19]. Table 3 details the adoption of DR programs by various utilities and demand service providers across different countries. The USA saw the pioneer organized DR initiatives introduced by various regions and utilities.

2.7.1. DR Implementation in the USA

Nine ISOs are available in North America, out of which five function as RTOs, collectively managing networks that serve nearly 66% of U.S. customers and more than half of the Canadian consumers. During the period the variations among the ISOs and RTOs in the U.S. have blurred significantly. such entities offer same services for transmission line under unified tariffs and rates, alongside operating energy markets within their respective regions [20]. Popular ISOs/RTOs include PJM, CAISO, ERCOT, MISO, NYISO, ISO-NE and SPP, all pivotal in implementing wholesale DR programs across the USA.

In fiscal year 2020, DLA Energy oversaw 46 installations participating in DR programs across 11 states and the District of Columbia, all within organized wholesale markets, with 93 MW of DR capacity enrolled. These incentive-driven programs are predominantly market-based and operate in both retail and wholesale sectors [2]. DLA Energy reported savings exceeding $2.7 million for FY 2020, accumulating to over $39 million since 2008 [5]. PJM and New England have developed market frameworks that successfully integrate DR into their capacity markets, enabling DR resources to compete effectively with generation. Similarly, the Midwest and New York regions have seen substantial DR participation in their capacity programs, demonstrating reliable performance and making significant contributions to system resource adequacy goals [21].

2.7.2. a PJM (Pennsylvania-New Jersey-Maryland) Interconnection

PJM (Pennsylvania-New Jersey-Maryland) Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of 13 states (Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia) in the Mid-Atlantic and Midwest regions. In 1997, it started its first market, a cost- based energy market and later in 2000 it launched its ancillary service market and a day ahead energ market [22]. The major objectives of such programs are shifting the load from peak hours to off peak hours. $1000 is the default Energy Offer Cap for both Economic and Emergency Energy Only registrations and beyond that incremental cost validation occurs. Retail end-use customers gain access to PJM's wholesale electricity market through agents who are members of PJM, called as Curtailment Service Providers (CSPs). Some of the major CSPs include AEP Energy Partners, Inc. and Boston Energy

Trading and Marketing, LLC.PJM has developed and operates various DR programs to help manage grid reliability and efficiency. Some of the key DR programs offered by PJM include:

Emergency Load Response Program (ELRP): The ELRP is designed for customers who can quickly curtail their electricity usage during system emergencies or severe weather events. Participants receive compensation for their willingness to reduce their load on short notice when called upon by PJM.

Economic Load Response Program (ELR): The ELR program allows participants to respond to price signals by voluntarily reducing their electricity consumption during high-demand periods when prices are elevated. Participants are compensated based on their ability to reduce load during these times.

Capacity Performance Program: This program aims to ensure grid reliability during periods of peak demand. DR providers commit to reducing load when required, primarily during capacity emergencies. In return, they receive payments for their capacity availability.

Base Residual Auction (BRA): PJM's BRA is an annual auction in which DR providers can offer their resources to the market. Successful bidders receive capacity payments in exchange for their commitment to reduce load or provide generation during peak demand periods.

Demand Side Ancillary Services Program (DSASP): This program allows DR providers to participate in the provision of ancillary services, such as frequency regulation and spinning reserves, to support grid stability.

Real-Time DR: PJM operates a real-time DR program that allows participants to respond to dispatch signals in real-time to curtail electricity consumption. This can be done manually or through automated systems.

Emergency Load Response Program for Price-Responsive Demand (ELRP-PRD): ELRP-PRD is designed for price-responsive demand resources. Participants agree to curtail load when market prices reach specific triggers during critical periods. Automated DR (ADR): ADR programs use automated systems, such as building management systems and smart meters, to respond to dispatch signals automatically. These systems can curtail electricity usage without direct customer intervention.

PJM's DR programs play a crucial role in maintaining grid reliability, managing electricity supply and demand, and ensuring efficient grid operation in its service region. These programs provide opportunities for various types of customers, including residential, commercial, and industrial, to participate in DR and contribute to the stability of the electrical grid. Program details and eligibility criteria may vary, so customers interested in participating should check with PJM or their local utility for specific information.

2.7.3. New York Independent System Operator (NYISO)

NYISO is responsible for managing the high-voltage electricity grid and wholesale electricity markets in the state of New York. NYISO has several DR programs in place to support grid reliability, reduce electricity costs, and enhance system efficiency [23]. Here are some of the key DR programs offered by NYISO:

The NYISO introduced the Demand-Side Ancillary Services Program (DSASP) in 2008 as a new Fast DR initiative in response to directives from the Federal Energy Regulatory Commission (FERC) in the USA [24]. From 2018 to 2019, potential peak demand savings in the United States saw an increase of approximately 125 MW, or 0.4%, rising from 30,895 MW to around 31,020 MW. This growth in savings was achieved through the implementation of retail DR programs, where "potential peak demand savings" refers to "the total amount of demand reduction possible during the system's peak hour assuming all DR measures are activated" [25].

Installed Capacity (ICAP) DR Program: The ICAP program allows DR resources to engage in capacity markets. Participants commit to reducing their electricity usage during peak periods or emergencies and receive capacity payments in return. This program helps ensure there is enough capacity to meet the state's electricity demand.

Day-Ahead DR Program (DADRP): DADRP is a voluntary program that allows DR providers to submit offers to reduce electricity consumption for the next day based on their availability. Participants receive compensation for their commitments.

Real-Time Emergency DR Program (RTEDRP): RTEDRP is designed for DR providers that can curtail their load on short notice during system emergencies or periods of high demand. Participants receive compensation based on their capacity to react to real-time dispatch signals.

By implementing the EDRP program in the New York power market in 2005, significant results were achieved, showing reductions in both price and peak demand. The ISO successfully normalized prices by estimating the load curve of July 29th and executing the EDRP and CAP programs [6].

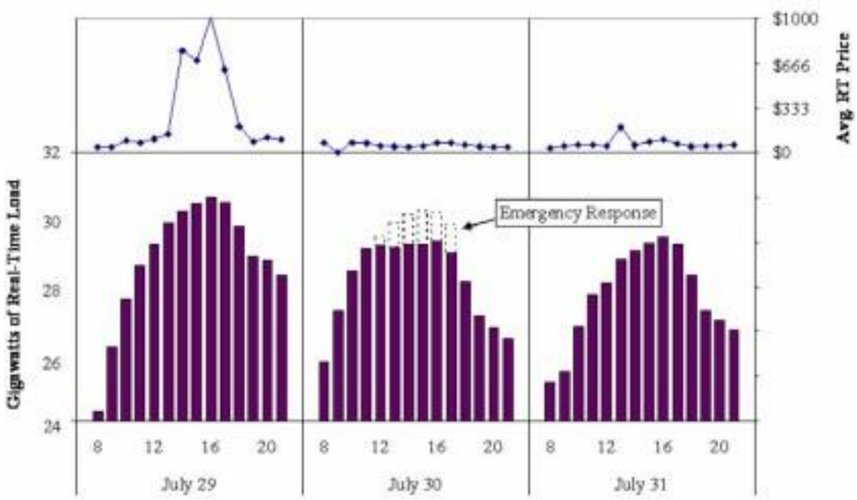


Figure 2.1: EDRP and CAP implementation in New York market in 2005

DR Auction Mechanism (DRAM): DRAM is a market mechanism that allows DR providers to submit offers to reduce load during times of high demand. The NYISO conducts auctions, and successful participants receive payments for their curtailment commitments.

Economic Load Response (ELR): The ELR program allows participants to respond to market signals, such as real-time electricity prices, by voluntarily reducing their electricity consumption during high-demand periods. Participants receive compensation for their contributions.

Special Case Resources (SCR): The SCR program is for DR resources that do not fit into the standard DR categories. It provides flexibility for unique and specialized resources to participate in the NYISO's programs.

These NYISO DR programs encourage a wide range of customers, including commercial, industrial, and residential consumers, to participate in managing their electricity usage to support grid reliability and efficiency. By participating in these programs, customers can help reduce peak demand, lower electricity costs, and contribute to a more stable and resilient electrical grid in the state of New York.

2.7.4. California Independent System Operator (CAISO)

CAISO is responsible for managing the high-voltage electricity grid and wholesale electricity markets in the state of California. CAISO has several DR programs and initiatives to support grid reliability, manage electricity supply and demand, and facilitate the integration of clean energy resources [26]. Major DR programs and mechanisms offered by CAISO include:

DR Auction Mechanism (DRAM): DRAM is a market mechanism that allows DR providers to submit offers to reduce load during times of high demand. The DRAM is part of CAISO's Energy Imbalance Market (EIM), which extends beyond California's borders, allowing participants from neighboring regions to participate in DR.

Proxy Demand Resources (PDR): PDRs are DR resources that can be scheduled in real-time to provide energy and ancillary services. These resources can be used to help balance the grid and support grid reliability during periods of high demand or when supply is constrained.

DR Enhancement (DRE) Proposal: CAISO introduced a DRE proposal to enhance DR in the California market by improving the compensation and participation opportunities for DR resources.

Flexible Capacity (Flexi Ramp) Program: The Flexi Ramp program aims to enhance the grid's operational flexibility by encouraging market participants to provide upward or downward ramping capability to respond to changing grid conditions, including accommodating intermittent renewable energy resources.

Day-Ahead DR Program (DADRP): DADRP is a voluntary program that allows DR providers to submit offers to reduce electricity consumption for the next day based on their availability. Participants receive compensation for their commitments.

Resource Sufficiency Program (RSP): RSP is designed to ensure that there is enough generation and DR capacity available to meet the state's electricity needs during periods of high demand. It helps maintain grid reliability by addressing capacity shortfalls.

Capacity Bidding Program (CBP): The CBP is part of CAISO's capacity market, which allows capacity providers, including DR resources, to submit offers for capacity resources. Participants receive capacity payments for their availability. These CAISO DR programs are designed to provide opportunities for various types of DR resources, including residential, commercial, and industrial consumers, to participate in grid management and contribute to the stability and reliability of the electrical grid in California. The specific program details, eligibility criteria, and participation mechanisms may evolve over time, so it's advisable to refer to CAISO's official website or contact the organization for the most up-to-date information on DR programs in California.

2.7.5. Midcontinent Independent System Operator (MISO)

MISO, a non-profit and independent organization, focuses on three main tasks:

1. Managing Electricity Flow: MISO oversees the transmission of high voltage electricity across 15 U.S. states and the Manitoba province of Canada.
2. Facilitating Energy Markets: It operates one of the largest energy markets globally, facilitating transactions exceeding $40 billion annually.
3. Grid Planning: MISO plays a crucial role in planning the future grid infrastructure.

MISO has introduced the DR Tool (DRT), an application system designed for registering and evaluating Demand Response Resources (DRRs). This includes managing physical location registrations, tracking Ancillary Services events, monitoring Energy Market dispatch information, and evaluating resource performance. The DRT also handles approvals from Local Balancing Authorities (LBAs) and Load Serving Entities (LSEs).

MISO has implemented Emergency Demand Response (EDR) programs across most regions. Under these programs, if the total payments made for EDR Initiatives in an hour exceed market revenues, the additional funds required are recovered through debits on Market Participants, proportionally depend on their Metered Load Ratio shared in the local Authority Area(s) affected by the emergency event.

Rodan manages energy within the MISO region served by Ameren Power Company in Illinois. While MISO offers DR programs such as Operating Reserves and Planning Resources that incentivize participants to reduce consumption during stressed grid conditions, these programs do not address demand charges. Demand charges are based on the highest hourly consumption each month on the Ameren system. This can significantly lower monthly electricity costs for facilities.ISO New England

This ISO launched its real-time DR program in 2005, mandating customers to enact energy reductions promptly upon receiving notice from the ISO [28]. New England, situated in the northeastern United States, encompasses six distinct states.

According to the Demand Reduction Threshold Price Detail Report, ISO New England offers prices ranging from $35/MWh to $92/MWh for load curtailment, with the curtailed load ranging from 11,050 MW to 18,850 MW [28]. This framework incentivizes participants to reduce their energy consumption during periods of high demand or system stress, contributing to the overall reliability and efficiency of the electricity grid in the New England region.

2.7.6. Electric Reliability Council of Texas (ERCOT)

ERCOT is a prominent American organization overseeing the operation of Texas's electrical grid, specifically the Texas Interconnection. This grid serves over 25 million customers in Texas, exemplifying nearly 90 percent of the province’s electric load [29]. DR plays a vital role in contributing valuable reliability and economic services to the ERCOT market. By preserving system reliability, fostering competition, mitigating price spikes, and encouraging a more responsive demand side, DR enhances the overall efficiency and stability of the market. In collaboration with market participants, ERCOT has developed various DR products and services designed for customers capable of adjusting or reducing their electricity usage in response to instructions or signals. Loads have the option to directly offer into the ERCOT markets or indirectly participate by voluntarily modifying their energy consumption based on wholesale electricity prices.

The Emergency Response Service, a facet of ERCOT's initiatives, is now open to participation by specific generators. According to [30], ERCOT has established and adopted seven baseline types for use in DR measurement and verification. These baseline types, referred to as "default baseline types" within ERCOT's administration of the Emergency Response Service (ERS), may also be eligible for use in administering DR participation in other services. This structured approach ensures transparency and consistency in measuring and verifying the impact of DR initiatives, contributing to the effective management of the grid and its services.

2.8. DR Implementation in the Canada

IESO in Canada established its wholesale electricity market in 2002. However, it wasn't until December 2015 that the organization launched its inaugural Demand Response Auction (DRA) through which participants could bid in the price range of 1000 CAD/MWh to 1999.99 CAD/MWh [31].

In Ontario, Canada, the IESO introduced an incentive-based DR program known as the Industrial Conservation Initiative (ICI). This program is tailored for medium and large-sized businesses and facilities. Under ICI, participating customers are incentivized for adjusting their energy consumption patterns to shift away from high- demand periods. By doing so, Ontario's ICI participants collectively have the potential to reduce their electricity demand by as much as 1,500 MW. Given the variation in electricity demand throughout the day, these initiatives contribute to a more adaptive and reliable electricity supply, ensuring that different forms of supply can be deployed strategically to meet the diverse requirements of the grid [31]

IESO categorized the DR resources as:

a) **Dispatchable Load** – Dispatchable loads are such DR resources which can be available/respond on or before the 5 minutes of dispatch instruction and whose demand is planned based on the price of electrical energy [32]. These participants may offer one or all 3 types of operating reserve such as 10 minutes synchronized (spinning reserve),10 minutes non-synchronized reserve(non-spinning) and 30 minutes reserve(non-synchronized) [33].

b) **Hourly DR** – The hourly DR resources schedule is not pre-defined and are not dispatched as per IESO but these resources need to be registered in IESO participant market [34].

Since 2002, dispatchable loads have actively engaged in the IESO electricity power market by submitting bids and being deliverable on a one twelfth hour criteria. The DR Auction (DRA) is held annually as a competitive process where participants compete for DR capacity obligations over two seasonal commitment periods. Successful participants receive incentives for providing capacity in the power market, whether as Deliverable Loads or Hourly DR (HDR) resources. The IESO's auction rules allow DR bids within a price range of $100.00/MWh to $1999.99/MWh.

Compensation models for DR participation vary widely across jurisdictions, especially regarding how payments are structured for dispatch. These models range from no compensation beyond avoided costs (as observed in Alberta) to methods such as payment depend upon Locational Marginal Prices subtract the generation component of the retail cost (LMP minus G, the former U.S. model), full LMP payment contingent upon passing a profits test (current U.S. model), cost sharing with customers (Singapore), and a wholesale purchase and buyback model (as planned in Australia). Each approach is justified economically, though some are perceived as more persuasive than others.

Australia's purchase and buyback model and the former United States model of differences between LMP and are acknowledged for their efficient economic signals and practical value in promoting DR development. However, in many markets, there has been a predominant focus on the value of DR through curtailment, often overlooking how to incentivize increased consumption during periods of low or negative pricing. This issue is particularly relevant in the Ontario market, where surplus base load generation (SBG) events and negative pricing occur frequently. Enhancing incentives during low- and negative-priced hours could enable the IESO to effectively utilize the expected rise in electric vehicle integration to enhance efficiency.

Similarly, In Saskatchewan province of Canada, for the reliable power supply to the end consumers' three major utilities are actively working such as Saskatoon L&P is a utility operated as part of the city administration. They provide electrical service inside the Circle Drive boundary for the City of Saskatoon. Residents and businesses outside Circle Drive are serviced by SaskPower. The utility purchases power from SaskPower but owns and maintains the distribution network. Saskatoon L&P also owns and maintains the City's streetlights. With the implementation of DR programs, especially during peak power demand periods, SaskPower aims to ensure that consumers receive the necessary power supply. The DR Program plays a crucial role in mitigating the strain on SaskPower's system by incentivizing larger industrial customers to either reduce or shift their power consumption. This proactive approach not only helps balance demand and supply but also proves to be a cost-effective alternative compared to the construction of additional power stations. By leveraging DR strategies, SaskPower enhances system reliability, manages peak demand effectively, and optimizes the utilization of existing infrastructure. When the demand on the electric power system is high, Saskpower will rely on such DR programs and hence can motivate the participant to lower or shift their demand with providing the compensation on doing so.

Eligibility:

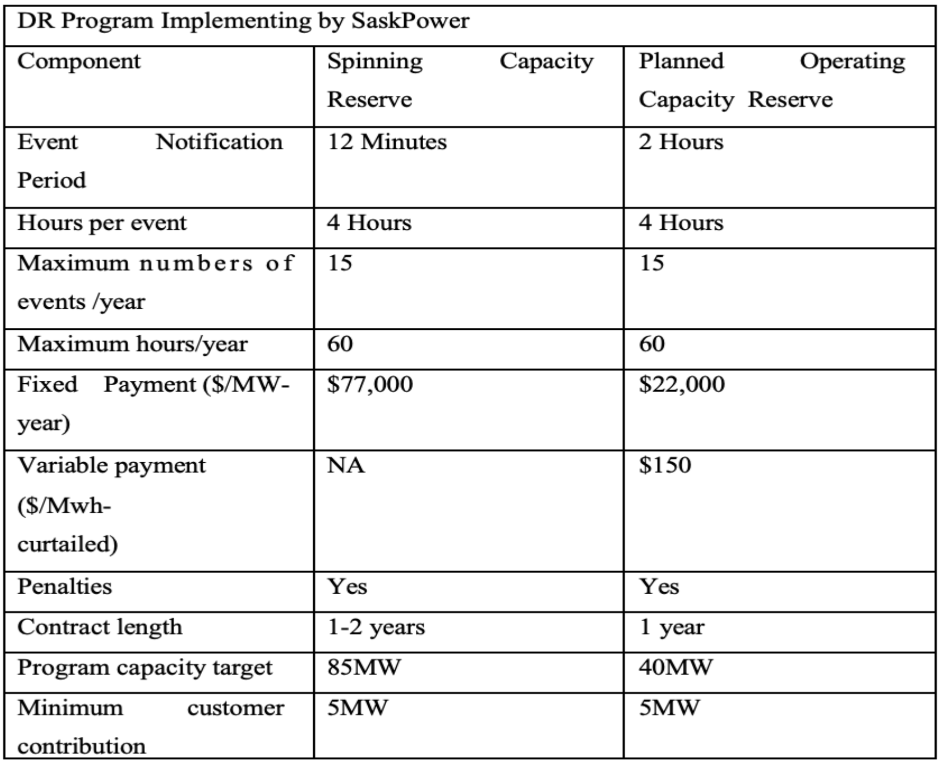
- Should be an Industrial type consumer and of the largest.
- Should have load characteristics and is of consistent.
- The participant should be able to curtail minimum of 5MW at a time from the single point.

How to Participate:

- Should meet the criteria mentioned in the table below.
- Those who meet the criteria should contact the manager of Saskpower.
- Saskpower will access the participants' application operation once they meet

the cited mentioned criteria.

Table 2.1 IBDR program by SaskPower, Saskatoon



DR Program Implementing by SaskPower		
Component	Spinning Capacity Reserve	Planned Operating Capacity Reserve
Event Notification Period	12 Minutes	2 Hours
Hours per event	4 Hours	4 Hours
Maximum numbers of events /year	15	15
Maximum hours/year	60	60
Fixed Payment ($/MW-year)	$77,000	$22,000
Variable payment ($/Mwh-curtailed)	NA	$150
Penalties	Yes	Yes
Contract length	1-2 years	1 year
Program capacity target	85MW	40MW
Minimum customer contribution	5MW	5MW

SaskPower is a power generation and distribution company owned by the Province of Saskatchewan as a crown corporation. They operate a variety of power generating stations including coal plants, hydro plants, and wind turbines. SaskPower has a monopoly on electrical power utilities in Saskatchewan with the only exceptions being Saskatoon Light & Power (for a portion of Saskatoon) and the City of Swift Current. SaskPower launched a capacity market type DR program in 2023 in which the participant should be a large industrial customer who can able to reduce the power by 5MW from a single location and for minimum of 4 hours. The spinning capacity reserve will receive fixed payment of 77,000CAD per year as participating in this program and planned capacity operating reserve will receive 22,000CAD per year and due to which the big industrial customer also gets benefited and there will be reliable power supply during peak hours also [35].

The IESO procures four ancillary services in the electricity sector and the brief explanation of each are as follows:

Certified Black Start Facilities: These services play a vital role in enhancing system reliability by having the ability to restart their generation facilities independently after a blackout. At the time of a widespread blackout, these services are essential for the restoration process. They are tasked with re-energizing other parts of the power system, thereby supporting systematic recovery and facilitating a faster and more efficient restoration process.

Regulation Service: Regulation service, also known as frequency regulation, plays a critical role in aligning total system generation with total system load, which includes accounting for transmission losses. Its primary role is to maintain power system frequency stability by addressing short-term fluctuations in electricity usage. This service is crucial for ensuring the reliability of the power network. Currently, regulation services are provided by generation facilities equipped with Automatic Generation Control (AGC) capability. These facilities adjust their output based on signals from the utilities.

The utilities consistently plan a minimum of ±100 MW of regulation assist to stabilize the power grid. Similar to other regions in North America, the IESO in Ontario is closely controlling several factors influencing the expansion of the regulation service market. These factors include uncertainties in weather forecasts affecting changeable generation, the independent behavior of embedded distributed energy resources (such as controllable loads, embedded generation, and storage) not under IESO dispatch control, and the non-linear demand patterns between 5-minute dispatch intervals. The objective is to adapt and improve the regulation service market to meet these evolving challenges and maintain power system reliability.

Reactive Assistant with Voltage control Service: The IESO mandates Reactive assistant and Voltage Control (RAVC) services to balance adequate levels of phantom power and voltage stability throughout the network. In electricity distribution, both real power (used for tasks like lighting and motor operation) and reactive power are essential for meeting load demands. Reactive power facilitates the transmission of active power from generators to end-users within the transmission and distribution system. However, due to its localized nature, providing reactive power over long distances is impractical. All generation companies injecting energy into the IESO-monitored grid must adhere to market regulations by offering a specified level of RSVC service. Additionally, the IESO may contract with specific facilities to provide supplementary RSVC beyond mandatory requirements, addressing specific system needs. These contracted facilities can operate in either speed-no-load or condense mode. In speed-no-load operation, a generation unit remains operational at synched rotational speed with its breaker in but with minimal current. In condense mode, units function as synchronous condensers, capable of generating or absorbing reactive power as necessary to stabilize voltage levels.

Reliability Must-Run: RMR contracts play a pivotal role in ensuring the reliability of the IESO-controlled grid. These contracts empower the IESO to enlist the counterparty's assistance in electricity production whenever necessary to uphold the system's reliability. Market participants entering into RMR contracts commit to supplying a particular operating reserve or fixed amount of energy into the IESO-administered markets in a commercially sound way and in adherence to designated specific standards.

The inception of the DRA by the IESO in December 2015 marked a significant step towards enhancing grid flexibility, with approximately 391 MW secured for the summer of 2016. Subsequently, the volume procured through DRA has gradually risen, reaching a sum of 810 MW for the winter of 2019/2020. Despite this growth, the activation of DR resources has historically been infrequent. Dispatchable Loads, since the program's initiation in 2016, have been dispatched less than 1% of the time, and

Hourly DR resources were activated for only 3 hours in total.

The IESO's short-term capacity forecast suggests that the activation of economic DR will probably continue to be occasional in the coming years. Moving ahead, the utilities plan to broaden Demand Response Auction (DRA) into a high extensive capacity auction. This initiative aims to promote equitable competition among different technologies, including DR.
Some important points that are implementing in the DR program in Canada by IESO are as follows:

- Energy market payments for DR activations have the potential to boost DR participation, offering a cost-effective alternative to relying on more expensive generation resources, such as the construction of new peaking generation capacity.

- Recognizing that generation resources receive payments for producing electricity, a form of energy market payment, it is imperative that DR resources receive consistent treatment when they curtail consumption. This ensures a fair and equitable compensation framework across different contributors to the energy market.

- Recognizing that generation resources receive payments for producing electricity, a form of energy market payment, it is imperative that DR resources receive consistent treatment when they curtail consumption. This ensures a fair and equitable compensation framework across different contributors to the energy market.

- Retail prices, which are protected from changes in wholesale market prices, do not accurately represent real-time market conditions or the genuine cost of electricity. Customers enrolled in regulated pricing plans, shielded from these wholesale market signals, may not be encouraged to adopt more efficient energy consumption habits.

- Despite objections to energy market payments for activations, the wholesale market is considered efficient. Cost sensitive loads can assess whether it is more economical to operate or curtail based on current market price signals.

- Concerns arise regarding potential overcompensation of DR in energy market payments, as DR does not incur costs associated with electricity production. Achieving a fair balance in compensation mechanisms is crucial to uphold market integrity.

- There is a cautionary concern that energy market payments may lead to an inefficient level of DR participation, possibly depressing wholesale energy prices. This could impact the profitability of other supply resources in the market. Balancing incentives and maintaining market equilibrium is essential for the effective operation of the energy market.

- Curtailments of loads may result in economic losses, and the Value of Lost Load (VOLL) must be carefully weighed with respect to the price of producing a kilowatt (KW) of electricity for a load. Balancing these factors is crucial for making informed decisions in the energy market

DR participants respond to economic incentives within a program, adjusting their consumption based on market price and dispatch signals driven by their individual costs for load shedding. The marginal incentive for customers to react must align with the network's marginal cost. For a popular structured DR program, efficient curtailments mitigate overall network efficiency and lower costs by substituting maximum value generation or mitigating expensive reliability events by the reduction of less critical loads.

During periods of high demand, such as hot summer days, the electricity system may rely on expensive sources, leading to increased wholesale prices. DR participants can be activated to lower their energy consumption, thereby easing demand pressure on the system. During a DR event, contributors reduce their energy consumption relative to their baseline, enhancing the resilience and efficiency of the electricity grid.

The IESO introduced the Market Renewal Program (MRP) in 2016 to enhance market effectiveness. The program aims to achieve this by implementing competitive mechanisms that address both system requirements and participant needs while minimizing costs. The MRP is a comprehensive initiative intended to improve the functionality and efficiency of the electricity market, aligning with broader efforts to optimize the energy sector for enhanced performance and cost-effectiveness. Effective management of operating reserves is crucial for grid operations, with grid operators utilizing advanced forecasting, monitoring, and control systems to optimize the reliability of the power system.

2.9. DR Development in the Australia

DR programs in Australian utilities are designed to help manage electricity demand, improve grid reliability, and provide customers with opportunities to reduce their energy costs. DR programs in Australia vary in availability and structure across different states and territories, typically organized by private electricity retailers, distribution network firms, and occasionally by government companies.

In Australia, the ARENA (Australian Renewable Energy Agency) DR trial operates on a direct concept. Rather on investing substantial funds in expanding power network capacity, ARENA compensates consumers—through energy retailers—with a lesser amount for actively reducing energy consumption [13]. Additionally, under the new Technical Regulator Guideline, South Australia is enforcing the mandate that specific air conditioners installed after July 1, 2023, must be DR ready.

The various forms of DR programs implementing in Australia by main ISO/RTOs are as follows:

Peak Event DR: These programs involve notifying customers in advance of predicted peak demand periods or grid stress events. Customers are encouraged to voluntarily reduce their electricity consumption during these times to help alleviate strain on the grid. In some cases, they may receive incentives or bill credits.

Critical Peak Pricing (CPP): Under this pricing scheme, electricity retailers charge higher rates during critical peak periods when demand is exceptionally high. Customers are encouraged to shift their electricity usage to off-peak hours to avoid higher costs.

Time-of-Use (TOU) Pricing: TOU pricing plans offer customers different electricity rates based on the time of day. Customers can benefit from lower rates during off- peak hours and are encouraged to reduce usage during peak periods when rates are higher.

Capacity Contracts: Some large commercial and industrial customers may enter into capacity contracts with their electricity retailers or grid operators. These contracts involve commitments to reduce electricity consumption during peak periods, and customers may receive financial incentives or reduced demand charges.

Emergency DR: In the event of an electricity supply emergency or grid instability, electricity authorities or retailers can call on customers to reduce their electricity usage immediately. This can involve temporary load shedding.

Distributed Energy Resources (DER) Programs: These programs promote the use of distributed energy resources, such as solar panels and battery storage, to participate in DR by reducing grid demand or providing grid support services.

Government-Backed Initiatives: Some states and territories in Australia have government-funded DR programs and incentives aimed at promoting energy efficiency and grid reliability. These programs may include grants, subsidies, or rebates for energy-efficient technologies and demand management solutions.

DR Aggregators: DR aggregators in Australia work with a group of customers to coordinate and participate in DR events. These aggregators help streamline the process and provide customers with compensation for their participation.

The structure and availability of these programs can vary by region and utility, and participation often depends on factors such as the type of customer (residential, commercial, industrial), location, and the specific utility or retailer. To take advantage of DR programs in Australia, customers should contact their electricity provider or check with relevant state and territory energy agencies for information on available programs and eligibility criteria. Additionally, the Australian Energy Market Operator (AEMO) plays a role in facilitating DR in the National Electricity Market (NEM) and provides guidance on DR opportunities.

2.10. DR Introduction in the South Korea

In South Korea, two types of DR program implemented by the Korea Electric Power Company (KEPCO) from 2000 such as one is Day-ahead (DA) market and the other is Hour-ahead (HA) market where Customers with the capability to curtail their loads by more than 300 kW are eligible to participate in the DR market [12]. In December 2022, Korea introduced a groundbreaking pilot program for Automated Demand Response (Auto DR). This innovative initiative involves intelligent appliances autonomously responding to demand reduction requests, eliminating the need for manual entries by consumers. The outcome of this program has been noteworthy, demonstrating a remarkable 24% improvement in electricity savings.

Table 2.2 Initiatives of DR types in across the Globe

S. No.	Implementation of DR Programs		
1	USA	NYISO,2008	Demand side Ancillary service programs (DSASP), EDRP
		PJM	Day-ahead scheduling reserve market (DASR) [7]
		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

2.11. DR Initiation and progress in the Japan

DR programs were first introduced in 2012 with the launch of smart house and building standardization initiatives, alongside the establishment of a business study committee. These programs utilize an ADR server to offer services such as reducing charges by utilizing renewable energy sources, minimizing curtailment, avoiding imbalance, and balancing P.Q.KW, all depend on the flow of current and communication between resource aggregators. The lowest demand requirement for bidding is 5MW, whereas no maximum criteria below the power market-based demand bidding scheme.

2.12. DR Progress and possibilities in the China

While presently restricted in power market of China, DR is increasingly recognized within China's energy strategy and ongoing electricity reform initiatives. Since 2014, cities such as Beijing and Shanghai, along with other pilot cities for Demand-Side Management (DSM), have been actively experimenting with DR projects. Available data suggests that DR is set for significant growth and advancement in China, indicating a potential expansion of its importance and impact in the country's evolving energy sector [9].

Nonetheless, the current DR market in China faces several obstacles. Grid companies exhibit low participation rates, with closely guarded grid operation data. The absence of public channels exacerbates the challenge. Non-grid companies encounter hurdles in providing DR due to insufficient data for economic operation analysis. Users, lacking real-time electricity usage data analysis, find it challenging to foster enthusiasm for DR participation. Overcoming these barriers is crucial for the broader adoption and success of DR initiatives in the Chinese energy market.

Currently, China Energy Storage Alliance (CNESA) is spearheading the development of a DR management platform. This platform aims to facilitate the organized participation of user groups in DR within the NDRC's pilot projects, subject to specific conditions. CNESA aspires to contribute to the ongoing enhancement of related policies through collaborative efforts and coordination among various stakeholders, thereby creating additional opportunities for the development of energy storage solutions.

Notably, the invitation mode and real-time mode have seen increased application in recent years across various provinces in China, showcasing regional variations in their utilization. In the invitation mode, the initiation of a DR event is undertaken by the local government, aiming to adjust a predefined level of load at a specific time. This mode extends invitations to diverse types of load resources on the demand side, encouraging their participation in the event.

In the real-time mode, grid companies take the lead in initiating DR events and issuing instructions through the local DR platform (also called as Virtual Power Plant (VPP) platform in some regions, such as Guangdong).

2.13. DR emerging involvement in the United Kingdom (U.K.)

The DR program in the UK is introducing with the emergence of two main types: the capacity market and network balancing services provided by utilities such as the National Grid and other ISOs. When participating privately without external technological, engineering, or market expertise, participants need to have 2MW of flexibility to connect the capacity market or 1MW for involvement in frequency response and other balancing services. However, when participating as part of an aggregated portfolio, which is as usual when working with a Demand Side Response (DSR) provider, the threshold is typically lowered to around 200kW, or even reduce in some cases [19].

In October 2022, the European Union endorsed an action plan aimed at digitalizing the energy system, with a focus on facilitating data access for DR. The plan outlines specific requirements and procedures, such as the mandatory installation of solar photovoltaic (PV) panels on the roofs of all commercial and public buildings by 2027, extending to all new residential buildings by 2029. Additionally, the initiative aims to deploy 10 million heat pumps within the next 5 years and replace 30 million conventional cars with zero-emission vehicles on the road by 2030. Achieving the ambitious targets of a 55% reduction in greenhouse gas emissions and a 45% share of renewables in the energy mix by 2030 hinges on the preparedness of the energy system to accommodate these changes [36].

2.14. DR In SAARC (South Asian Association for Regional Cooperation) Countries

However, DR practiced started from 1980s, there is still delaying in SAARC countries and the main reason for this is DR cons for the difficulty on understanding the customer behaviors. It is very cumbersome to change the inelastic nature of consumer to elastic one and in the countries like Nepal, Bhutan, Pakistan and Afghanistan the awareness among the people is also very low during that decade because of less implementation of internet. In Maldives, Sri Lanka and Bangladesh partial DR is implemented but in the name of DSM and there is no specific distinguishing between DSM and DR.

CHAPTER THREE: METHODOLOGY

3.1. DR Methodology Approach

The overall approach of this thesis 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. Some papers [6] generalized that 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:

1. Identification of the pricing methods such as real time pricing (RTP), Time of use (TOU) pricing, CPP (Critical peak pricing) method.
2. Collection of electricity price data and demand data for the particular system area.
3. Modeling of the price elasticity matrix for the calculation of new demand pattern.
4. Finding the new peak from the newly demand array and with the help of such maximum demand value, reliability evaluation is carried out.
5. Performing load flow the reference 6-bus RBTS with the new load data and once the power flow success furnishes the load loss report for the various contingencies.
6. Performing techno-economic comparison of both before and after DR implementation.
7. Drawing the conclusions and recommendations.

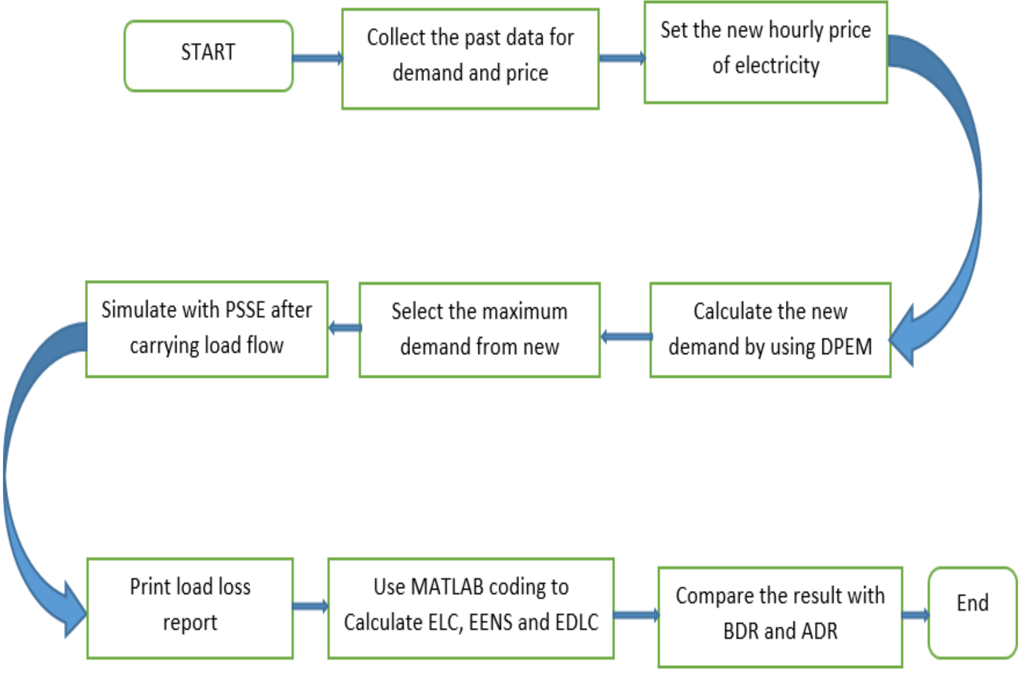


Figure 3.:3.1 Flowchart showing methodology of thesis

3.2. Pre-requisites for analysis

For the evaluation of reliability indices of bulk power system (HLI and HLII), the necessary test system is chosen and for this thesis 6-bus RBTS test system is selected and the single diagram of the same is constructed by using PSSE software as in the figure 3.2 .

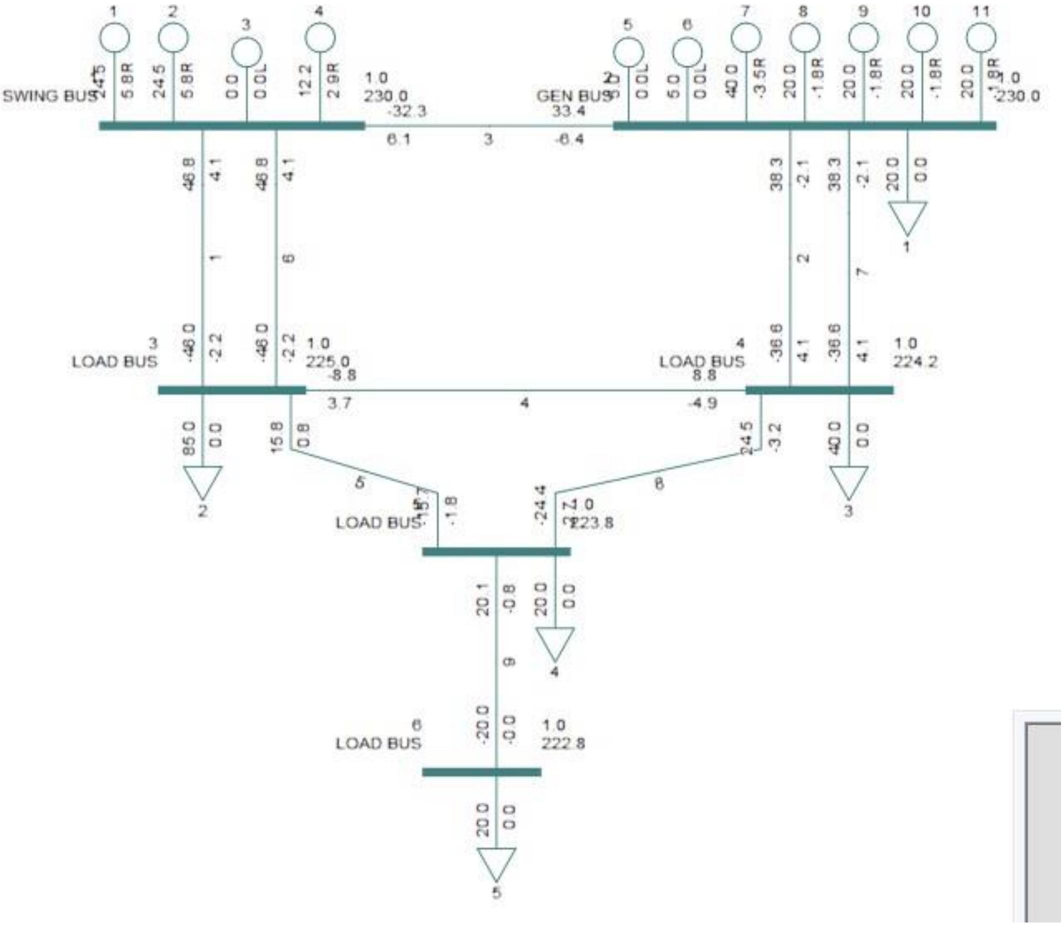
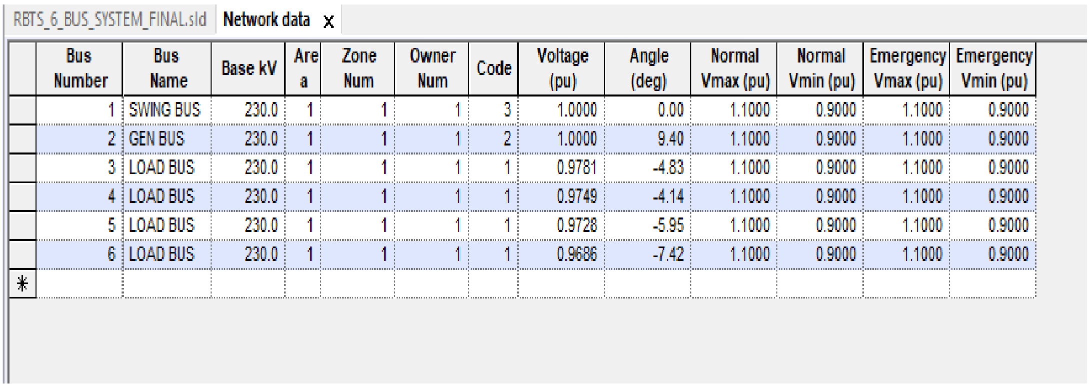


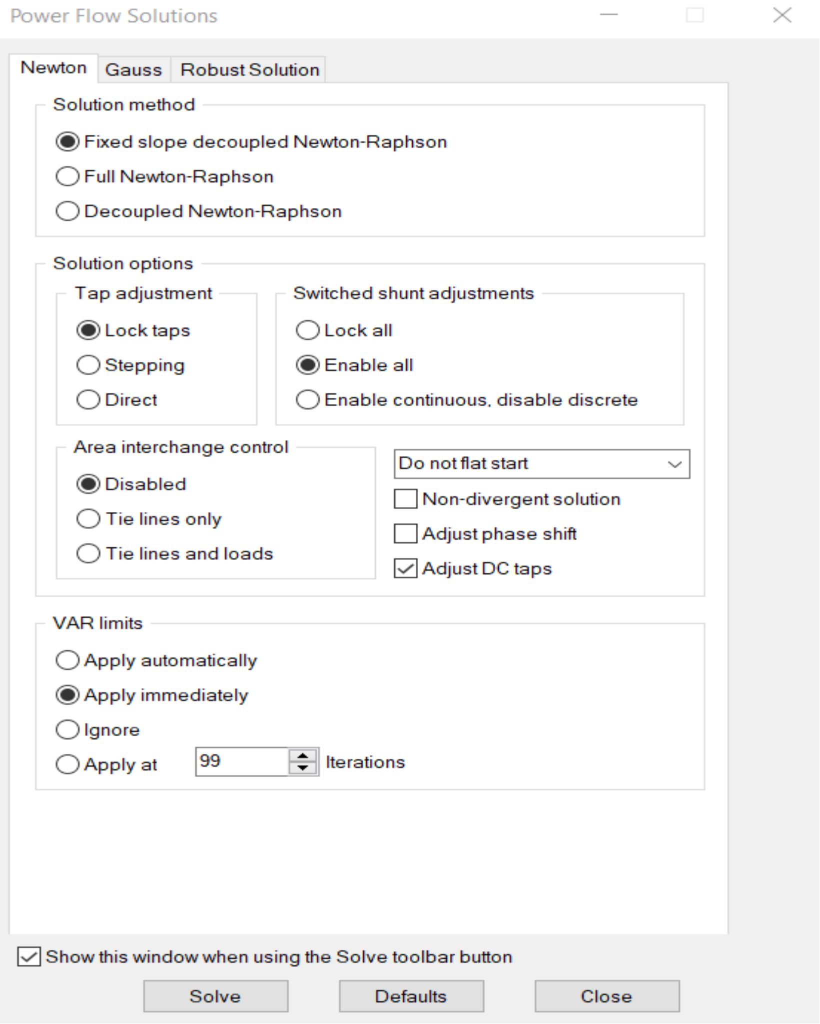
Figure 3.2: RBTS -6 bus system SLD in PSSE



Bus Number	Bus Name	Base kV	Area	Zone Num	Owner Num	Code	Voltage (pu)	Angle (deg)	Normal Vmax (pu)	Normal Vmin (pu)	Emergency Vmax (pu)	Emergency Vmin (pu)
1	SWING BUS	230.0	1	1	1	3	1.0000	0.00	1.1000	0.9000	1.1000	0.9000
2	GEN BUS	230.0	1	1	1	2	1.0000	9.40	1.1000	0.9000	1.1000	0.9000
3	LOAD BUS	230.0	1	1	1	1	0.9781	-4.83	1.1000	0.9000	1.1000	0.9000
4	LOAD BUS	230.0	1	1	1	1	0.9749	-4.14	1.1000	0.9000	1.1000	0.9000
5	LOAD BUS	230.0	1	1	1	1	0.9728	-5.95	1.1000	0.9000	1.1000	0.9000
6	LOAD BUS	230.0	1	1	1	1	0.9686	-7.42	1.1000	0.9000	1.1000	0.9000

Figure 3.3: Snapshot of network data of RBTS -6 bus system

For load flow using the different iteration approaches the PSSE very useful tool and it checks for the power flow. The usable tab available in PSSE for the power flow is shown in figure 3.3:



Solution method

● Fixed slope decoupled Newton-Raphson
○ Full Newton-Raphson
○ Decoupled Newton-Raphson

Solution options

Tap adjustment

● Lock taps
○ Stepping
○ Direct

Switched shunt adjustments

○ Lock all
● Enable all
○ Enable continuous, disable discrete

Area interchange control

● Disabled
○ Tie lines only
○ Tie lines and loads

Do not flat start
☐ Non-divergent solution
☐ Adjust phase shift
☑ Adjust DC taps

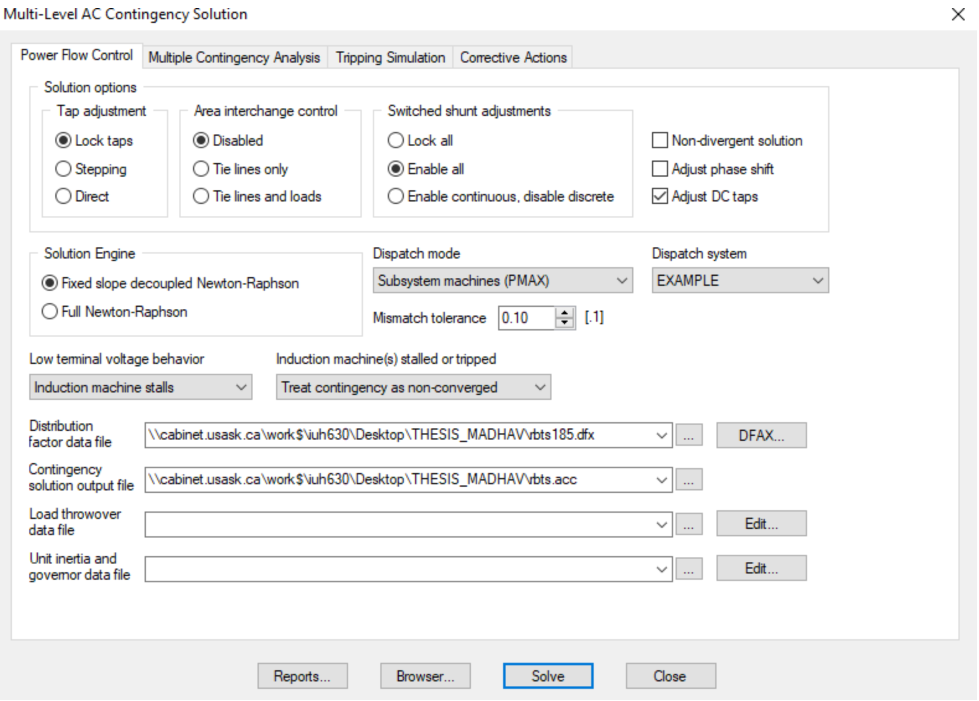
VAR limits

○ Apply automatically
● Apply immediately
○ Ignore
○ Apply at 99 Iterations

☑ Show this window when using the Solve toolbar button

Figure 3.4: Snapshot of power flow tab in element of PSSE

In PSSE for the comparative analysis of before and after the DR implementation, the EENS is evaluated under the same conditions of the system for contingency analysis as



Solution options

Tap adjustment
● Lock taps
○ Stepping
○ Direct

Area interchange control
● Disabled
○ Tie lines only
○ Tie lines and loads

Switched shunt adjustments
○ Lock all
● Enable all
○ Enable continuous, disable discrete

☐ Non-divergent solution
☐ Adjust phase shift
☑ Adjust DC taps

Solution Engine
● Fixed slope decoupled Newton-Raphson
○ Full Newton-Raphson

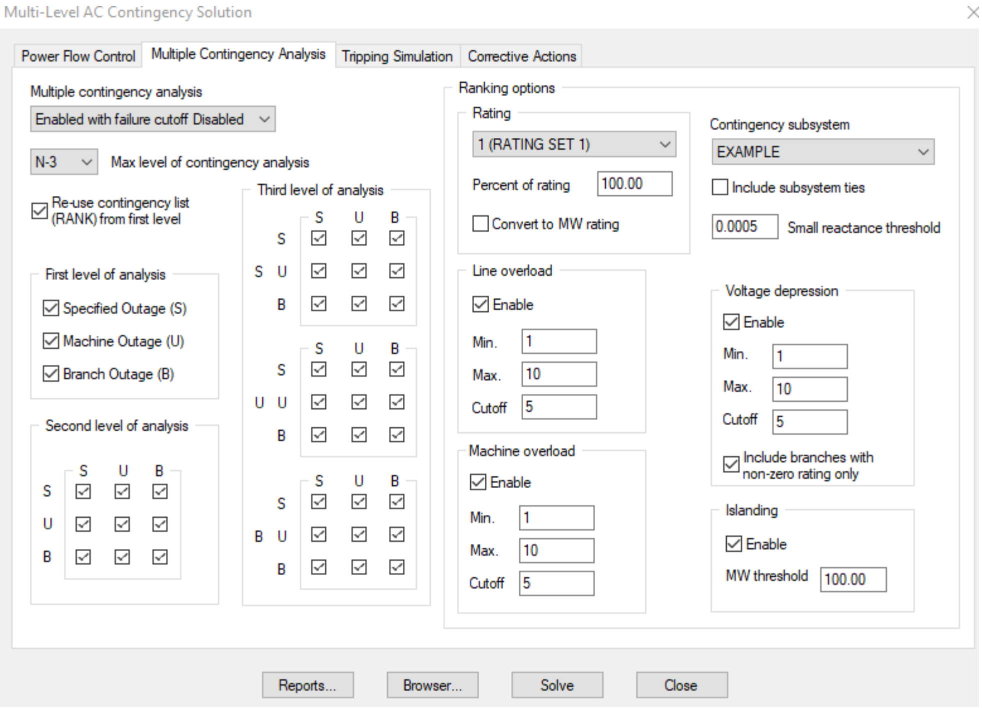
Dispatch mode: Subsystem machines (PMAX)
Dispatch system: EXAMPLE
Mismatch tolerance: 0.10 [.1]

Low terminal voltage behavior: Induction machine stalls
Induction machine(s) stalled or tripped: Treat contingency as non-converged

Distribution factor data file: \\cabinet.usask.ca\work$\iuh630\Desktop\THESIS_MADHAV\rbts185.dfx
Contingency solution output file: \\cabinet.usask.ca\work$\iuh630\Desktop\THESIS_MADHAV\rbts.acc
Load throwover data file:
Unit inertia and governor data file:

Figure 3.5: Snapshot of PSSE for the same selection before and after DR implementation

Under the multiple contingency analysis tab, specified outage, machine outage and branch outage all selected and 100 MW threshold is provided for the Island scenarios as



Multiple contingency analysis: Enabled with failure cutoff Disabled
N-3 Max level of contingency analysis
☑ Re-use contingency list (RANK) from first level

First level of analysis
☑ Specified Outage (S)
☑ Machine Outage (U)
☑ Branch Outage (B)

Second level of analysis

	S	U	B
S	☑	☑	☑
U	☑	☑	☑
B	☑	☑	☑

Third level of analysis

		S	U	B
S	S	☑	☑	☑
	U	☑	☑	☑
	B	☑	☑	☑
U	S	☑	☑	☑
	U	☑	☑	☑
	B	☑	☑	☑
B	S	☑	☑	☑
	U	☑	☑	☑
	B	☑	☑	☑

Ranking options

Rating: 1 (RATING SET 1)
Percent of rating: 100.00
☐ Convert to MW rating

Contingency subsystem: EXAMPLE
☐ Include subsystem ties
0.0005 Small reactance threshold

Line overload
☑ Enable
Min. 1
Max. 10
Cutoff 5

Machine overload
☑ Enable
Min. 1
Max. 10
Cutoff 5

Voltage depression
☑ Enable
Min. 1
Max. 10
Cutoff 5
☑ Include branches with non-zero rating only

Islanding
☑ Enable
MW threshold 100.00

Figure 3.6 Snapshot of PSSE for multiple contingency analysis

3.3. Methodology for the formation of the price elasticity matrix

As per the rule of economics the price elasticity is the responsive behavior of demand with respect to price and mathematically it can be expressed as:

$$\varepsilon = \frac{\Delta D/_{D}}{\Delta P/_{P}} - - - - - - - - - - - - - - - - - (1)$$

In this context, ε represents the elasticity coefficient, D stands for demand, P for price, ΔD for demand changes, and ΔP for price changes. A high value of ε suggests that demand is highly responsive to price fluctuations, whereas ε = 0 implies that changes in price have no impact on demand.

Electricity, being a distinctive commodity, exhibits high timeliness, with prices subject to real-time fluctuations and demand capable of temporal shifts. The variation in electricity prices within each interval not only influences consumption during that period but also impacts consumption across other intervals. Consequently, the elasticity coefficient is categorized into self-elasticity coefficient and cross-elasticity coefficient.

Self-elasticity, also known as own price elasticity, is defined as the ratio of the percentage change in demand during time interval t_i to the percentage change in price within the same time interval. Mathematically, this relationship can be expressed as equation (2)

$$\epsilon(i,i) = \frac{\Delta D(t_i)/_{D}}{\Delta P(t_i)/_{P}} - (2)$$

Since there is an inverse relation between the demand and price, the self-elasticity value is generally taken as negative.

In the other hand, cross elasticity defined as the ratio of percentage change of demand in one time interval $t_{i\,)}$to the percentage change of price in time interval $t_{j)}$. Mathematically, it can be expressed as

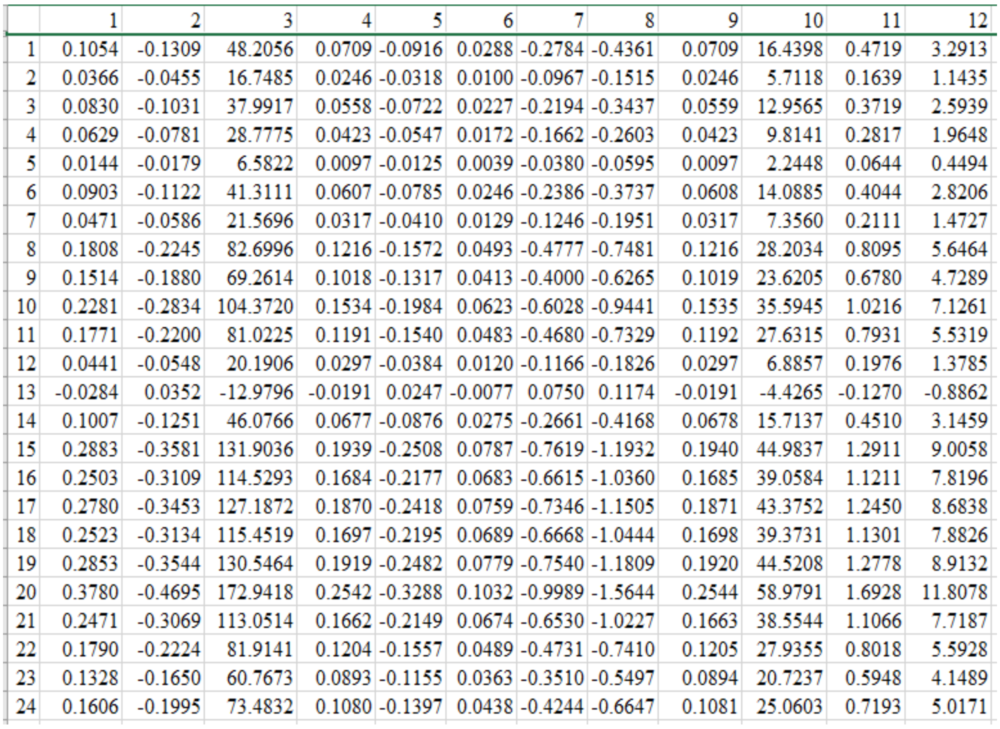
$$\varepsilon(i,j) = \frac{\Delta D(t_i)/_{D}}{\Delta P(t_{j)})/_{P}} - - - - - - - - - - - - - - - - (3)$$

The cross-elasticity coefficient may either plus, minus or zero based on the whether the consumer willing to alter the load in other time interval or not. The real time TOU or simply RTP will form the PEM of size 24*24 where the diagonal elements represent the self-elasticity and off diagonal elements represents the cross elasticity.

3.4. Price elasticity matrix as per normal calculation

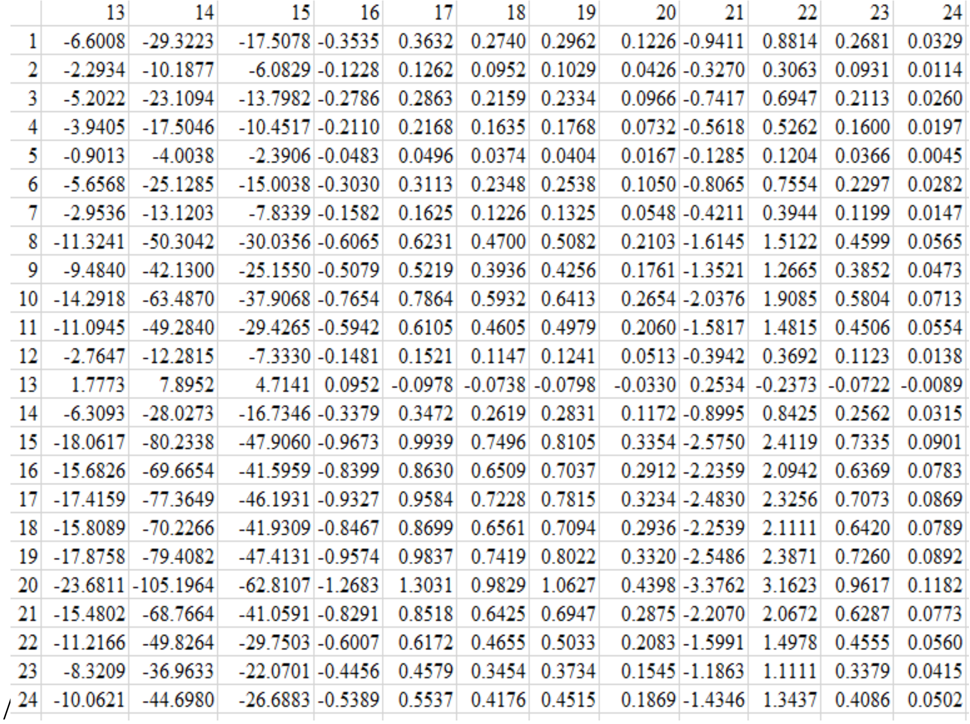
With the definition of price elasticity matrix in 3.1.2 the 24*24 matrix can be formed. Here, for the formation of this matrix the demand data has been selected from the IESO website of the two dates i.e.,15th Dec. 2023 and 16th Dec.2023. The corresponding hourly prices has been taken for calculating the change in price difference form HOEP (Hourly Ontario electricity prices). The formed 24*24 PEM matrix is given below in table 3.1 and 3.2:

Table 3.1 PEM formation with basic equation (for first 12 hours)



	1	2	3	4	5	6	7	8	9	10	11	12
1	0.1054	-0.1309	48.2056	0.0709	-0.0916	0.0288	-0.2784	-0.4361	0.0709	16.4398	0.4719	3.2913
2	0.0366	-0.0455	16.7485	0.0246	-0.0318	0.0100	-0.0967	-0.1515	0.0246	5.7118	0.1639	1.1435
3	0.0830	-0.1031	37.9917	0.0558	-0.0722	0.0227	-0.2194	-0.3437	0.0559	12.9565	0.3719	2.5939
4	0.0629	-0.0781	28.7775	0.0423	-0.0547	0.0172	-0.1662	-0.2603	0.0423	9.8141	0.2817	1.9648
5	0.0144	-0.0179	6.5822	0.0097	-0.0125	0.0039	-0.0380	-0.0595	0.0097	2.2448	0.0644	0.4494
6	0.0903	-0.1122	41.3111	0.0607	-0.0785	0.0246	-0.2386	-0.3737	0.0608	14.0885	0.4044	2.8206
7	0.0471	-0.0586	21.5696	0.0317	-0.0410	0.0129	-0.1246	-0.1951	0.0317	7.3560	0.2111	1.4727
8	0.1808	-0.2245	82.6996	0.1216	-0.1572	0.0493	-0.4777	-0.7481	0.1216	28.2034	0.8095	5.6464
9	0.1514	-0.1880	69.2614	0.1018	-0.1317	0.0413	-0.4000	-0.6265	0.1019	23.6205	0.6780	4.7289
10	0.2281	-0.2834	104.3720	0.1534	-0.1984	0.0623	-0.6028	-0.9441	0.1535	35.5945	1.0216	7.1261
11	0.1771	-0.2200	81.0225	0.1191	-0.1540	0.0483	-0.4680	-0.7329	0.1192	27.6315	0.7931	5.5319
12	0.0441	-0.0548	20.1906	0.0297	-0.0384	0.0120	-0.1166	-0.1826	0.0297	6.8857	0.1976	1.3785
13	-0.0284	0.0352	-12.9796	-0.0191	0.0247	-0.0077	0.0750	0.1174	-0.0191	-4.4265	-0.1270	-0.8862
14	0.1007	-0.1251	46.0766	0.0677	-0.0876	0.0275	-0.2661	-0.4168	0.0678	15.7137	0.4510	3.1459
15	0.2883	-0.3581	131.9036	0.1939	-0.2508	0.0787	-0.7619	-1.1932	0.1940	44.9837	1.2911	9.0058
16	0.2503	-0.3109	114.5293	0.1684	-0.2177	0.0683	-0.6615	-1.0360	0.1685	39.0584	1.1211	7.8196
17	0.2780	-0.3453	127.1872	0.1870	-0.2418	0.0759	-0.7346	-1.1505	0.1871	43.3752	1.2450	8.6838
18	0.2523	-0.3134	115.4519	0.1697	-0.2195	0.0689	-0.6668	-1.0444	0.1698	39.3731	1.1301	7.8826
19	0.2853	-0.3544	130.5464	0.1919	-0.2482	0.0779	-0.7540	-1.1809	0.1920	44.5208	1.2778	8.9132
20	0.3780	-0.4695	172.9418	0.2542	-0.3288	0.1032	-0.9989	-1.5644	0.2544	58.9791	1.6928	11.8078
21	0.2471	-0.3069	113.0514	0.1662	-0.2149	0.0674	-0.6530	-1.0227	0.1663	38.5544	1.1066	7.7187
22	0.1790	-0.2224	81.9141	0.1204	-0.1557	0.0489	-0.4731	-0.7410	0.1205	27.9355	0.8018	5.5928
23	0.1328	-0.1650	60.7673	0.0893	-0.1155	0.0363	-0.3510	-0.5497	0.0894	20.7237	0.5948	4.1489
24	0.1606	-0.1995	73.4832	0.1080	-0.1397	0.0438	-0.4244	-0.6647	0.1081	25.0603	0.7193	5.0171

Table 3.2 PEM formation with basic equation (for next 12 hours)



	13	14	15	16	17	18	19	20	21	22	23	24
1	-6.6008	-29.3223	-17.5078	-0.3535	0.3632	0.2740	0.2962	0.1226	-0.9411	0.8814	0.2681	0.0329
2	-2.2934	-10.1877	-6.0829	-0.1228	0.1262	0.0952	0.1029	0.0426	-0.3270	0.3063	0.0931	0.0114
3	-5.2022	-23.1094	-13.7982	-0.2786	0.2863	0.2159	0.2334	0.0966	-0.7417	0.6947	0.2113	0.0260
4	-3.9405	-17.5046	-10.4517	-0.2110	0.2168	0.1635	0.1768	0.0732	-0.5618	0.5262	0.1600	0.0197
5	-0.9013	-4.0038	-2.3906	-0.0483	0.0496	0.0374	0.0404	0.0167	-0.1285	0.1204	0.0366	0.0045
6	-5.6568	-25.1285	-15.0038	-0.3030	0.3113	0.2348	0.2538	0.1050	-0.8065	0.7554	0.2297	0.0282
7	-2.9536	-13.1203	-7.8339	-0.1582	0.1625	0.1226	0.1325	0.0548	-0.4211	0.3944	0.1199	0.0147
8	-11.3241	-50.3042	-30.0356	-0.6065	0.6231	0.4700	0.5082	0.2103	-1.6145	1.5122	0.4599	0.0565
9	-9.4840	-42.1300	-25.1550	-0.5079	0.5219	0.3936	0.4256	0.1761	-1.3521	1.2665	0.3852	0.0473
10	-14.2918	-63.4870	-37.9068	-0.7654	0.7864	0.5932	0.6413	0.2654	-2.0376	1.9085	0.5804	0.0713
11	-11.0945	-49.2840	-29.4265	-0.5942	0.6105	0.4605	0.4979	0.2060	-1.5817	1.4815	0.4506	0.0554
12	-2.7647	-12.2815	-7.3330	-0.1481	0.1521	0.1147	0.1241	0.0513	-0.3942	0.3692	0.1123	0.0138
13	1.7773	7.8952	4.7141	0.0952	-0.0978	-0.0738	-0.0798	-0.0330	0.2534	-0.2373	-0.0722	-0.0089
14	-6.3093	-28.0273	-16.7346	-0.3379	0.3472	0.2619	0.2831	0.1172	-0.8995	0.8425	0.2562	0.0315
15	-18.0617	-80.2338	-47.9060	-0.9673	0.9939	0.7496	0.8105	0.3354	-2.5750	2.4119	0.7335	0.0901
16	-15.6826	-69.6654	-41.5959	-0.8399	0.8630	0.6509	0.7037	0.2912	-2.2359	2.0942	0.6369	0.0783
17	-17.4159	-77.3649	-46.1931	-0.9327	0.9584	0.7228	0.7815	0.3234	-2.4830	2.3256	0.7073	0.0869
18	-15.8089	-70.2266	-41.9309	-0.8467	0.8699	0.6561	0.7094	0.2936	-2.2539	2.1111	0.6420	0.0789
19	-17.8758	-79.4082	-47.4131	-0.9574	0.9837	0.7419	0.8022	0.3320	-2.5486	2.3871	0.7260	0.0892
20	-23.6811	-105.1964	-62.8107	-1.2683	1.3031	0.9829	1.0627	0.4398	-3.3762	3.1623	0.9617	0.1182
21	-15.4802	-68.7664	-41.0591	-0.8291	0.8518	0.6425	0.6947	0.2875	-2.2070	2.0672	0.6287	0.0773
22	-11.2166	-49.8264	-29.7503	-0.6007	0.6172	0.4655	0.5033	0.2083	-1.5991	1.4978	0.4555	0.0560
23	-8.3209	-36.9633	-22.0701	-0.4456	0.4579	0.3454	0.3734	0.1545	-1.1863	1.1111	0.3379	0.0415
24	-10.0621	-44.6980	-26.6883	-0.5389	0.5537	0.4176	0.4515	0.1869	-1.4346	1.3437	0.4086	0.0502

3.5. pre-defined price elasticity matrix as per customer rationality

As the normal formation of PEM cannot understand the nature of customer whether they are changing/shifting their load from the as usual pattern or not and hence the concept of pre-defined PEM arises, and it is formed through the extensive experiment and research. The coefficient calculation for these matrices is out of cope of this research as extensive study through regression model is ongoing for that work. The electrical consumers are dividing into the following 5 parts based on the nature shifting their loads near time zone or wide time zone.

a) Optimizing consumer or Long-Range consumer
b) Non optimizing consumer or short-range consumer
c) Real world postponing consumer
d) Real world advancing consumer.
e) Real world mixed consumer

To develop DR models, consumer behavior assumptions are rationalized as detailed in table 3-1. The Price Elasticity Models developed correspond to this specific summer peak day RTP and are intended for calculating DR exclusively during such peak periods. Historical RTP data across various seasons, coupled with corresponding consumer load patterns, enables the development of PEMs tailored to different seasons.

The self-elasticity coefficients are supposed to remain constant at extremely low prices. However, beyond a threshold of 3 cents per kWh, the self-elasticity increases with higher price signals. These elasticity coefficients, both self and cross, are derived from extensive data on price relationships and consumer load profiles throughout the year.

Table 3.3 hours electricity prices (in cents per KWH) and self-elasticity coefficient

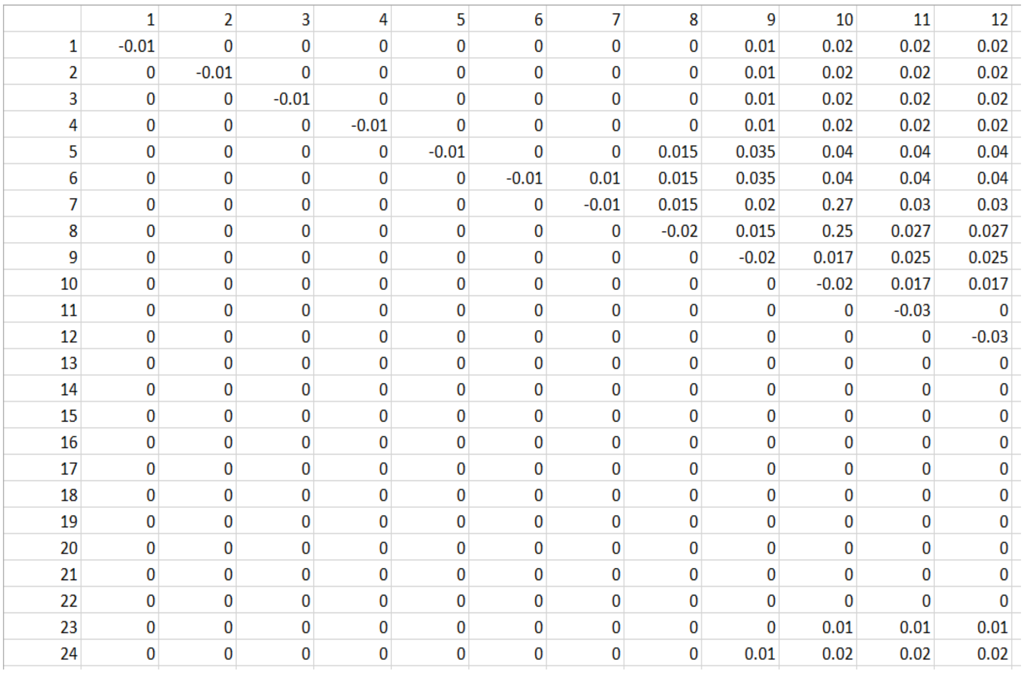
Hrs.in a day	Price in cents/kwh	Self-elasticity	Hrs.in a day	Price in cents/kwh	Self-elasticity
1	2	-.01	13	11	-0.04
2	2	-.01	14	12	-.16
3	2	-.01	15	13	-.20
4	2	-.01	16	14	-.25
5	2	-.01	17	15	-.45
6	2	-.01	18	12	-.16
7	3	-.01	19	12	-.20
8	4	-.02	20	10	-.25
9	6	-.02	21	13	-.45
10	8	-.02	22	9	-.16
11	10	-.03	23	7	-.16
12	10	-.03	24	5	-.20

The brief explanation of five different consumers classification based on the consumer rationality are as follows:

a) Optimizing or Long-range consumer

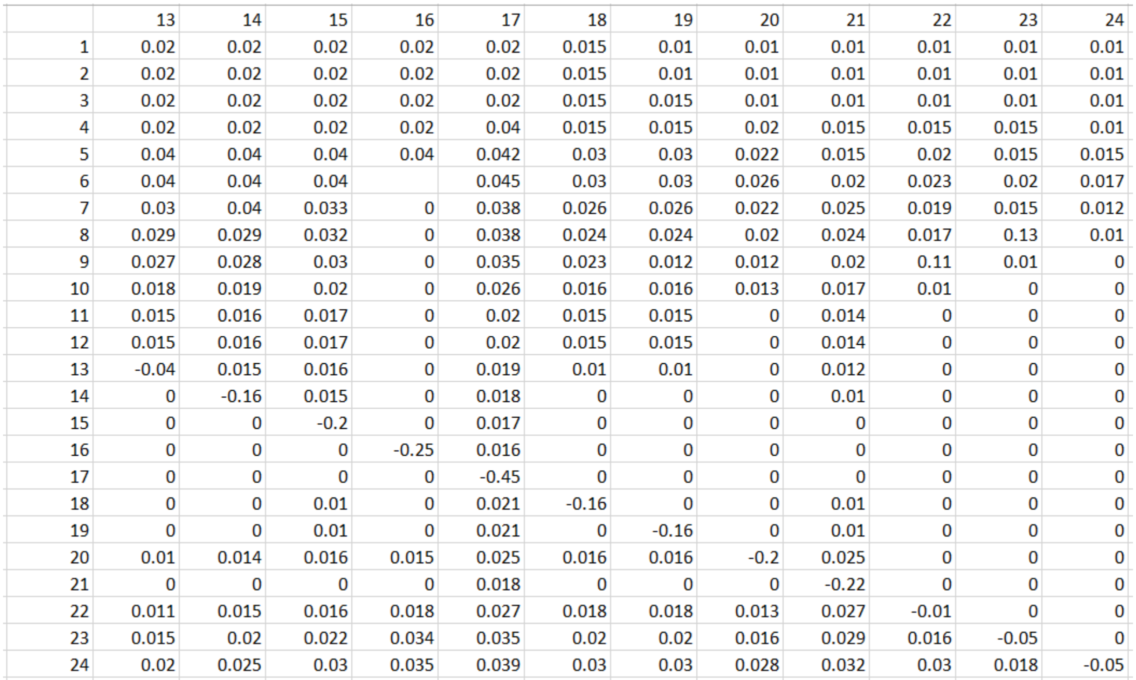
This type of consumers has the habit of wide range of shifting nature throughout the day. Therefore, there are more nos of non-zero elements in 24*24 PEM matrix and diagonal elements are also different. As there is low pricing from hour 1 to hour 7, most of the consumer may not shift their load because of low pricing and hence the coefficient elements below diagonal are zero.

Table 3.4 Price Elasticity Models of Long-range consumer (for first 12 hours)



	1	2	3	4	5	6	7	8	9	10	11	12
1	-0.01	0	0	0	0	0	0	0	0.01	0.02	0.02	0.02
2	0	-0.01	0	0	0	0	0	0	0.01	0.02	0.02	0.02
3	0	0	-0.01	0	0	0	0	0	0.01	0.02	0.02	0.02
4	0	0	0	-0.01	0	0	0	0	0.01	0.02	0.02	0.02
5	0	0	0	0	-0.01	0	0	0.015	0.035	0.04	0.04	0.04
6	0	0	0	0	0	-0.01	0.01	0.015	0.035	0.04	0.04	0.04
7	0	0	0	0	0	0	-0.01	0.015	0.02	0.27	0.03	0.03
8	0	0	0	0	0	0	0	-0.02	0.015	0.25	0.027	0.027
9	0	0	0	0	0	0	0	0	-0.02	0.017	0.025	0.025
10	0	0	0	0	0	0	0	0	0	-0.02	0.017	0.017
11	0	0	0	0	0	0	0	0	0	0	-0.03	0
12	0	0	0	0	0	0	0	0	0	0	0	-0.03
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01
24	0	0	0	0	0	0	0	0	0.01	0.02	0.02	0.02

Table 3.5 Price Elasticity Models of Long-range consumer (for next 12 hours)



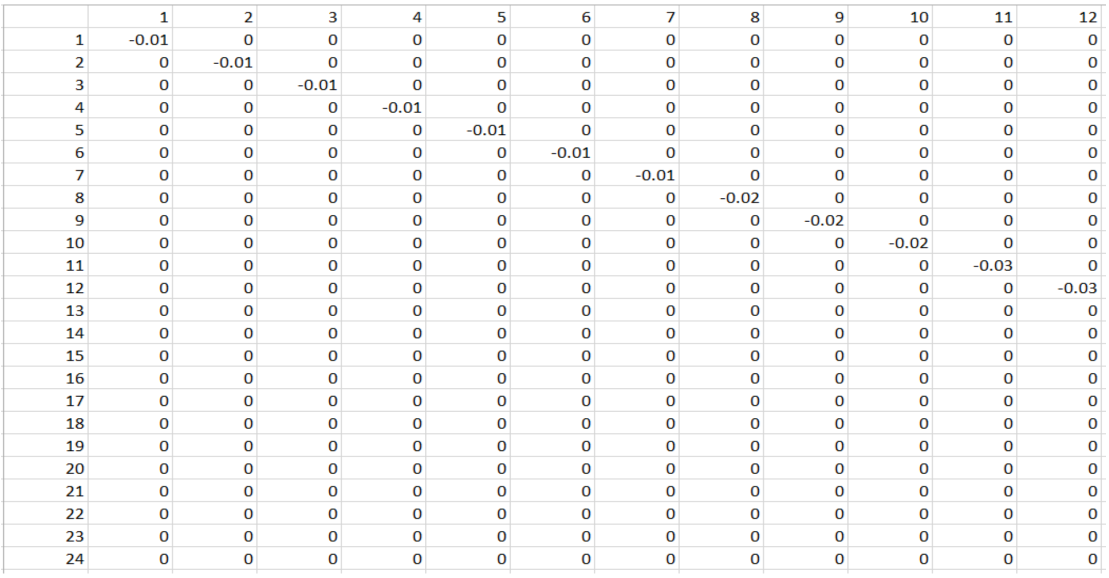
	13	14	15	16	17	18	19	20	21	22	23	24
1	0.02	0.02	0.02	0.02	0.02	0.015	0.01	0.01	0.01	0.01	0.01	0.01
2	0.02	0.02	0.02	0.02	0.02	0.015	0.01	0.01	0.01	0.01	0.01	0.01
3	0.02	0.02	0.02	0.02	0.02	0.015	0.015	0.01	0.01	0.01	0.01	0.01
4	0.02	0.02	0.02	0.02	0.04	0.015	0.015	0.02	0.015	0.015	0.015	0.01
5	0.04	0.04	0.04	0.04	0.042	0.03	0.03	0.022	0.015	0.02	0.015	0.015
6	0.04	0.04	0.04		0.045	0.03	0.03	0.026	0.02	0.023	0.02	0.017
7	0.03	0.04	0.033	0	0.038	0.026	0.026	0.022	0.025	0.019	0.015	0.012
8	0.029	0.029	0.032	0	0.038	0.024	0.024	0.02	0.024	0.017	0.13	0.01
9	0.027	0.028	0.03	0	0.035	0.023	0.012	0.012	0.02	0.11	0.01	0
10	0.018	0.019	0.02	0	0.026	0.016	0.016	0.013	0.017	0.01	0	0
11	0.015	0.016	0.017	0	0.02	0.015	0.015	0	0.014	0	0	0
12	0.015	0.016	0.017	0	0.02	0.015	0.015	0	0.014	0	0	0
13	-0.04	0.015	0.016	0	0.019	0.01	0.01	0	0.012	0	0	0
14	0	-0.16	0.015	0	0.018	0	0	0	0.01	0	0	0
15	0	0	-0.2	0	0.017	0	0	0	0	0	0	0
16	0	0	0	-0.25	0.016	0	0	0	0	0	0	0
17	0	0	0	0	-0.45	0	0	0	0	0	0	0
18	0	0	0.01	0	0.021	-0.16	0	0	0.01	0	0	0
19	0	0	0.01	0	0.021	0	-0.16	0	0.01	0	0	0
20	0.01	0.014	0.016	0.015	0.025	0.016	0.016	-0.2	0.025	0	0	0
21	0	0	0	0	0.018	0	0	0	-0.22	0	0	0
22	0.011	0.015	0.016	0.018	0.027	0.018	0.018	0.013	0.027	-0.01	0	0
23	0.015	0.02	0.022	0.034	0.035	0.02	0.02	0.016	0.029	0.016	-0.05	0
24	0.02	0.025	0.03	0.035	0.039	0.03	0.03	0.028	0.032	0.03	0.018	-0.05

The fading effect is clearly visible in the matrix formation as the customer always tends to shift their load from higher prices to lower prices but the time slot for reaching the destination should be lower.

b) Non optimizing or short-range customer

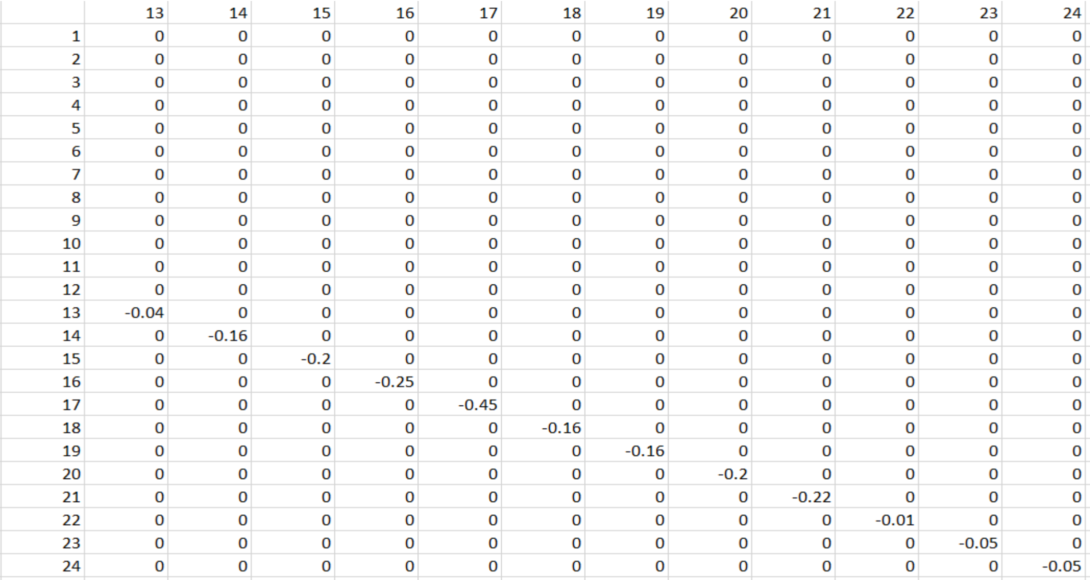
As this class of customers rigid to shift their loads in other time intervals and are only serious on the prices of the current instant, hence except a diagonal elements all other elements are zero as depicted in the 24*24 PEM below:

Table 3.6 Price Elasticity Models of short-range consumer (for first 12 hours)



	1	2	3	4	5	6	7	8	9	10	11	12
1	-0.01	0	0	0	0	0	0	0	0	0	0	0
2	0	-0.01	0	0	0	0	0	0	0	0	0	0
3	0	0	-0.01	0	0	0	0	0	0	0	0	0
4	0	0	0	-0.01	0	0	0	0	0	0	0	0
5	0	0	0	0	-0.01	0	0	0	0	0	0	0
6	0	0	0	0	0	-0.01	0	0	0	0	0	0
7	0	0	0	0	0	0	-0.01	0	0	0	0	0
8	0	0	0	0	0	0	0	-0.02	0	0	0	0
9	0	0	0	0	0	0	0	0	-0.02	0	0	0
10	0	0	0	0	0	0	0	0	0	-0.02	0	0
11	0	0	0	0	0	0	0	0	0	0	-0.03	0
12	0	0	0	0	0	0	0	0	0	0	0	-0.03
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.7 Price Elasticity Models of short-range consumer (for next 12 hours)

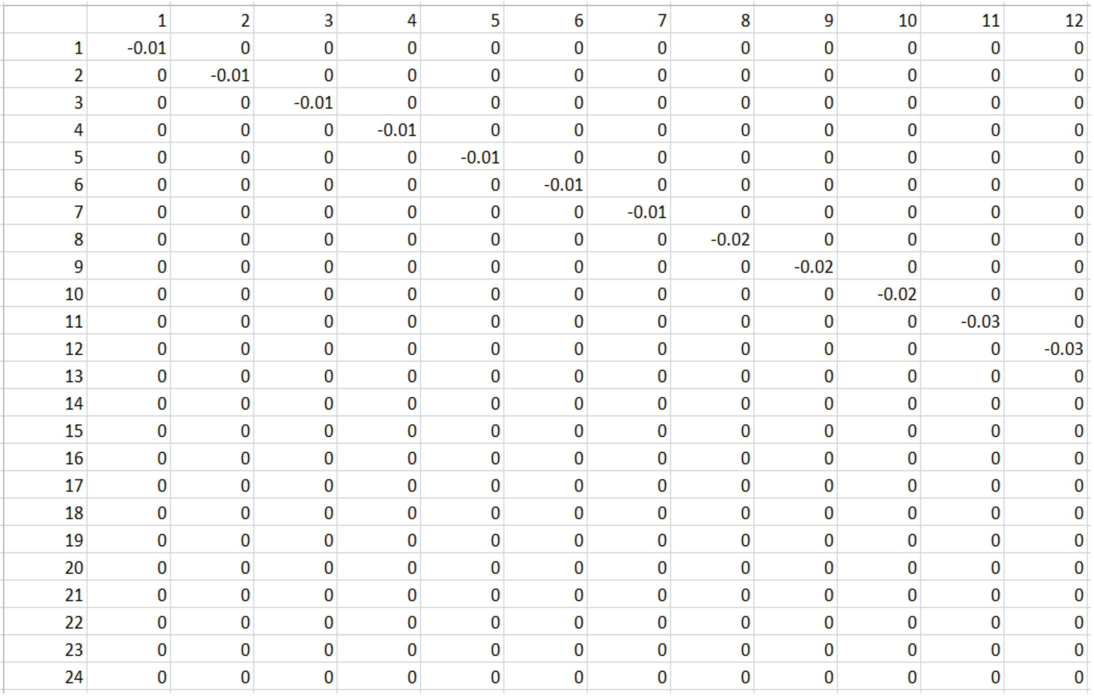


	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	-0.04	0	0	0	0	0	0	0	0	0	0	0
14	0	-0.16	0	0	0	0	0	0	0	0	0	0
15	0	0	-0.2	0	0	0	0	0	0	0	0	0
16	0	0	0	-0.25	0	0	0	0	0	0	0	0
17	0	0	0	0	-0.45	0	0	0	0	0	0	0
18	0	0	0	0	0	-0.16	0	0	0	0	0	0
19	0	0	0	0	0	0	-0.16	0	0	0	0	0
20	0	0	0	0	0	0	0	-0.2	0	0	0	0
21	0	0	0	0	0	0	0	0	-0.22	0	0	0
22	0	0	0	0	0	0	0	0	0	-0.01	0	0
23	0	0	0	0	0	0	0	0	0	0	-0.05	0
24	0	0	0	0	0	0	0	0	0	0	0	-0.05

c) Real world postponing consumers

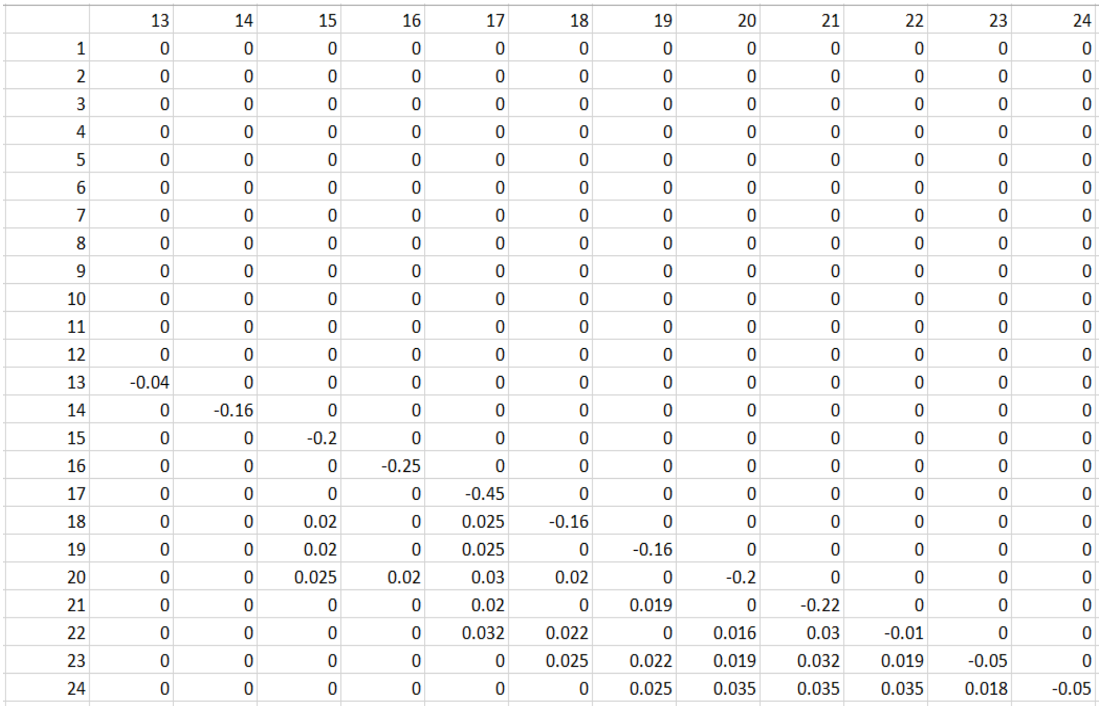
This sort of consumers looks for the current and future prices only, but the future time slot is not more than 5 hours. So, the cross-elasticity coefficients values will be higher than that of long-range consumers. These consumers more interesting to change load within the time range. The diurnal PEM of a RW consumers is shown below:

Table 3.8 PEM of real-world postponing consumer (for first 12 hours)



	1	2	3	4	5	6	7	8	9	10	11	12
1	-0.01	0	0	0	0	0	0	0	0	0	0	0
2	0	-0.01	0	0	0	0	0	0	0	0	0	0
3	0	0	-0.01	0	0	0	0	0	0	0	0	0
4	0	0	0	-0.01	0	0	0	0	0	0	0	0
5	0	0	0	0	-0.01	0	0	0	0	0	0	0
6	0	0	0	0	0	-0.01	0	0	0	0	0	0
7	0	0	0	0	0	0	-0.01	0	0	0	0	0
8	0	0	0	0	0	0	0	-0.02	0	0	0	0
9	0	0	0	0	0	0	0	0	-0.02	0	0	0
10	0	0	0	0	0	0	0	0	0	-0.02	0	0
11	0	0	0	0	0	0	0	0	0	0	-0.03	0
12	0	0	0	0	0	0	0	0	0	0	0	-0.03
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.9 PEM of real-world postponing consumer (for next 12 hours)

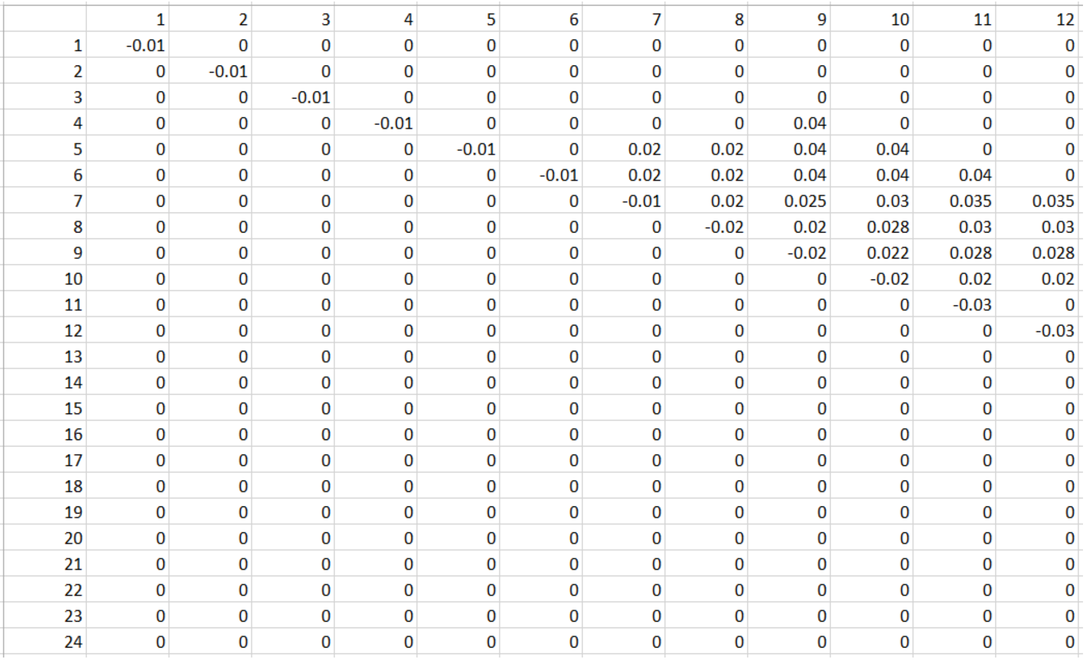


	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	-0.04	0	0	0	0	0	0	0	0	0	0	0
14	0	-0.16	0	0	0	0	0	0	0	0	0	0
15	0	0	-0.2	0	0	0	0	0	0	0	0	0
16	0	0	0	-0.25	0	0	0	0	0	0	0	0
17	0	0	0	0	-0.45	0	0	0	0	0	0	0
18	0	0	0.02	0	0.025	-0.16	0	0	0	0	0	0
19	0	0	0.02	0	0.025	0	-0.16	0	0	0	0	0
20	0	0	0.025	0.02	0.03	0.02	0	-0.2	0	0	0	0
21	0	0	0	0	0.02	0	0.019	0	-0.22	0	0	0
22	0	0	0	0	0.032	0.022	0	0.016	0.03	-0.01	0	0
23	0	0	0	0	0	0.025	0.022	0.019	0.032	0.019	-0.05	0
24	0	0	0	0	0	0	0.025	0.035	0.035	0.035	0.018	-0.05

d) Real world advancing consumers.

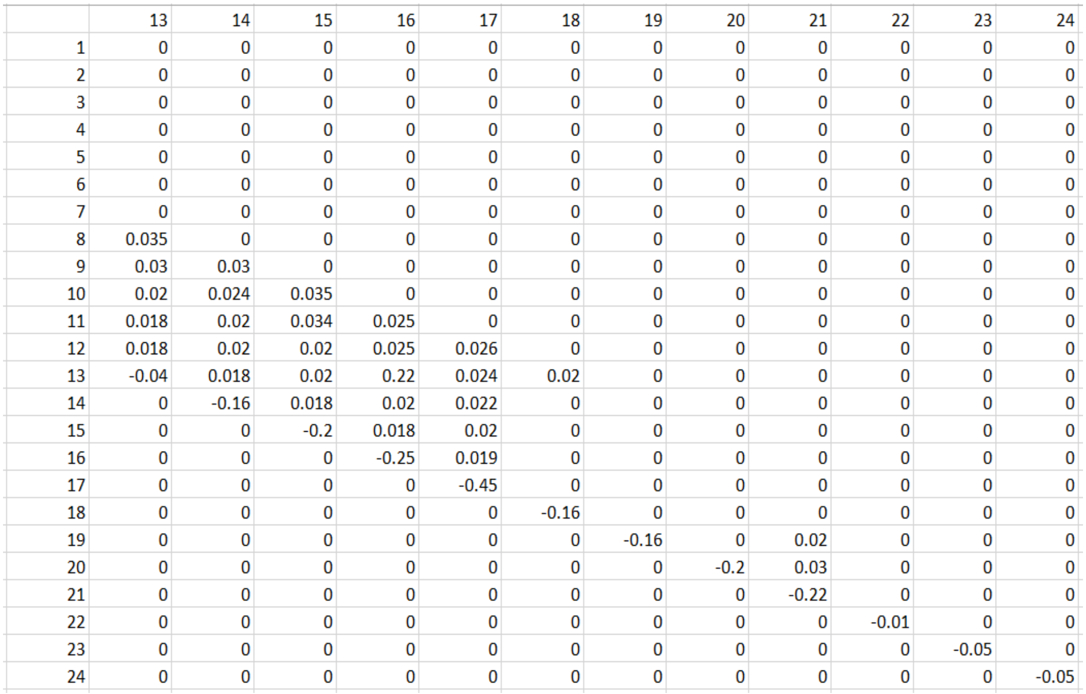
This type of consumers is similar like the Real-world postponing consumers, but they focus only on the current instant price and 5 hours nearby time slot prices on above and below the diagonal prices. Looking at the 24*24PEM, load is shifted around the high price period of t10 to t21 around the diagonal.

Table 3.10 PEM of real-world advancing consumer (for first 12 hours)



	1	2	3	4	5	6	7	8	9	10	11	12
1	-0.01	0	0	0	0	0	0	0	0	0	0	0
2	0	-0.01	0	0	0	0	0	0	0	0	0	0
3	0	0	-0.01	0	0	0	0	0	0	0	0	0
4	0	0	0	-0.01	0	0	0	0	0.04	0	0	0
5	0	0	0	0	-0.01	0	0.02	0.02	0.04	0.04	0	0
6	0	0	0	0	0	-0.01	0.02	0.02	0.04	0.04	0.04	0
7	0	0	0	0	0	0	-0.01	0.02	0.025	0.03	0.035	0.035
8	0	0	0	0	0	0	0	-0.02	0.02	0.028	0.03	0.03
9	0	0	0	0	0	0	0	0	-0.02	0.022	0.028	0.028
10	0	0	0	0	0	0	0	0	0	-0.02	0.02	0.02
11	0	0	0	0	0	0	0	0	0	0	-0.03	0
12	0	0	0	0	0	0	0	0	0	0	0	-0.03
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.11 PEM of real-world advancing consumer (for next 12 hours)

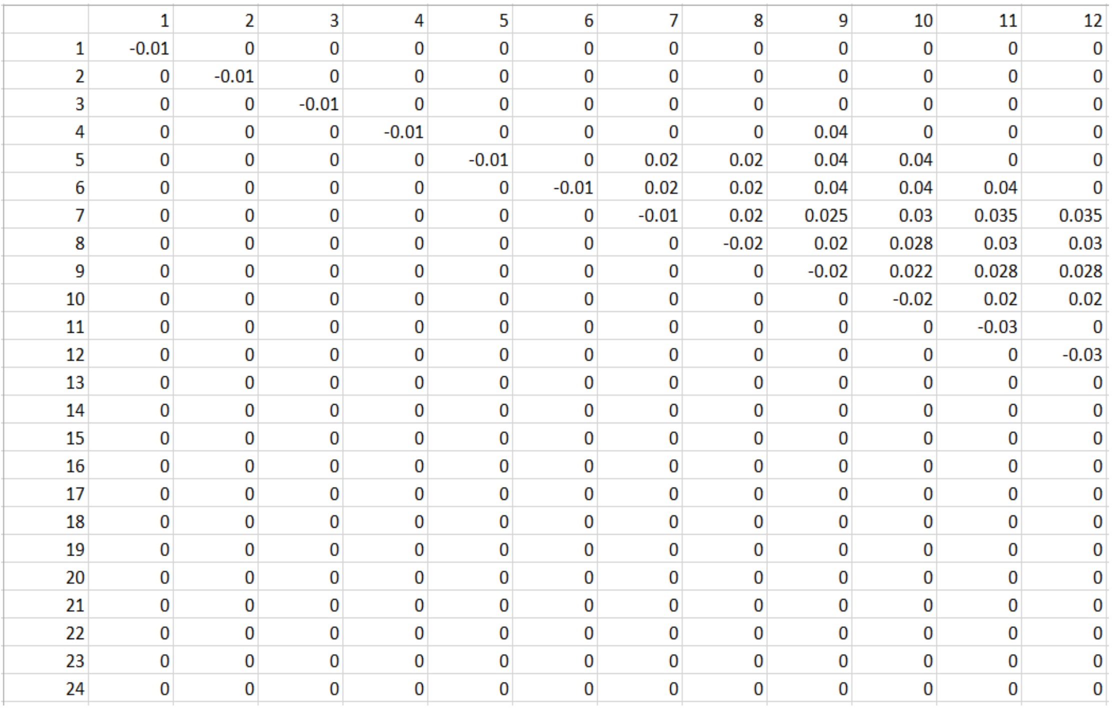


	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0.035	0	0	0	0	0	0	0	0	0	0	0
9	0.03	0.03	0	0	0	0	0	0	0	0	0	0
10	0.02	0.024	0.035	0	0	0	0	0	0	0	0	0
11	0.018	0.02	0.034	0.025	0	0	0	0	0	0	0	0
12	0.018	0.02	0.02	0.025	0.026	0	0	0	0	0	0	0
13	-0.04	0.018	0.02	0.22	0.024	0.02	0	0	0	0	0	0
14	0	-0.16	0.018	0.02	0.022	0	0	0	0	0	0	0
15	0	0	-0.2	0.018	0.02	0	0	0	0	0	0	0
16	0	0	0	-0.25	0.019	0	0	0	0	0	0	0
17	0	0	0	0	-0.45	0	0	0	0	0	0	0
18	0	0	0	0	0	-0.16	0	0	0	0	0	0
19	0	0	0	0	0	0	-0.16	0	0.02	0	0	0
20	0	0	0	0	0	0	0	-0.2	0.03	0	0	0
21	0	0	0	0	0	0	0	0	-0.22	0	0	0
22	0	0	0	0	0	0	0	0	0	-0.01	0	0
23	0	0	0	0	0	0	0	0	0	0	-0.05	0
24	0	0	0	0	0	0	0	0	0	0	0	-0.05

e) Mixed type of consumer or Real-world mixed consumer

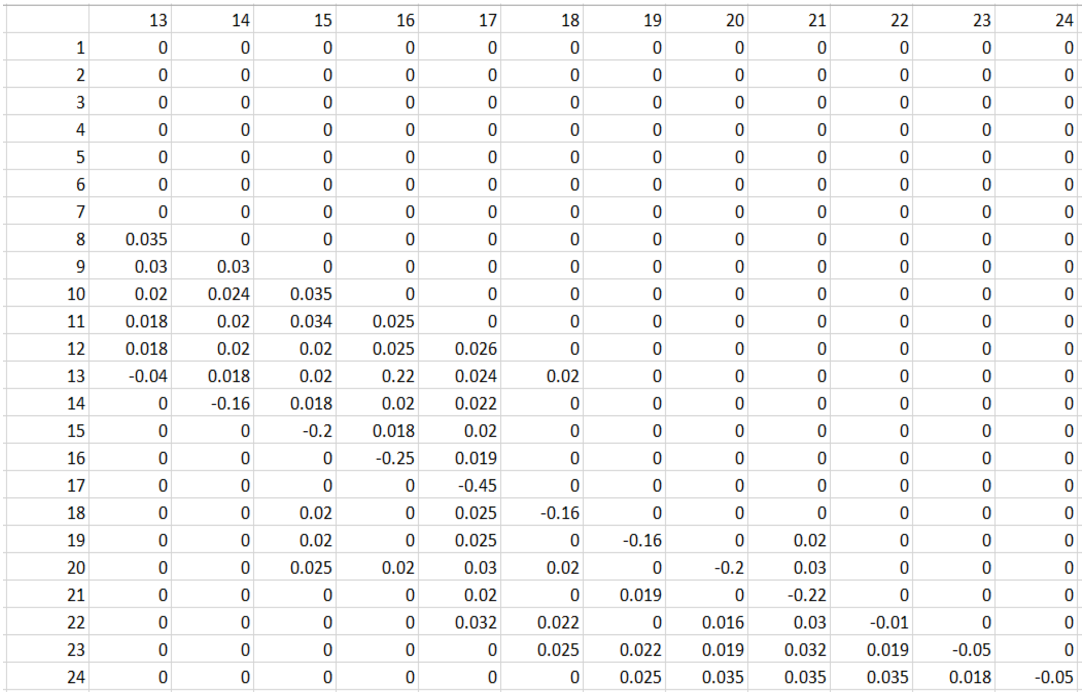
This classification consists of both the real-world postponing consumers and real-world advancing consumers. Their flexibility goes 5 hours past and future and hence the 24*24 PEM consist of fewer non-zero coefficient than the LR consumers as shown in matrix below:

Table 3.12 PEM of real-world mixed consumer (for first 12 hours)



	1	2	3	4	5	6	7	8	9	10	11	12
1	-0.01	0	0	0	0	0	0	0	0	0	0	0
2	0	-0.01	0	0	0	0	0	0	0	0	0	0
3	0	0	-0.01	0	0	0	0	0	0	0	0	0
4	0	0	0	-0.01	0	0	0	0	0.04	0	0	0
5	0	0	0	0	-0.01	0	0.02	0.02	0.04	0.04	0	0
6	0	0	0	0	0	-0.01	0.02	0.02	0.04	0.04	0.04	0
7	0	0	0	0	0	0	-0.01	0.02	0.025	0.03	0.035	0.035
8	0	0	0	0	0	0	0	-0.02	0.02	0.028	0.03	0.03
9	0	0	0	0	0	0	0	0	-0.02	0.022	0.028	0.028
10	0	0	0	0	0	0	0	0	0	-0.02	0.02	0.02
11	0	0	0	0	0	0	0	0	0	0	-0.03	0
12	0	0	0	0	0	0	0	0	0	0	0	-0.03
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.13 PEM of real-world mixed consumer (for next 12 hours)



	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0.035	0	0	0	0	0	0	0	0	0	0	0
9	0.03	0.03	0	0	0	0	0	0	0	0	0	0
10	0.02	0.024	0.035	0	0	0	0	0	0	0	0	0
11	0.018	0.02	0.034	0.025	0	0	0	0	0	0	0	0
12	0.018	0.02	0.02	0.025	0.026	0	0	0	0	0	0	0
13	-0.04	0.018	0.02	0.22	0.024	0.02	0	0	0	0	0	0
14	0	-0.16	0.018	0.02	0.022	0	0	0	0	0	0	0
15	0	0	-0.2	0.018	0.02	0	0	0	0	0	0	0
16	0	0	0	-0.25	0.019	0	0	0	0	0	0	0
17	0	0	0	0	-0.45	0	0	0	0	0	0	0
18	0	0	0.02	0	0.025	-0.16	0	0	0	0	0	0
19	0	0	0.02	0	0.025	0	-0.16	0	0.02	0	0	0
20	0	0	0.025	0.02	0.03	0.02	0	-0.2	0.03	0	0	0
21	0	0	0	0	0.02	0	0.019	0	-0.22	0	0	0
22	0	0	0	0	0.032	0.022	0	0.016	0.03	-0.01	0	0
23	0	0	0	0	0	0.025	0.022	0.019	0.032	0.019	-0.05	0
24	0	0	0	0	0	0	0.025	0.035	0.035	0.035	0.018	-0.05

For the TOU (Time of use) DR programs the PEM is reduced to 3*3 from 24*24 for the accurate result and the pre-defined 3*3 PEM for TOU DR is as per below:

Table 3.14 self and cross elasticity for TOU pricing

	Peak	Off-peak	Low
Peak	-0.02	0.0032	0.0024
Off-peak	0.0032	-0.02	0.002
Low	0.0024	0.002	-0.02

3.6. Deterministic approach of PEM

In the deterministic approach, the elasticity value is dynamically adjusted to correlate the elasticity between peak and off-peak hours. This dynamic method encapsulates the impact of both self-elasticity and cross-elasticity to achieve efficient DR without losses. The underlying assumption is that the elasticity multiplied by the demand during peak hours equals the elasticity multiplied by the demand during other intervals.

Mathematically it can be expressed as:

$$\varepsilon_{peak} * d_{peak} = \varepsilon_t * d_t \qquad \forall t \in T ----------------(3)$$

The above considered relation is defined if the peak hour's elasticity and demand are known then the elasticity of other time states can be evaluated in reference to peak hours. Some literature[adaptive] suggest that there are two approaches for selecting the peak hours, one is peak hour where the maximum demand occurs, and another is a peak hour where the maximum price occurred. But this thesis taking the peak hours as the hour where the maximum demand of customer occurred. Thus, the above equation becomes for the other hours elasticity as:

$$\varepsilon_t = \frac{\max(d_t)}{d_t} \qquad \forall t \in T ----------------(4)$$

With the help of above equation (4), the elasticity for all 24 hours will be determined and the new demand pattern after DR (ADR) will be like below:

$$d(i) = d_0(i)\{1 + \varepsilon_{peak} * \frac{\max(d_t)}{d_t} * \frac{[p(j)-p_0(i)+\alpha(j)]}{p_0(i)}\} \qquad \forall t \in T - - - (5)$$

The above equation represents ADR demand using the proposed DPEM, while maintaining the same energy consumption level BDR and ADR. It exhibits the complete load recovery using the proposed dynamic elasticity model. The one of the main features of the proposed dynamic elasticity model is that it is a time- variant model, which eliminates the drawbacks of the existing model, where elasticity is treated as static value as considered in the literature [9]. In addition, it amalgamates the attribute of self and cross-elasticity in the dynamic elasticity. It can be understood through the distinct trait of elasticity as discussed earlier. Since, self-elasticity will be relatively low during off-peak hours due to the small relative change in price [29], which makes demand increase small. Thus, the cross-elasticity should cause a significant increase in the demand during off- peak hours. It reflects the customers' adaptiveness to shift the demand on low price hours on the account of high price during peak hours.

3.7. Mathematical Formulation of New Demand Pattern

For the single time period modeling of self-elasticity let us consider the following

$d(i)$ =Customer demand in ith hour (MWhr)
$p(i)$ =RTP in ith hour (\$/MWhr)
$\alpha(i)$ = Incentive in ith hour (\$/MWhr)
$\beta(i)$ =Customer income in ith hour (\$/MWhr)

The customer changing their demand from the original demand as $d_0(i)$ to latest demand as $d(i)$ and hence the difference between those can be considered for the incentive as:

$$\Delta d(i) = d_0\,(i) - d(i) - - - - - - - - - - - - - - (4)$$

So, Incentive price P (in \$) due to the running DR program will be as

$$P\big(\Delta d(i)\big) = \alpha(i).\Delta d(i) - - - - - - - - - - - - - (5)$$

Therefore, the customer benefit 'S' (in \$) for the ith hour will be as:

$$S(d(i) = \beta(d(i) - d(i)p(i) + P\big(\Delta d(i)\big) - - - - - - - (6)$$

To maximize the customer benefit, the partial derivative of above equation should be equal to zero as:

$$\frac{\partial S}{\partial d(i)} = \frac{\partial \beta(d(i)}{\partial d(i)} - p(i) - \frac{\partial P\big(\Delta d(i)\big)}{\partial d(i)} = 0 - - - - - - - - - - (7)$$

$$\frac{\partial \beta(d(i)}{\partial d(i)} = p(i) - \alpha(i) - - - - - - - - - - - - - - - (8)$$

The benefit function most usually expressed in the quadratic expression as

$$\beta(d(i) = \beta_0(i) + p_0(i)[d(i) - d_0(i)]\left[\left\{1 + \frac{d(i) - d_0(i)}{2\varepsilon(i).d_0(i)}\right\}\right] ------(9)$$

Where,

$(i) = benefit\ when\ demand\ is\ at\ base\ value\ (i.e. initial)$ And

$p_0(i) = nominal\ electricity\ price\ when\ demand\ is\ nominal$

From the above two equations (8) and (9),

$$p(i) + \alpha(i) = p_0(i)\left\{1 + \frac{d(i) - d_0(i)}{2\varepsilon(i).d_0(i)}\right\} -------- (10)$$

$$p(i) - p_0(i) + \alpha(i) = p_0(i).\frac{d(i) - d_0(i)}{2\varepsilon(i).d_0(i)} ---------- (11)$$

Therefore, the new consumption of customer due to price changes will be as

$$d(i) = d_0(i)\left\{1 + \frac{\varepsilon(i).[p(i) - p_0(i) + \alpha(i)]}{p_0(i)}\right\} ---------------(12)$$

In the above equation if the incentive is not given, it will be useful for the Price Based DR program (PBDR) and that time $\alpha(i)$ = 0 (zero).

For the multi-period modeling, or in simply for the consumer other than short range (SR) customer, the concept of cross elasticity is applied as follow, by considering the equation (3) as:

$$\varepsilon(i,j) = \frac{\Delta D(t_i)/D}{\Delta P(t_j)/P}$$

This equation can be further expanded with the definition of cross elasticity as:

$$\varepsilon(i,j) = \frac{p_0\,(j)}{d_0\,(i)} * \frac{\partial d(i)}{\partial d(p)} --------------------(13)$$

And we know that for self-elasticity (i, j) <0 for i=j

And for cross –elasticity, ε(i, j)>=0 for $i \neq j$

Assume that the second part of equation (13), $\frac{\partial d(i)}{\partial d(p)}$ is constant. Thus, there is a linear relationship exist between the DR and price variation.

Now for the TOU DR of 24 hours blocks of time or simply say for TOU DR, the following equation will give the new demand as:

$$d(i) = d_0\,(i) + \sum_{i=1}^{24} \varepsilon(i,j).\frac{d_0\,(i)}{p_0(j)}\ [p(j) - p_0(i)] - - - - - - - - -(14)$$

For i=1, 2, 3   24.

If the incentive in jth hour is $\alpha(j)$, for the incentive-based DR, we could change the price change demand as$[p(j) - p_0(i) + \alpha(j)]$ from $[p(j) - p_0(i)]$ in the above equation (14).

For the peak periods the incentive value will be as positive and in other cases zeros if the incentive in \$/MWhr is paid in jth hours.

At last, the customer demand function on considering the incentive price can be written as below:

$$d(i) = d_0\,(i) + \sum_{i=1}^{24} \varepsilon(i,j).\frac{d_0\,(i)}{p_0(j)}\ [p(j) - p_0(i) + \alpha(j)] - - - - - - - -\ (15)$$

And on considering the 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:

$$d(i) = d_0(i)[\{1 + \frac{\varepsilon(i).[p(i) - p_0(i) + \alpha(i)]}{p_0(i)}\} + \{\textstyle\sum_{i=1}^{24} \varepsilon(i,j).\frac{[p(j) - p_0(i) + \alpha(j)]}{p_0(j)}\ \}] - (16)$$

This is the required equation for the customer consumption to achieve the maximum benefits in a 24 hours interval. Using this mathematical expression, this thesis shows how incentive could change the demand curve while running both Incentive based DR (Capacity market DR) and Price based DR (TOU and RTP type DR).

CHAPTER FOUR: SYSTEM MODELING AND SIMULATION

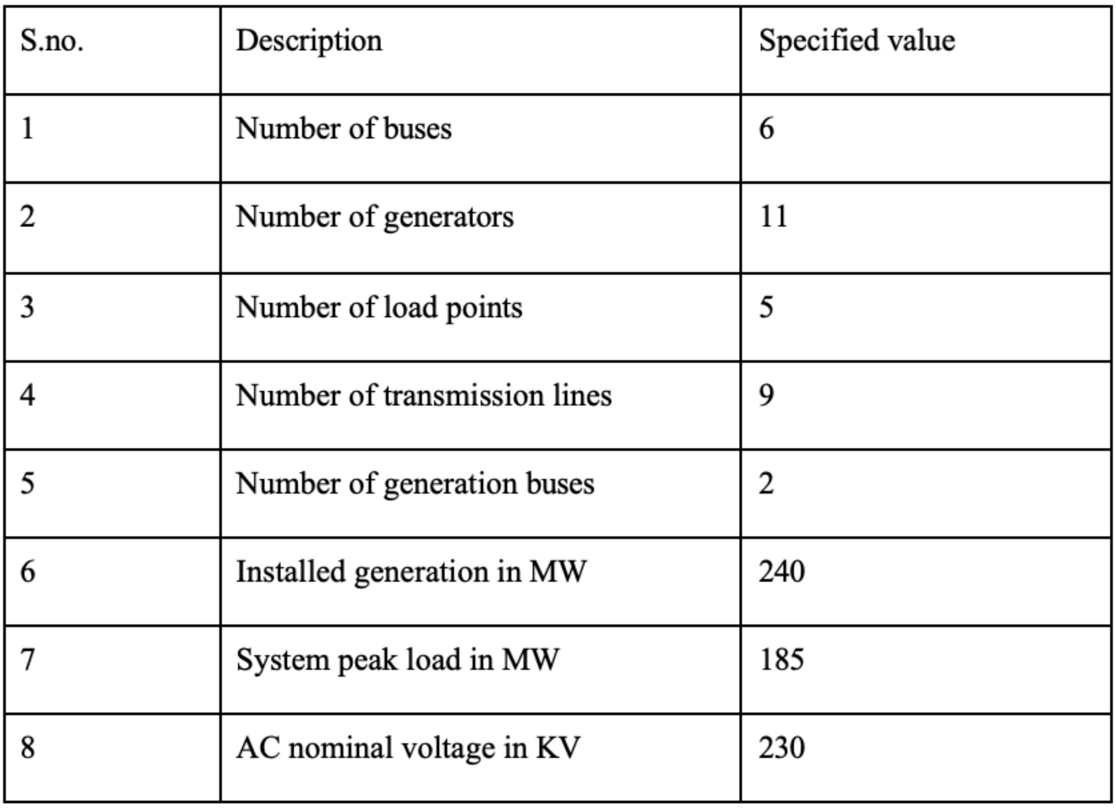
4.1. Tools and Software

Modeling of RBTS 6 bus system was carried out in the PSSE software. This tool is used for the power flow /load flow simulation where the case was studied for 6 bus Roy billon test system. The contingency analysis was carried with the help of this software tool. To coding required for thesis, MATLAB R2021a coding platform was used.

4.2. RBTS 6 Bus system basic data

The Roy Blinton test system (RBTS) is a model for reliabilities studies at the. Transmission level. Table below shows the brief description of the system properties. As this system is easy to understand and the various load points (LPs) in five load buses can be considered for the distributed system, peak shaving of DR is comfortable to explain by this 6-bus test system.

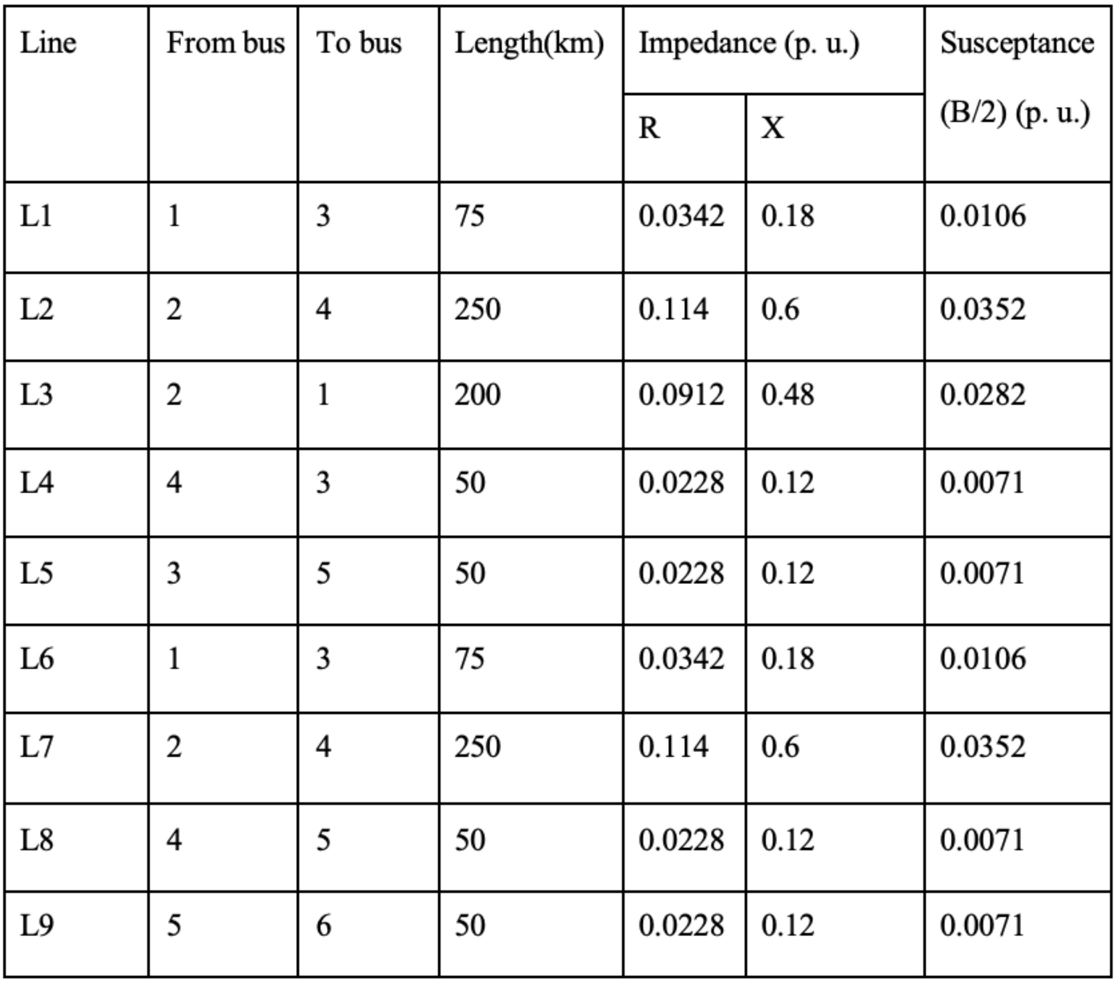
Table 4.1 RBTS summary of system data



S.no.	Description	Specified value
1	Number of buses	6
2	Number of generators	11
3	Number of load points	5
4	Number of transmission lines	9
5	Number of generation buses	2
6	Installed generation in MW	240
7	System peak load in MW	185
8	AC nominal voltage in KV	230

The RBTS transmission data is shown in the table 4.2:

Table 4.2 RBTS transmission data



Line	From bus	To bus	Length(km)	Impedance (p. u.)		Susceptance (B/2) (p. u.)
				R	X	
L1	1	3	75	0.0342	0.18	0.0106
L2	2	4	250	0.114	0.6	0.0352
L3	2	1	200	0.0912	0.48	0.0282
L4	4	3	50	0.0228	0.12	0.0071
L5	3	5	50	0.0228	0.12	0.0071
L6	1	3	75	0.0342	0.18	0.0106
L7	2	4	250	0.114	0.6	0.0352
L8	4	5	50	0.0228	0.12	0.0071
L9	5	6	50	0.0228	0.12	0.0071

The system frequency is assumed to be as 60HZ and the base MVA considered as 100MVA, and based voltage taken as 230KV.The rating for the 11 generators are shown in the table below, here bus 1 is defined as the swing bus the power flow analysis.

4.3. Price Elasticity matrix modeling approaches

The normal calculated formation of PEM does not adaptable to the dynamic nature of the customer response and hence we need to take the comprehensive PEM model to analyze different effects and implications of DR in distributed grids. A link between the real time pricing and load behaviors is cumbersome. Cost, in other hand influence the behaviors of end user load. This thesis paper approaches all the PEM matrix approaches but the deterministic approach is primarily focused.

Table 4.3 RBTS generators data

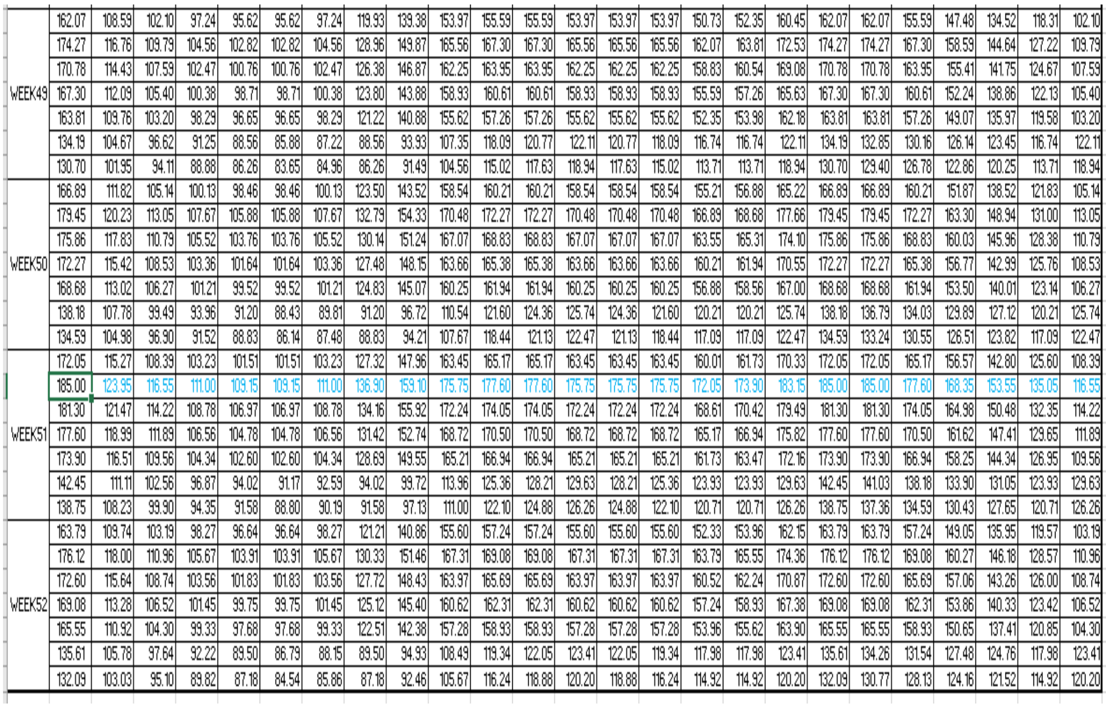
Generator	Location	Rating	Capability (Mvar)		Type
			Min.	Max.	
G1	Bus 1	40	-15	17	Thermal
G2	Bus 1	40	-15	17	Thermal
G3	Bus 1	10	0	7	Thermal
G4	Bus 1	20	-7	12	Thermal
G5	Bus 2	5	0	5	Hydro
G6	Bus 2	5	0	5	Hydro
G7	Bus 2	40	-15	17	Hydro
G8	Bus 2	20	-7	12	Hydro
G9	Bus 2	20	-7	12	Hydro
G10	Bus 2	20	-7	12	Hydro
G11	Bus 2	20	-7	12	Hydro

CHAPTER FIVE: RESULTS AND DISCUSSIONS

5.1. Before DR Implementation

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 DR 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 selects the 51st week, 2nd weekday, and 24 hours data. (Detailed table is attached in appendix).

Table 5.1 selection of 24 hours data from 8760 of RBTS system



WEEK49	162.07	108.59	102.10	97.24	95.62	95.62	97.24	119.93	139.38	153.97	155.59	155.59	153.97	153.97	153.97	150.73	152.35	160.45	162.07	162.07	155.59	147.48	134.52	118.31	102.10
	174.27	116.76	109.79	104.56	102.82	102.82	104.56	128.96	149.87	165.56	167.30	167.30	165.56	165.56	165.56	162.07	163.81	172.53	174.27	174.27	167.30	158.59	144.64	127.22	109.79
	170.78	114.43	107.59	102.47	100.76	100.76	102.47	126.38	146.87	162.25	163.95	163.95	162.25	162.25	162.25	158.83	160.54	169.08	170.78	170.78	163.95	155.41	141.75	124.67	107.59
	167.30	112.09	105.40	100.38	98.71	98.71	100.38	123.80	143.88	158.93	160.61	160.61	158.93	158.93	158.93	155.59	157.26	165.63	167.30	167.30	160.61	152.24	138.86	122.13	105.40
	163.81	109.76	103.20	98.29	96.65	96.65	98.29	121.22	140.88	155.62	157.26	157.26	155.62	155.62	155.62	152.35	153.98	162.18	163.81	163.81	157.26	149.07	135.97	119.58	103.20
	134.19	104.67	96.62	91.25	88.56	85.88	87.22	88.56	93.93	107.35	118.09	120.77	122.11	120.77	118.09	116.74	116.74	122.11	134.19	132.85	130.16	126.14	123.45	116.74	122.11
	130.70	101.95	94.11	88.88	86.26	83.65	84.96	86.26	91.49	104.56	115.02	117.63	118.94	117.63	115.02	113.71	113.71	118.94	130.70	129.40	126.78	122.86	120.25	113.71	118.94
WEEK50	166.89	111.82	105.14	100.13	98.46	98.46	100.13	123.50	143.52	158.54	160.21	160.21	158.54	158.54	158.54	155.21	156.88	165.22	166.89	166.89	160.21	151.87	138.52	121.83	105.14
	179.45	120.23	113.05	107.67	105.88	105.88	107.67	132.79	154.33	170.48	172.27	172.27	170.48	170.48	170.48	166.89	168.68	177.66	179.45	179.45	172.27	163.30	148.94	131.00	113.05
	175.86	117.83	110.79	105.52	103.76	103.76	105.52	130.14	151.24	167.07	168.83	168.83	167.07	167.07	167.07	163.55	165.31	174.10	175.86	175.86	168.83	160.03	145.96	128.38	110.79
	172.27	115.42	108.53	103.36	101.64	101.64	103.36	127.48	148.15	163.66	165.38	165.38	163.66	163.66	163.66	160.21	161.94	170.55	172.27	172.27	165.38	156.77	142.99	125.76	108.53
	168.68	113.02	106.27	101.21	99.52	99.52	101.21	124.83	145.07	160.25	161.94	161.94	160.25	160.25	160.25	156.88	158.56	167.00	168.68	168.68	161.94	153.50	140.01	123.14	106.27
	138.18	107.78	99.49	93.96	91.20	88.43	89.81	91.20	96.72	110.54	121.60	124.36	125.74	124.36	121.60	120.21	120.21	125.74	138.18	136.79	134.03	129.89	127.12	120.21	125.74
	134.59	104.98	96.90	91.52	88.83	86.14	87.48	88.83	94.21	107.67	118.44	121.13	122.47	121.13	118.44	117.09	117.09	122.47	134.59	133.24	130.55	126.51	123.82	117.09	122.47
WEEK51	172.05	115.27	108.39	103.23	101.51	101.51	103.23	127.32	147.96	163.45	165.17	165.17	163.45	163.45	163.45	160.01	161.73	170.33	172.05	172.05	165.17	156.57	142.80	125.60	108.39
	185.00	123.95	116.55	111.00	109.15	109.15	111.00	136.90	159.10	175.75	177.60	177.60	175.75	175.75	175.75	172.05	173.90	183.15	185.00	185.00	177.60	168.35	153.55	135.05	116.55
	181.30	121.47	114.22	108.78	106.97	106.97	108.78	134.16	155.92	172.24	174.05	174.05	172.24	172.24	172.24	168.61	170.42	179.49	181.30	181.30	174.05	164.98	150.48	132.35	114.22
	177.60	118.99	111.89	106.56	104.78	104.78	106.56	131.42	152.74	168.72	170.50	170.50	168.72	168.72	168.72	165.17	166.94	175.82	177.60	177.60	170.50	161.62	147.41	129.65	111.89
	173.90	116.51	109.56	104.34	102.60	102.60	104.34	128.69	149.55	165.21	166.94	166.94	165.21	165.21	165.21	161.73	163.47	172.16	173.90	173.90	166.94	158.25	144.34	126.95	109.56
	142.45	111.11	102.56	96.87	94.02	91.17	92.59	94.02	99.72	113.96	125.36	128.21	129.63	128.21	125.36	123.93	123.93	129.63	142.45	141.03	138.18	133.90	131.05	123.93	129.63
	138.75	108.23	99.90	94.35	91.58	88.80	90.19	91.58	97.13	111.00	122.10	124.88	126.26	124.88	122.10	120.71	120.71	126.26	138.75	137.36	134.59	130.43	127.65	120.71	126.26
WEEK52	163.79	109.74	103.19	98.27	96.64	96.64	98.27	121.21	140.86	155.60	157.24	157.24	155.60	155.60	155.60	152.33	153.96	162.15	163.79	163.79	157.24	149.05	135.95	119.57	103.19
	176.12	118.00	110.96	105.67	103.91	103.91	105.67	130.33	151.46	167.31	169.08	169.08	167.31	167.31	167.31	163.79	165.55	174.36	176.12	176.12	169.08	160.27	146.18	128.57	110.96
	172.60	115.64	108.74	103.56	101.83	101.83	103.56	127.72	148.43	163.97	165.69	165.69	163.97	163.97	163.97	160.52	162.24	170.87	172.60	172.60	165.69	157.06	143.26	126.00	108.74
	169.08	113.28	106.52	101.45	99.75	99.75	101.45	125.12	145.40	160.62	162.31	162.31	160.62	160.62	160.62	157.24	158.93	167.38	169.08	169.08	162.31	153.86	140.33	123.42	106.52
	165.55	110.92	104.30	99.33	97.68	97.68	99.33	122.51	142.38	157.28	158.93	158.93	157.28	157.28	157.28	153.96	155.62	163.90	165.55	165.55	158.93	150.65	137.41	120.85	104.30
	135.61	105.78	97.64	92.22	89.50	86.79	88.15	89.50	94.93	108.49	119.34	122.05	123.41	122.05	119.34	117.98	117.98	123.41	135.61	134.26	131.54	127.48	124.76	117.98	123.41
	132.09	103.03	95.10	89.82	87.18	84.54	85.86	87.18	92.46	105.67	116.24	118.88	120.20	118.88	116.24	114.92	114.92	120.20	132.09	130.77	128.13	124.16	121.52	114.92	120.20

The daily load cure is plotted for the 24 hours and it is obvious from the graph that the peak demand occurred during the evening time (6pm to 8 pm) and hence this thesis approached to reduce this peak or shift this hike in demand to other interval time where is less demand occurred. The system load curve for this 185MW peak is as follows (before DR implementation):

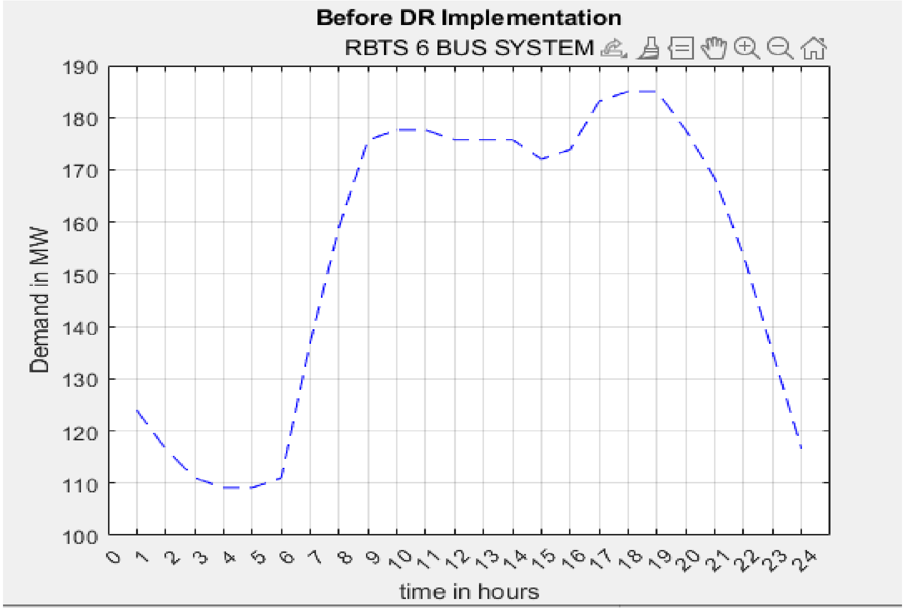
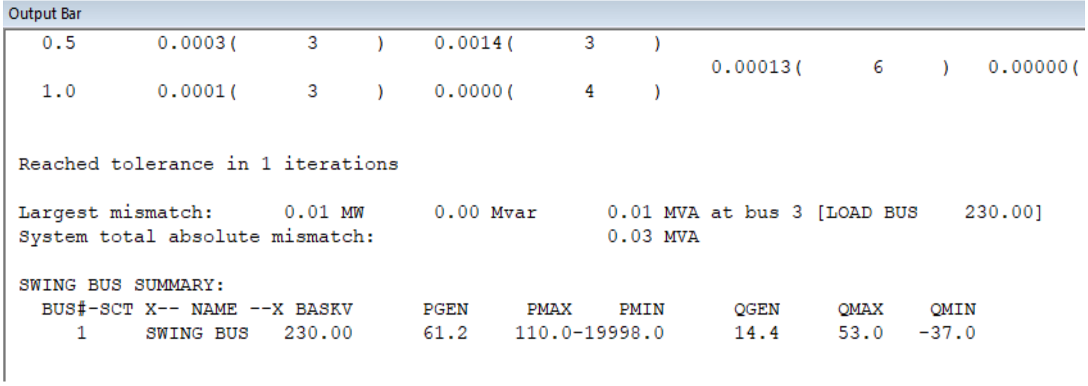


Figure 5.1: Before DR Implementation

In the standard 6 bus RBTS system power flow is carried out by fixed slope decoupled newton Raphson method and the system convergent occurs as below:



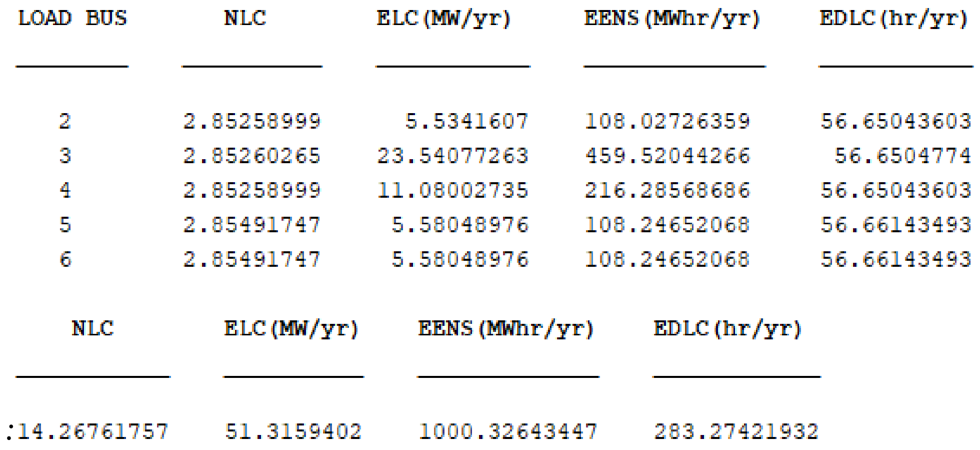
```
   0.5        0.0003(      3     )     0.0014(      3     )
                                                                    0.00013(      6     )     0.00000(
   1.0        0.0001(      3     )     0.0000(      4     )


 Reached tolerance in 1 iterations

 Largest mismatch:       0.01 MW      0.00 Mvar        0.01 MVA at bus 3 [LOAD BUS     230.00]
 System total absolute mismatch:                       0.03 MVA

 SWING BUS SUMMARY:
   BUS#-SCT X-- NAME --X BASKV      PGEN     PMAX      PMIN       QGEN     QMAX     QMIN
      1       SWING BUS    230.00     61.2    110.0-19998.0       14.4     53.0    -37.0
```

Figure 5.2: swing bus generation after load flow simulation



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

   2         2.85258999       5.5341607     108.02726359      56.65043603
   3         2.85260265     23.54077263     459.52044266       56.6504774
   4         2.85258999     11.08002735     216.28568686      56.65043603
   5         2.85491747      5.58048976     108.24652068      56.66143493
   6         2.85491747      5.58048976     108.24652068      56.66143493

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

:14.26761757     51.3159402     1000.32643447     283.27421932
```

Figure 5.3: Reliability indices before DR implementation

5.2. After DR Implementation

This EENS is validated with the references [37] where the EENS(MWhr/yr) calculated as 1081.01. Now the TOU DR is implemented and the new demand data is obtained from the deterministic approach of PEM and comparative plot is obtained as below where the peak demand is reduced from 185MW to 183.58 MW.

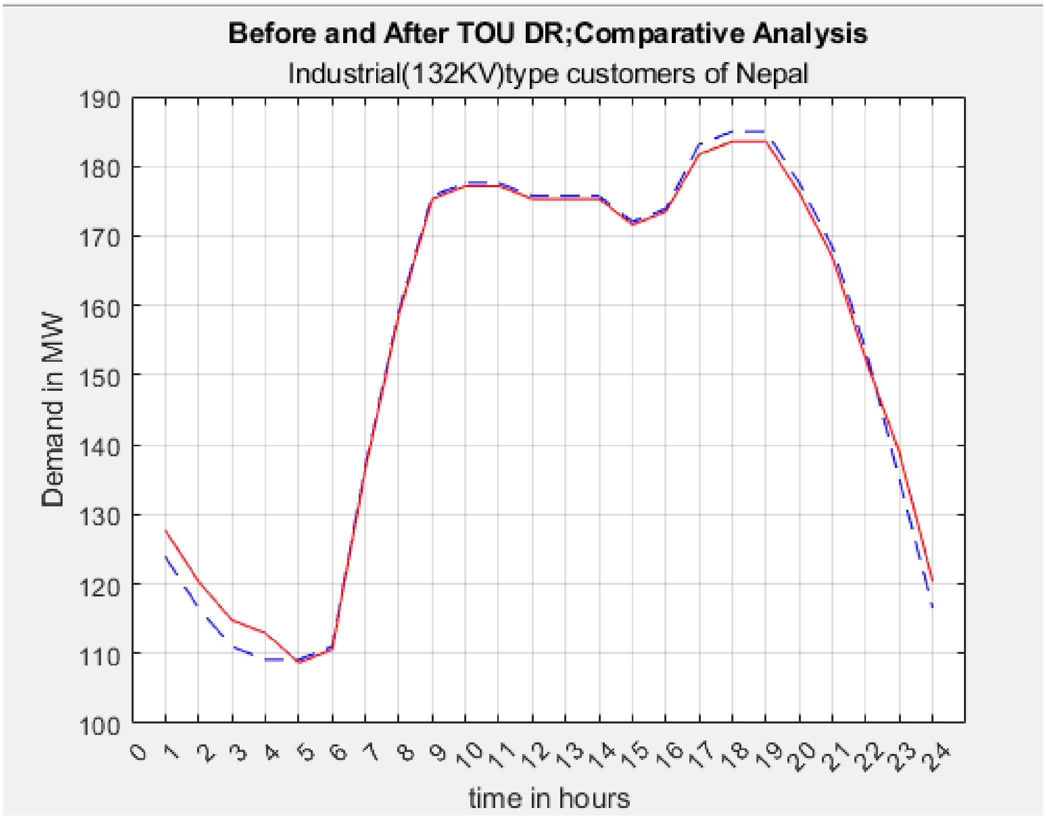
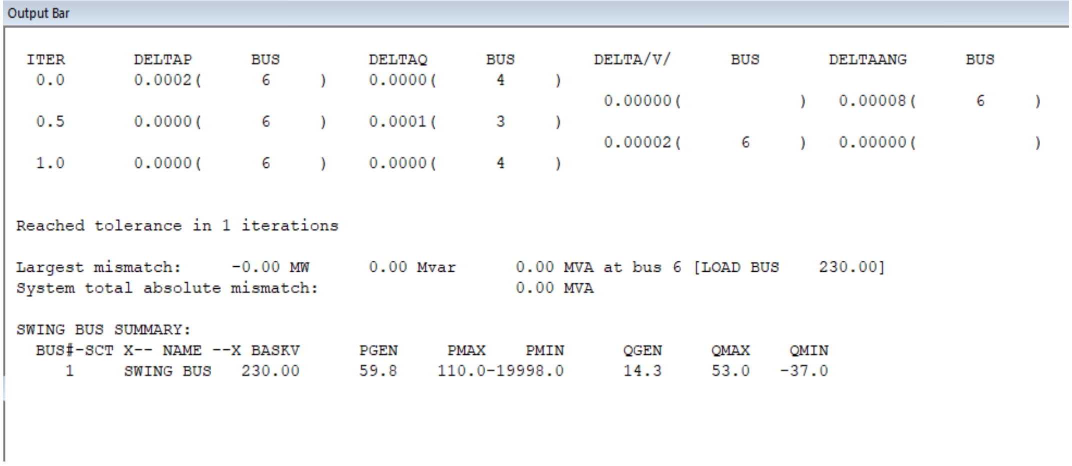


Figure 5.4: Before and after TOU DR; comparative analysis

Initially, the result below shows the load flow of changed demand in the 6-bus system:



```
 ITER       DELTAP      BUS         DELTAQ      BUS        DELTA/V/      BUS       DELTAANG      BUS
  0.0       0.0002(      6     )    0.0000(      4     )
                                                            0.00000(            )   0.00008(      6     )
  0.5       0.0000(      6     )    0.0001(      3     )
                                                            0.00002(      6     )   0.00000(            )
  1.0       0.0000(      6     )    0.0000(      4     )


Reached tolerance in 1 iterations

Largest mismatch:     -0.00 MW      0.00 Mvar      0.00 MVA at bus 6 [LOAD BUS    230.00]
System total absolute mismatch:                    0.00 MVA

SWING BUS SUMMARY:
  BUS#-SCT X-- NAME --X BASKV      PGEN     PMAX    PMIN      QGEN     QMAX    QMIN
     1     SWING BUS   230.00      59.8    110.0-19998.0      14.3     53.0   -37.0
```

Figure 5.5: Swing bus generation after the load flow simulation after DR implementation

5.3. Comparative study on before and after TOU DR

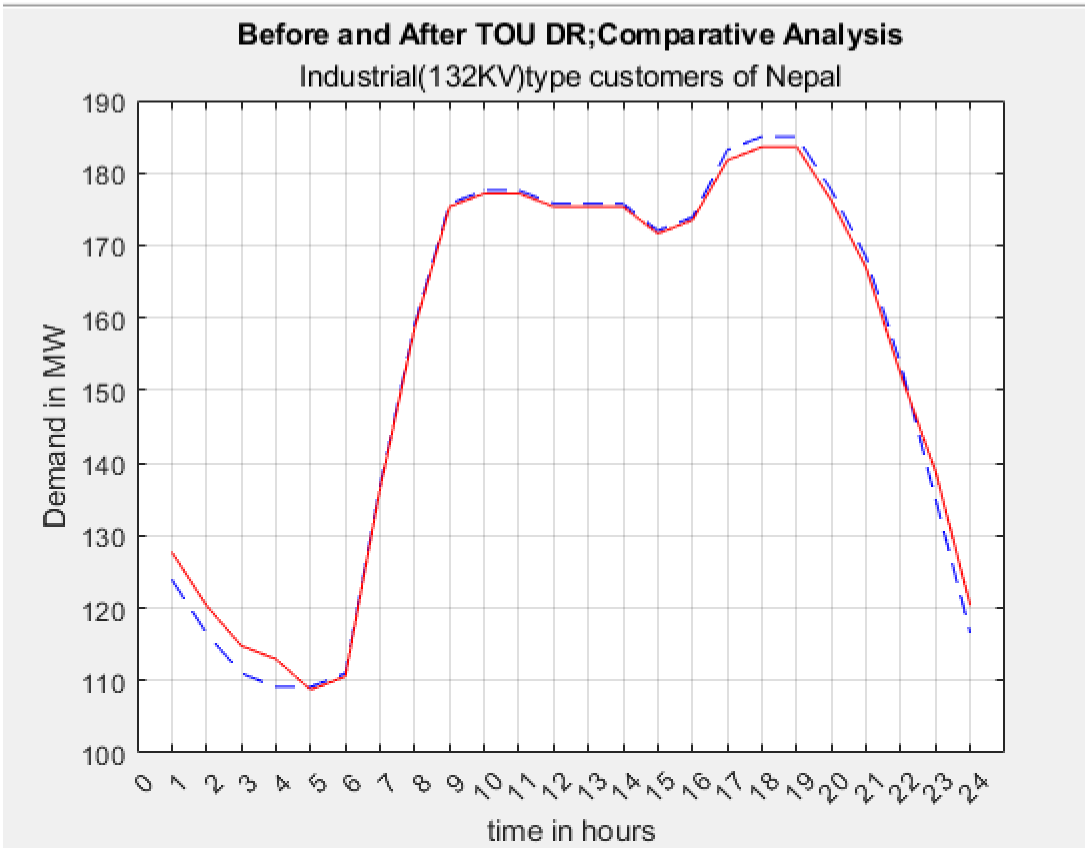
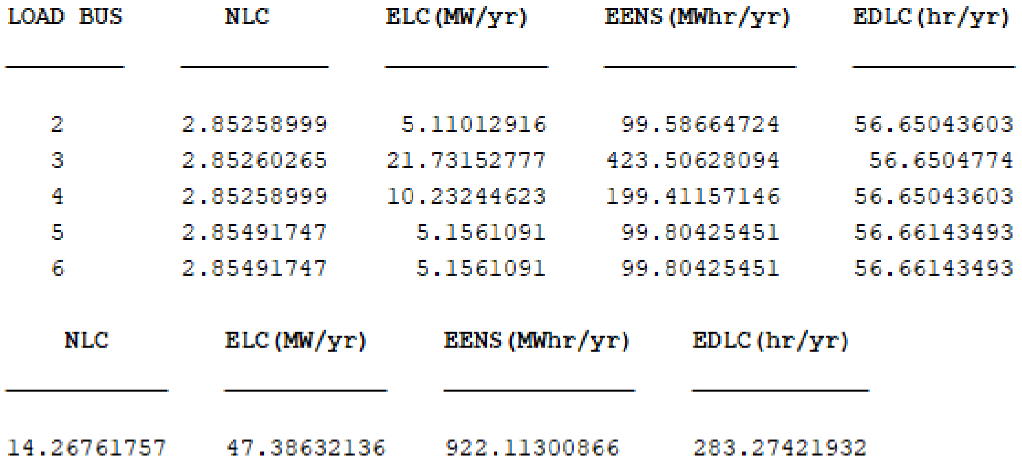


Figure 5.6: Before and after TOU DR for industrial customer of Nepal



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

    2          2.85258999      5.11012916      99.58664724     56.65043603
    3          2.85260265     21.73152777     423.50628094      56.6504774
    4          2.85258999     10.23244623     199.41157146     56.65043603
    5          2.85491747       5.1561091      99.80425451     56.66143493
    6          2.85491747       5.1561091      99.80425451     56.66143493

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

14.26761757     47.38632136     922.11300866      283.27421932
```

Figure 5.7: EENS and EDLC evaluation on all nodal buses for TOU pricing

Comparative analysis in between the various types of consumers based on pre-defined PEM:

For this demand data is taken for 24 hours of the peak day (2nd day of 51st week) of RBTS and new consumption is determined with the help of equation no.16

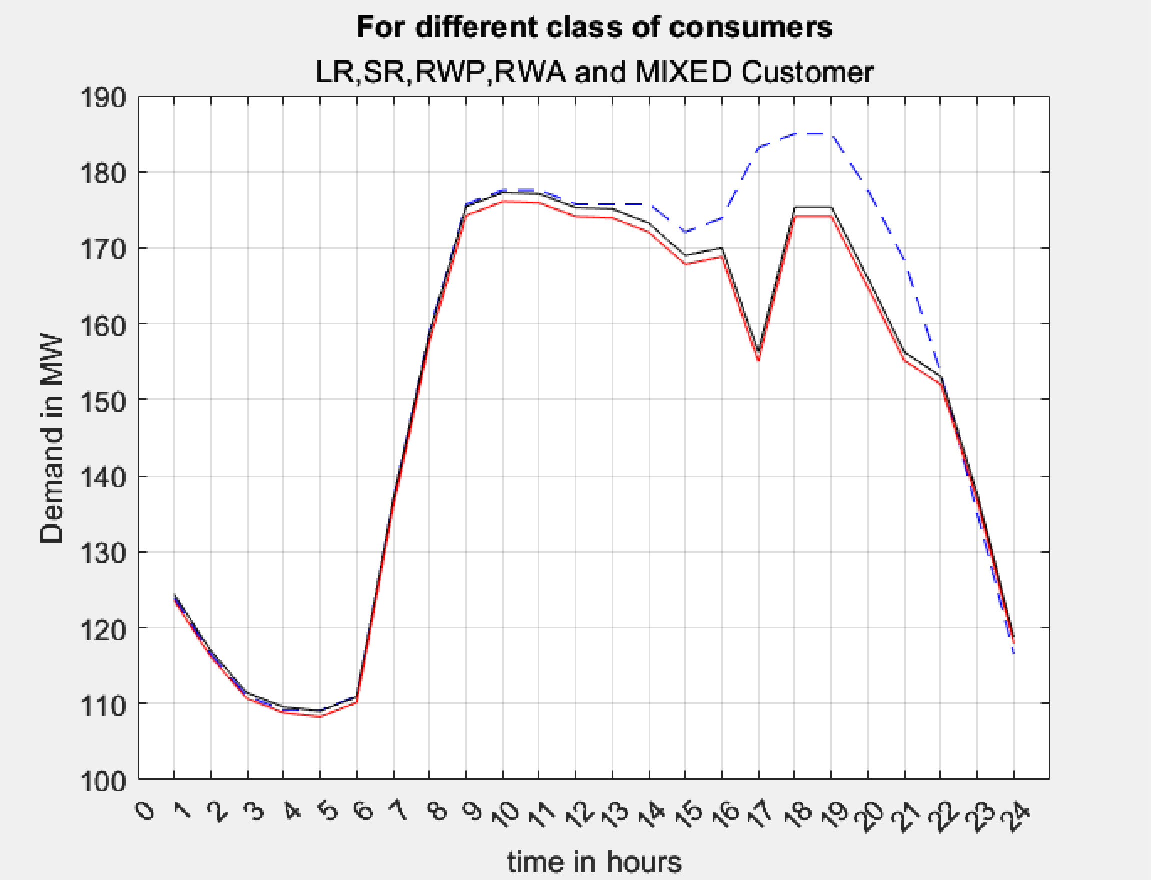


Figure 5.8: Load duration curve for different consumer based on respective PEMs

5.4. DR and reliability indices evaluation on different consumers of NEA

Based on the NEA report-2023, electricity consumers are classified in the following 5 categories as:

Table 5.2 Customer classifications of NEA consumers

Customer Category	Percent of total consumers (%)	Sales (%)	Revenue (%)
Domestic	92.32	41.58	38.15
Non-Commercial	0.70	2.95	4.30
Commercial	0.76	7.87	11.43
Industrial	1.31	38.31	38.44
Others	4.91	9.29	7.68

On analysis the above data and with our definition of DR, 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.

Most of the big industries (such as cement factories, food and brewery factory etc.) not paying the tariff to the NEA in time and the other horror scenario is NEA has been importing electricity from India's various states such Uttarakhand, Bihar and Uttar Pradesh when needed but these utilities taking more electricity from Bihar than the other 2 states. The importing rate has been set so that Nepal can get electricity in cheaper rate than that of previous rate.

The class wise elasticity values for different customers are given in literature [48] and can do the analogy in the context of Nepal by using deterministic approach of PEM:

Table 5.3 allocation of peak elasticity for NEA customers for deterministic PEM approach

CUSTOMER CLASS	PEAK ELASTICITY	NEA CUSTOMER CLASS
R (Residential customers)	-0.3	Domestic customers
LI (Large industrial customers)	-0.42	Industrial customers
MI (Medium industrial customers)	-0.38	Non-commercial customers
C (Commercial customers)	-0.30	Commercial customers
A (Agricultural customers)	-0.23	Other customers

Nepal and India have agreed to hike rates of electricity to be supplied via cross-border trade. At the revised rate, Nepal is set to procure electricity generated in Bihar and Uttar Pradesh at Rs 11.54 (INR 7.21) per unit. This new rate reflects a 5.5 percent increase compared to the current rate at which Nepal purchases electricity [38].

In this case, if we success to implement at least the IBDR programs to the existing industries NEA can meet the peak demand without importing the electricity from India which is far cheaper than those cost. As per NEA the current generation of our country is as follows:

Table 5.4 Electricity generation, import and interruption data of Nepal

Total energy demand	31338 MWH
NEA	6548 MWH
NEA subsidiaries company	3468 MWH
IPP	12875 MWH
IMPORT	7788 MWH
Interruption	660MWH
Total peak demand	1711MW

And in the process of compiling this report, it's noteworthy that the peak demand recorded on January 15, 2024, stands at 1711MW. Notably, the highest peak demands are consistently observed during festival periods, particularly during Laxmi Puja. Interestingly, despite the closure of industries and factories during these festive times, the demand remains high [39].

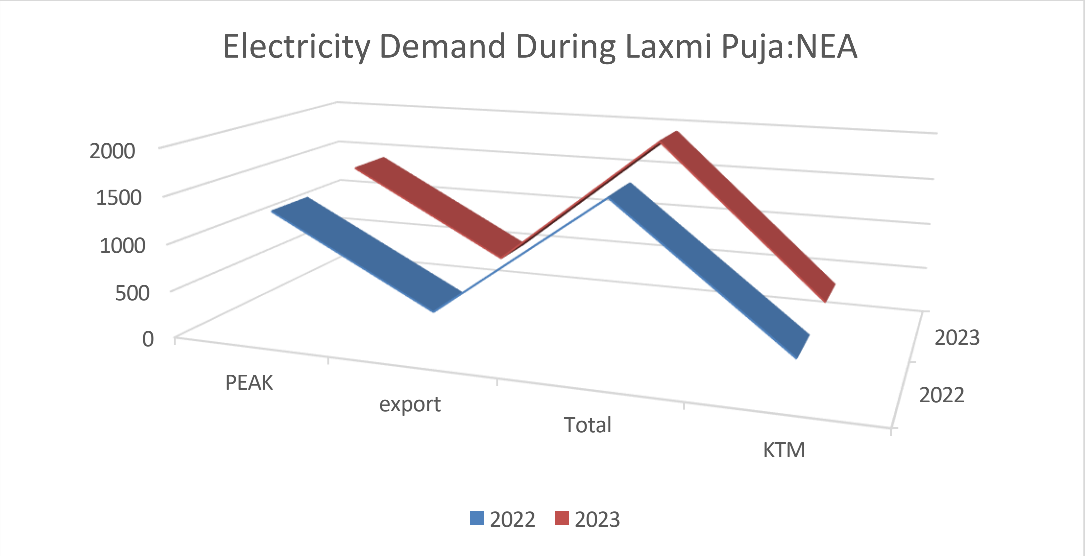


Figure 5.9: Electricity Demand during Laxmi Puja: NEA

For instance, during the current year's Tihar festival on November 13, 2023, at 6 pm, the peak demand surged to 1438MW. This represents a notable increase of 133MW compared to the previous year's peak demand recorded on October 24, 2022, at the same time. Such fluctuations in peak demand during festive periods underscore the importance of effective DR strategies to manage and optimize energy consumption during these critical times [39].

NEA has cut off the power of 24 industries after (22 December, 2023) 6th push, out of 61 industries which did not pay dues. After paying the installment, NEA has connected power to Himal Iron. NEA claims that 61 industries must pay 22.24 billion in arrears. In this case, if we have implemented the IBDR in such industries, the contract policy will be more effective, and it may not affect any parties (utilities and customer).

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. 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:

Table 5.5 Result of EENS and EDLC evaluation for various category of customers of NEA

Customer Category	After DR	Swing bus generation	NLC	ELC (MW/yr.)	EENS (Mwhr/yr.)	EDLC (hr. /yr.)
Domestic customers	173.6518	49.5	4.6824	19.5409	371.1601	91.0540
Industrial customers	184.6220	60.8	14.2676	50.2144	978.3515	283.2742
Non-commercial customers	179.9000	56	14.2676	36.836	712.4313	283.2742
Commercial customers	173.5202	49.4	4.6824	19.4365	369.0948	91.0540
Other customers	174.8589	50.7	4.9446	21.0506	398.6917	94.8396

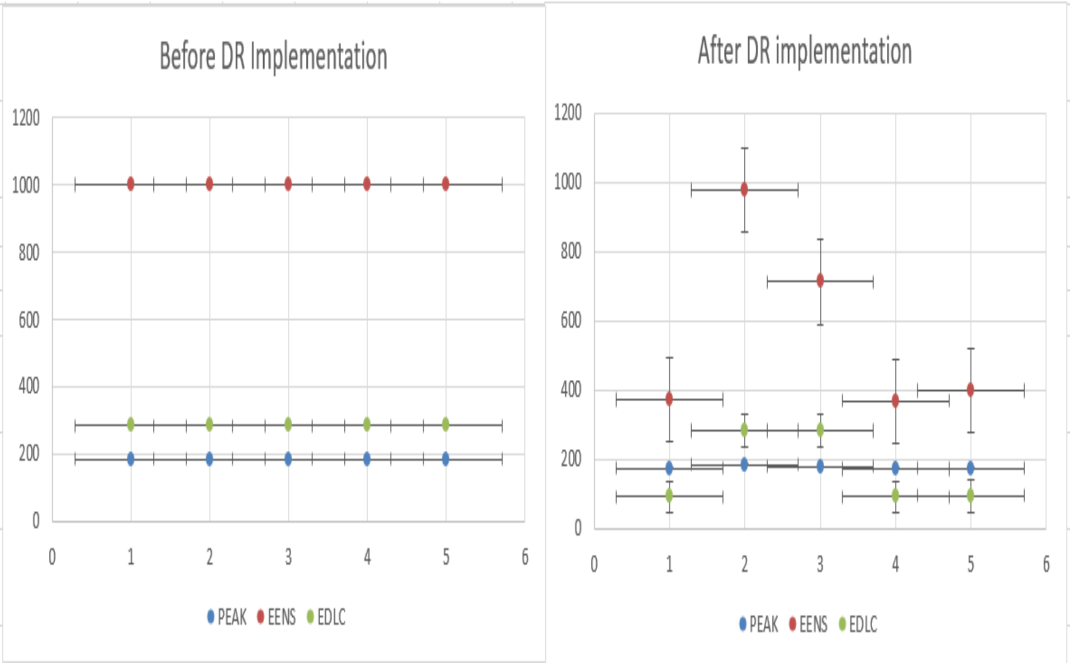


Figure 5.10: various indices comparisons on different category of customers BDR and ADR

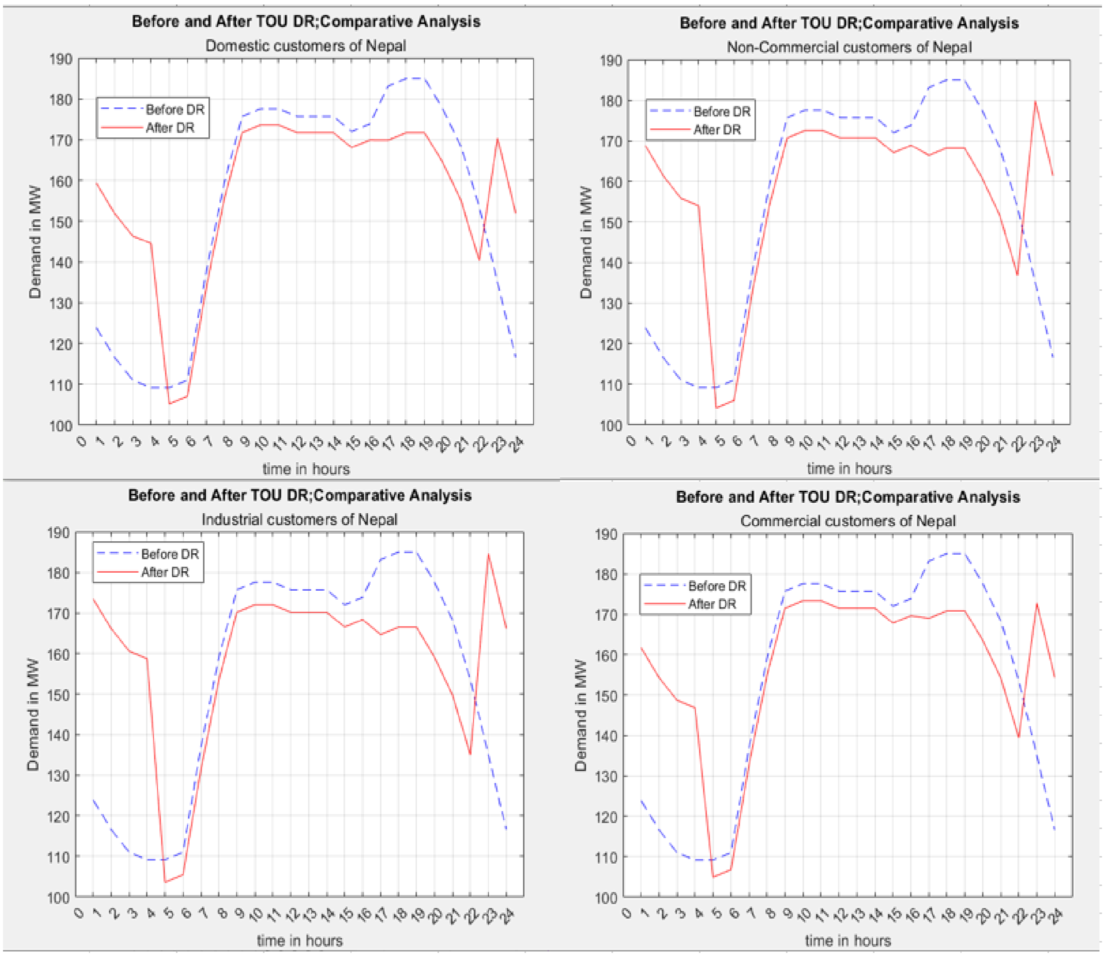


Figure 5.11Result of peak demand in BDR and ADR for various category of customers of NEA

5.5. IBDR and PBDR comparison result

PBDR resources primarily stem from residential users, whose engagement is entirely voluntary, rendering them non-dispatchable. The challenge lies in accurately gauging DR capacity due to its non-dispatchable nature. However, the proliferation of smart metering has ushered in new advancements for this type of DR resource. Through the aggregation of dispersed users and the strategic allocation of Energy Storage (ES) devices, an aggregate dispatchable resource emerges. This collective resource can respond to mutually bonded electricity prices or other logical price notices, providing a directional response and yielding financial returns.

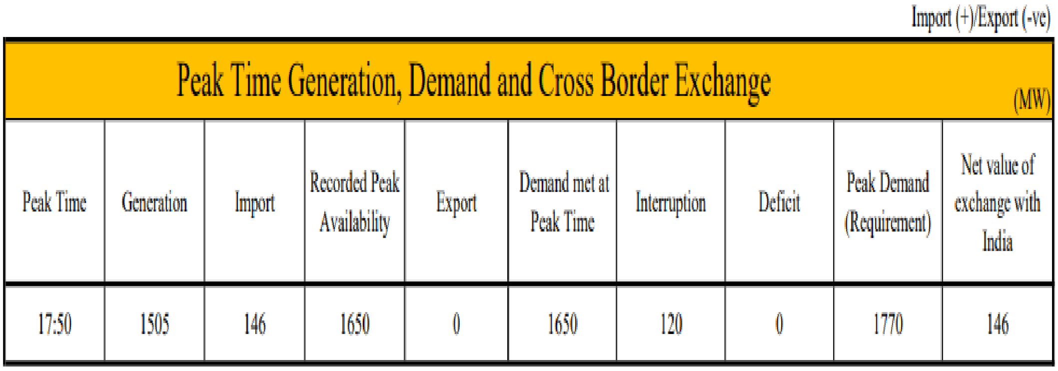
IBDR resources typically involve commercial and industrial users and are openly transacted on electricity markets. Grid dispatchers have the flexibility to prearrange electricity usage plans with participants, enabling them to be dispatched as needed. These DR resources typically incorporate Energy Storage (ES) devices, such as batteries, thermal storage, or ice storage air conditioning, enhancing their ability to respond efficiently to grid demands.

It can be anticipated that large industries in Nepal, capable of curtailing a minimum of 2MW and above, can fall under the category of IBDR. Simultaneously, the collective involvement of domestic and commercial consumers could exemplify the concept of PBDR. Consequently, if the 20 major large industries, spanning sectors like cement, brewery, food, and hospitals, garner an 80% participation rate from domestic and commercial consumers, they could collectively generate a peak capacity of 140MW as depicted in table 5.5. This self-sufficiency in power generation could potentially eliminate the need for importing electricity from India.

5.6. Role of DR in Nepal on reducing the Import power from India

According to the NEA records as of January 3, 2024, despite Nepal's installed generation capacity reaching 2900MW in the wet season, the dry season witnesses a significant drop to nearly 52% of the rainy season's output. Consequently, to fulfill the 1650MW demand, Nepal resorts to importing 146MW from India. Successful implementation of both a PBDR program for domestic consumers and an IBDR model for industrial consumers could alleviate the need for such high-rate electricity imports from India.

Table 5.6 NEA’s peak time (6pm) generation, demand and import from India



Import (+)/Export (-ve)

Peak Time Generation, Demand and Cross Border Exchange

(MW)

Peak Time	Generation	Import	Recorded Peak Availability	Export	Demand met at Peak Time	Interruption	Deficit	Peak Demand (Requirement)	Net value of exchange with India
17:50	1505	146	1650	0	1650	120	0	1770	146

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1. Conclusions

This thesis presents and formulates a model for electricity DR, which includes the development of extensive price elasticity models designed on diverse end users. On applying economic principles to these matrices, they serve as a foundation for quantifying the potential DR achievable for each type of consumer. The resulting DR mathematical models are successively integrated into the RBTS-6 Bus system and all contingencies analyzed with PSSE software.

Moreover, the thesis systematically evaluates the impact of DR on system reliability. Simulation results unequivocally demonstrate that DR programs significantly enhance both overall system reliability and the reliability of specific nodes within a deregulated power system. These findings underscore the effectiveness of DR initiatives in bolstering the reliability of power systems operating under deregulated frameworks.

6.2. Recommendations and future works

DR is increasingly recognized as a pivotal element in multi-objective DSM strategies. The advancement of modern control and communication technology within the network promises significant profits for both ISOs/RTOs and customers through DR implementation. One promising area for future research is the seamless integration of DR with volt/var control, which holds the potential for remarkable advantages. There is a critical need for a coordinated distribution management system that incorporates distribution automation, DR, volt/var control, and fault location, isolation, and restoration, to address current challenges in the distribution grid effectively. This thesis lays the groundwork for ambitious projects aimed at improving grid efficiency and reliability in the realm of modern distribution systems. DR has substantial potential beyond distribution systems, particularly at the transmission level. These programs can impact the market clearing price, thereby mitigating price spikes and promoting a more stable economic environment. A thorough study of such varied impacts of DR on the transmission network is crucial for fully understanding its potential benefits and implications.

REFERENCES

[1] M. H. Albadi and E. F. El-Saadany, “Demand Response in Electricity Markets: An Overview,” in *2007 IEEE Power Engineering Society General Meeting*, Tampa, FL, USA: IEEE, Jun. 2007, pp. 1–5. doi: 10.1109/PES.2007.385728.

[2] S. Ali *et al.*, “Demand Response Program for Efficient Demand-Side Management in Smart Grid Considering Renewable Energy Sources,” *IEEE Access*, vol. 10, pp. 53832–53853, 2022, doi: 10.1109/ACCESS.2022.3174586.

[3] H. Wang, S. Wang, and R. Tang, “Development of grid-responsive buildings: Opportunities, challenges, capabilities and applications of HVAC systems in non-residential buildings in providing ancillary services by fast demand responses to smart grids,” *Appl. Energy*, vol. 250, pp. 697–712, Sep. 2019, doi: 10.1016/j.apenergy.2019.04.159.

[4] “National Assessment and Action Plan on Demand Response | Federal Energy Regulatory Commission.” Accessed: Jan. 22, 2024. [Online]. Available:https://www.ferc.gov/electric/industry-activity/demand-response/national- assessment-and-action-plan-demand-response

[5] S. Khemakhem, M. Rekik, and L. Krichen, “Double layer home energy supervision strategies based on demand response and plug-in electric vehicle control for flattening power load curves in a smart grid,” *Energy*, vol. 167, pp. 312–324, Jan. 2019, doi: 10.1016/j.energy.2018.10.187.

[6] H. Aalami, G. R. Yousefi, and M. Parsa Moghadam, “Demand Response model considering EDRP and TOU programs,” in *2008 IEEE/PES Transmission and Distribution Conference and Exposition*, Chicago, IL, USA: IEEE, Apr. 2008, pp. 1–6. doi: 10.1109/TDC.2008.4517059.

[7] D. S. Kirschen, G. Strbac, P. Cumperayot, and D. De Paiva Mendes, “Factoring the elasticity of demand in electricity prices,” *IEEE Trans. Power Syst.*, vol. 15, no. 2,

pp. 612–617, May 2000, doi: 10.1109/59.867149.

[8] K. L. Lo and Z. Zakaria, “Electricity consumer classification using artificial intelligence”.

[9] “NEPAL ELECTRICITY AUTHORITY.” Accessed: Jan. 22, 2024. [Online].

Available: https://www.nea.org.np/annual_report

[10] D. Huang, R. Billinton, and W. Wangdee, “Effects of demand side management on bulk system adequacy evaluation,” in *2010 IEEE 11th International Conference on*

Probabilistic Methods Applied to Power Systems, Singapore, Singapore: IEEE, Jun. 2010, pp. 593–598. doi: 10.1109/PMAPS.2010.5529011.

[11] L. Goel, Qiuwei Wu, and Peng Wang, “Reliability enhancement of a deregulated power system considering demand response,” in *2006 IEEE Power Engineering Society General Meeting*, Montreal, Que., Canada: IEEE, 2006, p. 6 pp. doi: 10.1109/PES.2006.1708965.

[12] R. Azami and A. F. Fard, “Impact of demand response programs on system and nodal reliability of a deregulated power system,” in *2008 IEEE International Conference on Sustainable Energy Technologies*, Singapore, Singapore: IEEE, Nov. 2008, pp. 1262–1266. doi: 10.1109/ICSET.2008.4747200.

[13] X. Yan, Y. Ozturk, Z. Hu, and Y. Song, “A review on price-driven residential demand response,” *Renew. Sustain. Energy Rev.*, vol. 96, pp. 411–419, Nov. 2018, doi: 10.1016/j.rser.2018.08.003.

[14] V. C. Pandey, N. Gupta, K. R. Niazi, A. Swarnkar, T. Rawat, and C. Konstantinou, “A Bi-Level Decision Framework for Incentive-Based Demand Response in Distribution Systems,” *IEEE Trans. Energy Mark. Policy Regul.*, vol. 1, no. 3, pp. 211–225, Sep. 2023, doi: 10.1109/TEMPR.2023.3282443.

[15] M. Parvania and M. Fotuhi-Firuzabad, “Demand Response Scheduling by Stochastic SCUC,” *IEEE Trans. Smart Grid*, vol. 1, no. 1, pp. 89–98, Jun. 2010, doi: 10.1109/TSG.2010.2046430.

[16] “Program Operation Manual”.

[17] X. Qu, H. Hui, S. Yang, Y. Li, and Y. Ding, “Price elasticity matrix of demand in power system considering demand response programs,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 121, p. 052081, Feb. 2018, doi: 10.1088/1755- 1315/121/5/052081.

[18] R. Rajaraman, J. V. Sarlashkar, and F. L. Alvarado, “The effect of demand elasticity on security prices for the PoolCo and multi-lateral contract models,” *IEEE Trans. Power Syst.*, vol. 12, no. 3, pp. 1177–1184, Aug. 1997, doi: 10.1109/59.630459.

[19] V. J. Martinez and H. Rudnick, “Design of Demand Response programs in emerging countries,” in *2012 IEEE International Conference on Power System Technology (POWERCON)*, Auckland: IEEE, Oct. 2012, pp. 1–6. doi: 10.1109/PowerCon.2012.6401387.

[20] “RTOs and ISOs | Federal Energy Regulatory Commission.” Accessed: Jan. 22, 2024. [Online]. Available: https://www.ferc.gov/power-sales-and-markets/rtos- and-isos

[21] E. Hirst, “Reliability benefits of price-responsive demand,” *IEEE Power Eng.*

Rev., vol. 22, no. 11, pp. 16–21, Nov. 2002, doi: 10.1109/MPER.2002.1045557.

[22] “PJM - Demand Response.” Accessed: Jan. 22, 2024. [Online]. Available: https://www.pjm.com/markets-and-operations/demand-response.aspx

[23] A. Abate, “Demand Response Providing Ancillary Services with Direct to NYISO Connectivity”.

[24] “NYISO | Federal Energy Regulatory Commission.” Accessed: Jan. 22, 2024. [Online]. Available: https://www.ferc.gov/industries-data/electric/electric-power-markets/nyiso

[25] “9-Demand-Response.pdf.” Accessed: Jan. 22, 2024. [Online]. Available: https://www.nyiso.com/documents/20142/3037451/9-Demand-Response.pdf

[26] H. Yoshimura, “2022 Comprehensive Energy Strategy Technical Session #5 Active Demand Response”.

[27] “Business Practices Manuals.” Accessed: Jan. 22, 2024. [Online]. Available: https://www.misoenergy.org/legal/rules-manuals-and-agreements/business- practice-manuals/“ISO New England.” Accessed: Jan. 23, 2024. [Online]. Available: https://www.iso-ne.com/

[28] “Data Product Details.” Accessed: Jan. 22, 2024. [Online]. Available: https://www.ercot.com/mp/data-products/data-product-details?id=NP3-110

[29] “Demand Response.” Accessed: Jan. 22, 2024. [Online]. Available: https://www.ercot.com/services/programs/load

[30] “Demand Response.” Accessed: Jan. 23, 2024. [Online]. Available: https://www.ieso.ca/en/Learn/Ontario-Electricity-Grid/Demand-Response

[31] “Real-time Energy Market.” Accessed: Jan. 23, 2024. [Online]. Available: https://www.ieso.ca/en/Sector-Participants/Market-Operations/Markets-and-Related-Programs/Real-time-Energy-Market

[32] “Operating Reserve Markets.” Accessed: Jan. 23, 2024. [Online]. Available: https://www.ieso.ca/Sector-Participants/Market-Operations/Markets-and-Related-Programs/Operating-Reserve-Markets

[33] “Market Rules & Manuals Library.” Accessed: Jan. 23, 2024. [Online]. Available: https://www.ieso.ca/Sector-Participants/Market-Operations/Market-Rules-And-Manuals-Library

[34] “Qualtrics Survey | Qualtrics Experience Management.” Accessed: Jan. 22, 2024. [Online]. Available: https://feedback.saskpower.com/jfe/form/SV_2i5xMZLX8J0ku6a?Q_CHL=si&Q

_CanScreenCapture=1

[35] European Commission. Directorate General for Energy. and Tractebel Impact., *Benchmarking smart metering deployment in the EU-28: final report.* LU: Publications Office, 2020. Accessed: Jan. 23, 2024. [Online]. Available: https://data.europa.eu/doi/10.2833/492070

[36] “Composite system reliability evaluation using monte carlo simulation.pdf.”

[37] Republica, “Rates of Nepal-India cross border electricity supply hiked; India agrees allowing Nepal to use its border based transmission lines,” My Republica. Accessed: Jan. 22, 2024. [Online]. Available: http://myrepublica.nagariknetwork.com/news/137832/

[38] author, “Electricity demand hits record 1438 MW on Laxmi Puja: NEA.” Accessed: Jan. 22, 2024. [Online]. Available: https://en.nepalkhabar.com/news/detail/6999/

APPENDIX I: PUBLICATION

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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

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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 ith hour (MWhr)

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

$p(i)$ =RTP in ith hour (\$/MWhr)

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

$\beta(i)$ =Customer income in ith hour (\$/MWhr)

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

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.

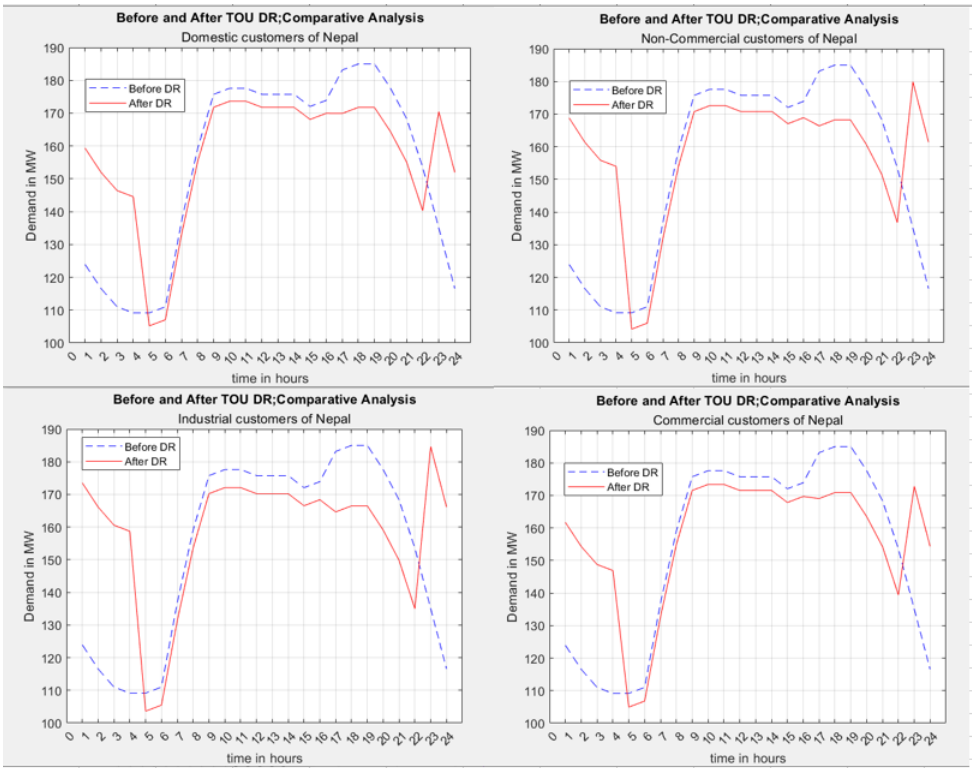

Figure 1. Changes in the peak demand after using TOU DR programs on various type customers of Nepal.

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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References

Aalami, H., Yousefi, G.R. and Parsa Moghadam, M., 2008. Demand Response model considering EDRP and TOU programs. In: *2008 IEEE/PES Transmission and Distribution Conference and Exposition*. [online] Exposition. Chicago, IL, USA: IEEE. pp.1–6. https://doi.org/10.1109/TDC.2008.4517059.

Ali, A.N.F., Sulaima, M.F., Razak, I.A.W.A., Kadir, A.F.A. and Mokhlis, H., 2023. Artificial Intelligence Application in Demand Response: Advantages, Issues, Status, and Challenges. *IEEE Access*, 11, pp.16907–16922. https://doi.org/10.1109/ACCESS.2023.3237737.

Ali, S., Rehman, A.U., Wadud, Z., Khan, I., Murawwat, S., Hafeez, G., Albogamy, F.R., Khan, S. and Samuel, O., 2022. Demand Response Program for Efficient Demand-Side Management in Smart Grid Considering Renewable Energy Sources. *IEEE Access*, 10, pp.53832–53853. https://doi.org/10.1109/ACCESS.2022.3174586.

Anon. 2024. *RTOs and ISOs | Federal Energy Regulatory Commission*. [Online] Available at: <https://www.ferc.gov/power-sales-and-markets/rtos-and-isos> [Accessed 22 January 2024].

Anon. n.d. *Yoshimura - 2022 Comprehensive Energy Strategy Technical Sessi.pdf*. Available at: <https://www.iso-ne.com/static-assets/documents/2022/11/iso_dr_11_03_2022_hy.pdf> [Accessed 22 January 2024h].

Anon. n.d. *Zhang and Li - 2012 - Demand response in electricity markets A review.pdf*.

Azami, R. and Fard, A.F., 2008. Impact of demand response programs on system and nodal reliability of a deregulated power system. In: *2008 IEEE International Conference on Sustainable Energy Technologies*. [online] 2008 IEEE International Conference on Sustainable Energy Technologies (ICSET). Singapore, Singapore: IEEE. pp.1262–1266. https://doi.org/10.1109/ICSET.2008.4747200.

Baboli, P.T., Moghaddam, M.P. and Eghbal, M., 2011. Present status and future trends in enabling demand response programs. In: *2011 IEEE Power and Energy Society General Meeting*. [online] 2011 IEEE Power & Energy Society General Meeting. San Diego, CA: IEEE. pp.1–6. https://doi.org/10.1109/PES.2011.6039608.

Ishii, H., n.d. Japan Demand Response Market Overview.

Liu, Y., 2017. Demand response and energy efficiency in the capacity resource procurement: Case studies of forward capacity markets in ISO New England, PJM and Great Britain. *Energy Policy*, 100, pp.271–282. https://doi.org/10.1016/j.enpol.2016.10.029.

Ma, J. and Venkatesh, B., 2022. New Real-Time Demand Response Market Co-Optimized with Conventional Energy Market. *IEEE Systems Journal*, 16(4), pp.6381–6392. https://doi.org/10.1109/JSYST.2021.3132786.

Martinez, V.J. and Rudnick, H., 2012. Design of Demand Response programs in emerging countries. In: *2012 IEEE International Conference on Power System Technology (POWERCON)*. [online] 2012 IEEE International Conference on Power System Technology (POWERCON 2012). Auckland: IEEE. pp.1–6. https://doi.org/10.1109/PowerCon.2012.6401387.

Pandey, V.C., Gupta, N., Niazi, K.R., Swarnkar, A. and Thokar, R.A., 2022. An adaptive demand response framework using price elasticity model in distribution networks. *Electric Power Systems Research*, 202, p.107597. https://doi.org/10.1016/j.epsr.2021.107597.

Parvania, M. and Fotuhi-Firuzabad, M., 2010. Demand Response Scheduling by Stochastic SCUC. *IEEE Transactions on Smart Grid*, 1(1), pp.89–98. https://doi.org/10.1109/TSG.2010.2046430.

Wang, H., Wang, S. and Tang, R., 2019. Development of grid-responsive buildings: Opportunities, challenges, capabilities and applications of HVAC systems in non-residential buildings in providing ancillary services by fast demand responses to smart grids. *Applied Energy*, 250, pp.697–712. https://doi.org/10.1016/j.apenergy.2019.04.159.

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Crossref

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