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Improving Demand Response Strategies Utilizing Data Collected by Industrial Assessments to Reduce Cost for Users

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IMPROVING DEMAND RESPONSE STRATEGIES UTILIZING DATA COLLECTED BY INDUSTRIAL ASSESSMENTS TO REDUCE COST FOR USERS

A Thesis

by

MONSUR HABIB

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IMPROVING DEMAND RESPONSE STRATEGIES UTILIZING DATA COLLECTED BY INDUSTRIAL ASSESSMENTS TO REDUCE COST FOR USERS

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ABSTRACT

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Demand Response Programs have the potential to incentivize users to modify their electricity consumption pattern based on their given price and any bonuses that come along with it. By utilizing renewable sources and energy storage devices, household electricity bills can be reduced since electricity consumption during high price periods can be replaced by either renewable resources or electricity from energy storage devices. The balancing of energy demand and generation using the latest management technologies is considered an immediate requirement to improve electrical distribution networks and peak demand management. Many Independent system operators have deployed several terms of demand response programs. Electric Reliability Council of Texas (ERCOT) is responsible for the electric market in most of Texas. In the past, ERCOT's demand response programs have provided promising outcomes from an economic and reliability perspective. Currently, demand-side resources, mainly on the industrial load class, can participate in the ancillary service market. The purpose of this thesis is to explore the methods in which current demand response techniques can be improved to promote it further and get it widely available to manufacturers. The thesis will also look into integrating renewable energy generation into these settings for further energy and cost savings.

DEDICATION

The completion of my Masters in Electrical Engineering at The University of Texas would not be possible without the financial and emotional support of my family. My gratitude goes out to my Father, Retd. Cdr. A K M Ahsan Habib; my mother, Wahida Habib; my sister, Sabiba Sumaita Habib; my brother, Waheed Habib; my Brother-in-law, Ishraq ul Islam and my niece, Inaaya Noor Islam; for being what keeps me striving to be better every day.

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Electricity demand has continuously grown ever since it became available for commercial use. However, this growth reveals many challenges to the utility industry posed by limited resources and environmental impacts. Net electricity generation is predicted to exceed 5000 billion kWh by 2035.[1] The creation of new power plants takes several years to complete, and it also brings environmental problems related to waste production based on the type of energy source used. A possible alternative to this includes improving energy efficiency, adopting Distributed Renewable Generation, participating in Demand Response, etc. Conventionally, electrical systems are designed in accordance with the peak demand they may have. On the contrary, DR aims to be a guide for load consumption to adapt to generation conditions. The peak can be lowered through this, and the needed capacity can be reduced, even though overall energy consumption may remain the same.

Recently, changes are being seen in the international energy market, which has kickstarted energy reforms. Methods for energy conservation, emission reduction, and energy efficiency improvement have become important research points. To achieve reduced emissions and greater energy efficiency, Demand-side Management(DSM) has received increasing attention.[1] Demand Response(DR) is an essential part of DSM application in the power market. It is both a fiscally and environmentally responsible way to occasional and temporary peak demand periods. Utilities provide demand response programs to improve energy efficiency and energy reliability by offering incentives to businesses that volunteer to temporarily reduce their electricity use when demand becomes more significant than supply. The customers determine their personal strategy for demand response, often based on the price information and the incentives provided. Some of them are motivated by economic factors, others by reliability concerns.

The problem with this method is that it is complicated and expensive to implement, especially for the vast number of small and medium-size commercial or industry customers. Though they want to adopt a demand response to get an incentive from utility and save cost, they cannot afford such a complex and expensive (both labor cost and facility cost) system. There are two main inputs for a demand response model:

- Utility message
- Measured power demand or predicted power demand of the system, if the meter has predicted power demand function, where more flexible strategy can make.

1.1 Methods applied for Demand management and Demand response

Due to the introduction of volatile energy sources and electro-mobility concepts into the electricity market, the traditional method of supply electricity to the consumer using a limited number of power plants has lost efficacy. The concept of changing the static nature of the electric load into a dynamic form is a long-known one. Still, the new affordability of communication networks and embedded systems allow it to be implemented in electrical loads. Demand-side management has needed development since electricity demand has risen even though loads have become more energy efficient. The biggest problem being faced is with the grid capacity, which is reaching its upper limits.[2] This is caused by large renewable energy projects such as offshore wind farms that strain the existing grid system. Due to this, intelligent demand-side management

(DSM) is needed to increase the capacity of the existing grid. DSM can be broadly categorized into four different categories.

Energy efficiency (EE), Demand response (DE), Spinning reserve (SR), and Virtual power plants (VPP) are the four effective methods for demand-side management and demand response. The consumer process they can influence can be defined as a manufacturing process, pump power, or even the consumer's well-being. The different methods are discussed below[1]:

- Energy Efficiency

  Improvement of the energy efficiency of buildings or industrial areas requires careful planning, and processes that need optimization need to be found out. For this, sensors at consumer sites have to be connected to a database so that the collected data can be used in an algorithm that makes decisions to improve efficiency.

- Demand Response

  The variation in electricity usage by end-use consumers from their regular consumption patterns in response to the change in electricity price over time is known as demand response (DR). The entire pattern changes by end-use consumers used to alter the timing of the electricity consumption are also included. It allows consumers to take part in the operation of the electric grid by shifting or decreasing their electricity usage during peak time in response to financial incentives. DR programs are used by electric operators and system planners to balance the supply and demand. DR programs can also reduce retail rates since they are capable of decreasing electricity costs in the wholesale market.[1]

  DR is considered a valuable resource option in the electric power industry because of its potential impacts and capabilities of grid modernization efforts. Recently, a massive focus has been made on DR programs aimed to improve market liquidity, reduce electricity prices, resolve transmission line congestion, and security enhancement. Demand Response currently has two main categories: incentive-based programs and price-based programs.

- Spinning Reserve

  The spinning reserve method of DSM involves supporting the traditional ancillary services by changing the loads on the demand side to maintain the power system's frequency. Two of the schemes used to implement the SR concept are grid-friendly and Integral Resource Optimization Network (IRON). The difference between the two schemes is that the IRON system uses telecommunication systems to implement cooperative algorithms to automatically adjust the different loads so that one of the loads is not turned off most of the time. On the other hand, a grid-friendly controller controls single loads that cannot communicate with different loads.

- Virtual power plant

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

1.1.1 Types of demand response programs:

There are two main categories that a demand response program can fall into[1]:

1. Incentive-based programs

   In these programs, participating customers are offered payments for load reduction during peak hours. As a result, the demand level of distribution networks is reduced by the limiting or adjusting production process by the end-use customer. In return, participating customers are awarded bill credit or discounted rates. Subcategories of such programs are:

i. Interruptible/curtailable service

ii. Capacity market program

iii. Direct load control

iv. Ancillary services market program

v. Emergency demand response programs

2. Time-based programs

These programs are generally based on utilization dynamic pricing rates and time-based rates. Here the real-time cost of electricity is followed. Promoting DR by increasing price rates during peak time and decreasing off-peak times is the ultimate objective for these programs. Subcategories of such programs are:

i. Time of use programs

ii. Real-time pricing program

iii. Critical peak pricing program

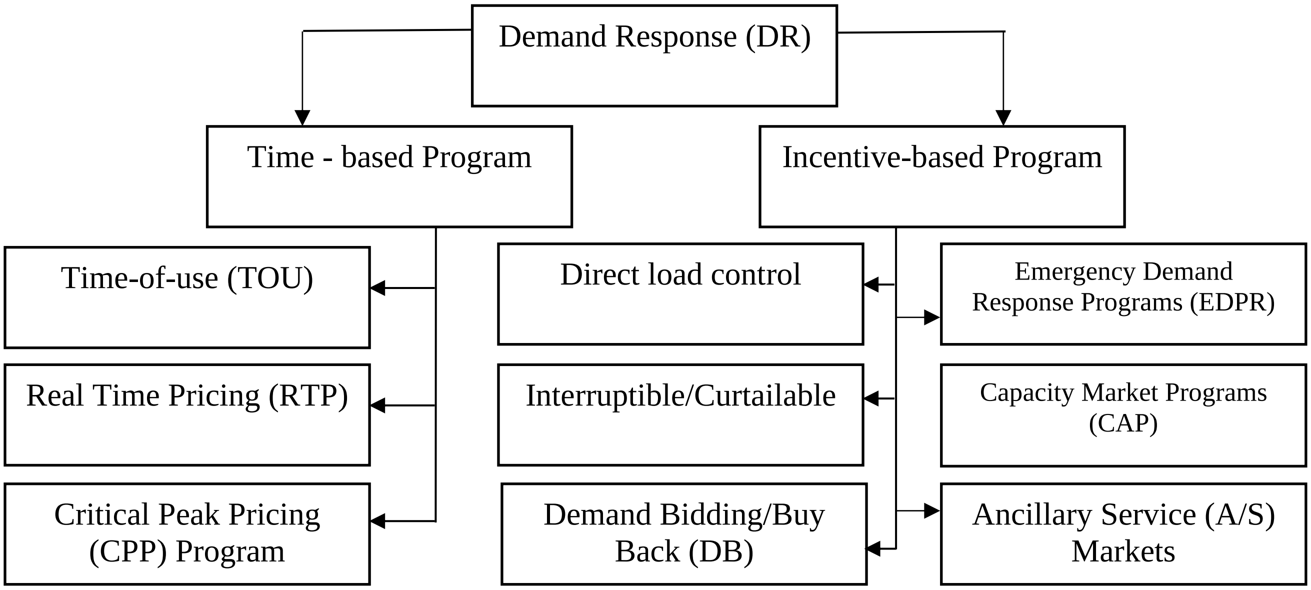

Fig. 1.1.1 Types of popular demand response program categories

Senate Bill (SB) 1125, Ch. 180, relating to energy efficiency goals and programs, public information regarding energy efficiency programs, and the participation of loads in certain energy markets, has been a law since 2011. The motivation of SB 1125 on DR is that Load Resource programs currently are limited to industrial classes and are prohibitive towards residential and commercial class customers. It establishes a goal to facilitate the involvement of the retail electric providers in the delivery of efficiency programs and demand response programs in the ERCOT region, including programs for demand-side renewable energy systems that use distributed renewal generation technologies.[3]

1.2 Existing Demand response programs at different U.S. ISOs/RTOs

Demand response is an essential element of competitive wholesale electricity markets. For the purpose of providing customers with the opportunities and rights to choose power, many ISOs/RTOs(Regional Transmission Organization) have developed load participation or demand response programs. The DR products and services may vary due to the ISOs/RTO's system and market design characteristics. Therefore, standardization is desirable to develop a common set of data definitions and interactions. According to the North American Electric Reliability Corporation (NERC), all demand response will be categorized as one of the following [2]:

1. Energy: compensation based solely on demand reduction performance during a Demand Response Event
2. Capacity: obligation of Demand resources to be available to provide Demand response upon deployment by a system operator over a defined period of time.
3. Reserve: obligation to be available to provide demand reduction upon deployment by the system operator, based on reserve capacity requirements that have been established to meet reliability standards

4. Regulation: Demand response can increase and decrease load when responding to real-time signals from the system operator. Providing Regulation services places demand resources subject to dispatch continuously during a commitment period.

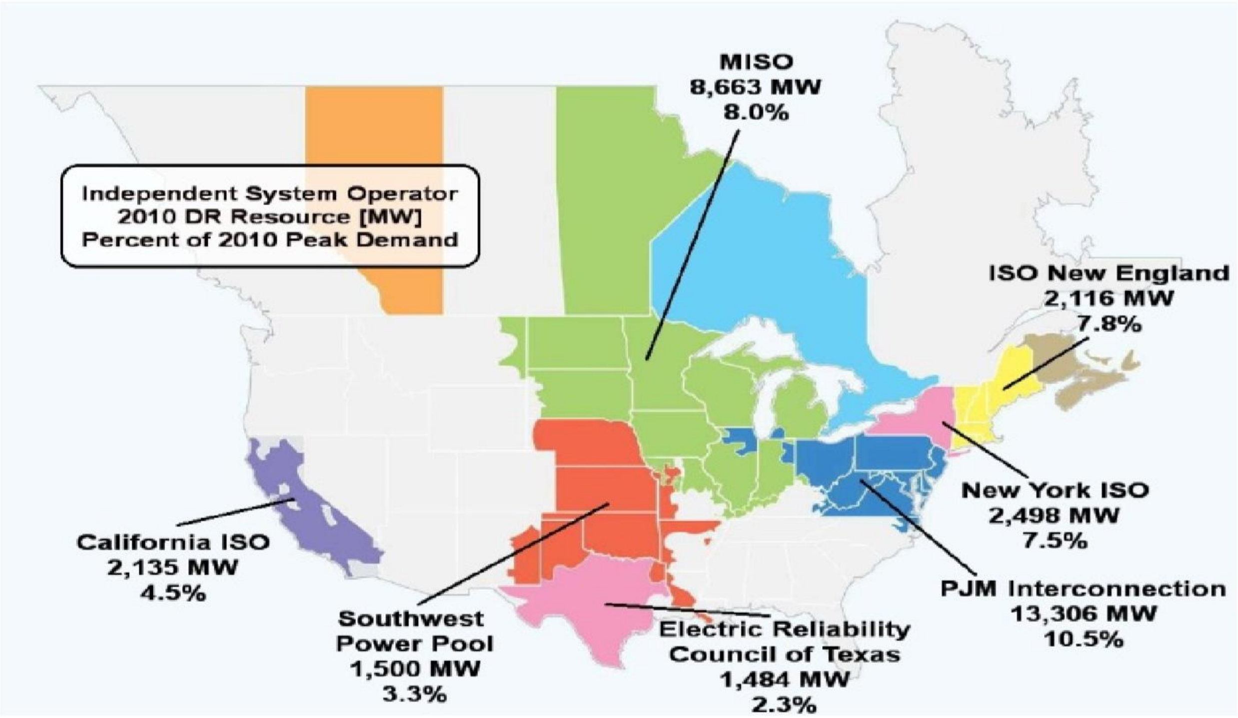

Fig. 1.1 2010 Demand Response Resource Potential at U.S. ISOs and RTOs

Below three of the five regions providing wholesale electricity demand response programs, products, and services administered by the ISOs and RTOs in the USA are discussed briefly[2]:

1.2.1 California ISO(CAISO)

The CAISO does not compromise with ensuring the safety and reliability of transporting electricity while also ensuring that diverse resources have equal access to the system and markets. It also offers the Proxy Demand Resource (PDR) Product to enable aggregators to offer demand response resources directly into the wholesale energy and ancillary services market. In addition, the CAISO maintains a demand responsiveness program identified as the Participating Load Program (PLP).

The program makes it possible for loads to participate in price-responsive demand in the CAISO Non-Spinning Reserves, Replacement Reserves, and Supplemental Energy markets.

The PDR product enables aggregators to offer demand response resources directly into the wholesale energy and ancillary services market. PDR is a load or an aggregation of loads capable of measurably and verifiably reducing their electric demand. PDRs can submit bids into the wholesale Day Ahead or Real-Time market and respond to dispatches at the direction of the CAISO

1.2.2 Midwest Independent Transmission System Operator(MISO)

MISO is the ISO/RTO responsible for delivering the electric power over 12 U.S. states and the Canadian Manitoba province safely, efficiently, and economically. The apparent feature of MISO is that it allows customers from the unbiased regional grid to manage and get into transmission facilities under MISO's functional supervision. The demand response in MISO includes Load Serving Entities (LSEs), Aggregators of Retail Customers (ARCs), and End-use customers that have Market Participant status. In MISO, the participants meeting the registration requirements are supposed to offer demand response services via four catalogs:

1) Economic Demand Response

The only economic-based demand resources are called Demand Response Resources (DDR). There are two types of DDRs named DDR-type I and DDR-type II.

- DDR-Type I is the resource with fixed item values such as hourly energy price, hourly curtailment price, startup price, etc., all of which are allotted to fixed periods of time.

- DDR-Type II is the demand resource with continuous item values during demand response, such as energy price curve, no-load offer, startup offer, etc.

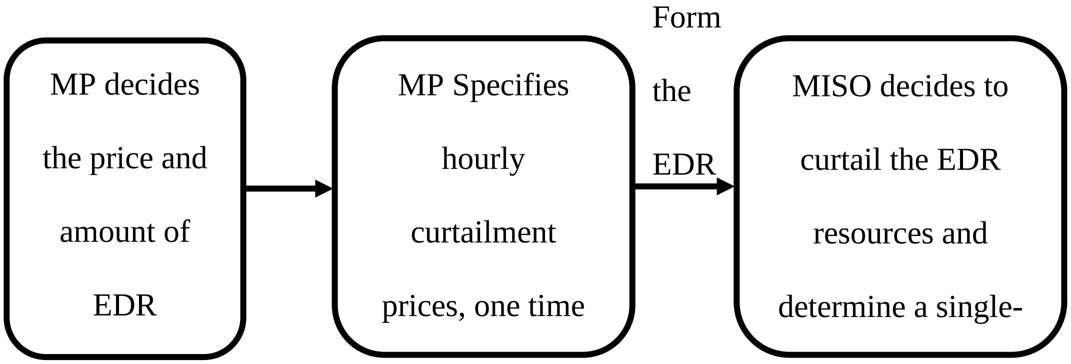

Fig. 1.2 Flowchart of EDR service deployment process

Both DDR types are eligible to register to provide Spinning Reserve Service and Supplemental Reserve Service if certain requirements are met. Only DDR-type II can provide Regulating Service because this service requires continuous output change over a range of values.

2) Operating Reserves Demand Response

MPs offer this kind of demand response to provide Regulating or Contingency (Spinning and Supplemental) Reserves under MISO's supervision. DDR Type I and DDR-type II can apply here as a kind of reserve resource. MISO is capable of making a decision whether to clear the DRR offer to provide more energy or operate Reserve Service in each 5-minute time interval.

3) Operating Reserves Demand Response

This response service is used to reduce the demand during system emergencies. Though the EDR resources from MPs do not belong to DRRs, they can still reduce the loads when MISO announces an Energy Emergency event, and EDR resources are not necessary to be provided in all the events.

4) Planning Resource Demand Response

The purpose of MISO employing this kind of demand response is to find a substitution for generating capacity. MPs register their facilities as Load Modifying Resources (LMRs), and those LMRs are qualified as Planning Resources.

1.2.3 New York Independent System Operator

At present, the NYISO consists of four Demand Response programs: the Emergency Demand Response Program (EDRP), the ICAP Special Case Resources (SCR) program, the Day-Ahead Demand Response Program (DADRP), and the Demand Side Ancillary Services Program (DSASP)[3]. In addition, there are four broad classes of Curtailment Service Providers (CSPs) in which wholesale market participants are grouped into:

- Load-Serving Entities (LSEs)
- individual retail customer taking service as an LSE
- NYISO-approved Curtailment Customer Aggregators (Aggregators)
- Curtailment Program End-Use Customers (EUCs)

The EDRP allows participants to subscribe retail end users able to provide Load Reduction during emergency situations. The EDRP pays for energy during times of emergency but not for capacity. Participation in the EDRP is also voluntary. The NYISO has a separate program called Special Case Resources (SCR) within the Installed Capacity (ICAP) market that pays for capacity and energy. SCR are end-use Loads capable of being interrupted upon demand, and distributed generators, both of which must be rated 100 kW or higher and invisible to the ISO's Market Information System (MIS), the scheduling interface between a Market Participant and the NYISO. It allows each Market Participant to enter, view, modify, and change bids for the following:

  - Day-Ahead Generation

- Day-Ahead Load
- Day-Ahead Hourly
- Load Forecast
- Day-Ahead Bilateral Transactions
- Real-Time Generation
- Real-Time Bilateral Transactions

The MIS is additionally a means by which market activities are tracked. The NYISO's Day-Ahead Demand Response Program (DADRP) allows energy users to bid their load reductions into the Day-Ahead energy market as generators do. If the customer does not reduce its load as scheduled, consumption during the scheduled curtailment is billed at the higher of the day-ahead price or the real-time price. DADRP pays for energy allowing flexible loads to increase supply in the market and moderate prices effectively.

CHAPTER II

PRESENT STATE OF DEMAND RESPONSE AT ERCOT

2.1 The Electric Reliability Council of Texas(ERCOT)

The Electric Reliability Council of Texas (ERCOT) manages electric power flow to 23 million Texas customers - representing 85 percent of the state's electric load and 75 percent of the Texas land area. As the ISO for the region, ERCOT schedules power on an electric grid that connects 40,530 miles of transmission lines and more than 550 generation units. ERCOT also manages financial settlement for the competitive wholesale bulk-power market and administers customer switching for 6.6 million Texans in competitive choice areas [4]. The demand response corresponds to a 1,063 MW(9%) in load resource program (equal to three major power plants); 421(4%) MW in emergency interruptible load service; and 128(1%) MW in energy efficiency programs.

2.2 Overview of Load Participation in the ERCOT Nodal Market

The current ERCOT Nodal market rules are such that they allow load participation to reward demand-side/load resources if they are willing to curtail or shift load, which helps maintain system reliability. One of the primary operational duties of ERCOT is to ensure the reliability of the ERCOT System so that it can ensure that sufficient resources are appropriately located, and required Ancillary Services have been committed for all expected Load on a Day-Ahead Real-Time basis[5]. Resource is the term used to refer to both a Generation Resource and a Load Resource. It is of major interest to work toward understanding Load Resources under Day-Ahead Operations and Operating Period (Real-Time). Day-Ahead Operations include Day-Ahead Energy Market, Ancillary Services Market, whereas Operating Period involves Real-Time Load Response to Prices and Emergency Interruption of Load Resources.

Fig. 2.1 ERCOT Regional Map[21]

2.3 Demand-Side Participation in the ERCOT Nodal Market

The types of load response or demand-side resources in the ERCOT Nodal Market

A. Voluntary Load Reduction

   This is dependent on the customer deciding to modify consumption from its scheduled or anticipated level in response to price signals Day-Ahead Market(DAM) or Real-time Market(RTM) prices.

   1. Day-Ahead Market(DAM)

      Load customers who can reduce consumption at certain times of the day or move energy consumption from one hour to another may use ERCOT's Day-Ahead energy market advantageously. These markets operate using ERCOT systems to match the buyer's and seller's bids and offers for energy for the upcoming days. Compared to Zonal Market, this is an entirely new market for ERCOT and its market participants [6].

   2. Real-time Market(RTM)

      Load customers may request their Retail Electric Provider (REP) to provide prices that match the prices ERCOT establishes during Real-Time operations [7]." These prices are provided to the public online or directly from the load's REP to enable the load to adjust its consumption pattern to reduce energy at high-priced periods and potentially increase consumption at lower prices. Load customers must be cautious when structuring contracts with their REPs to be clear if the REP or the Load customer will be responsible for ERCOT charges for any Reliability Unit Commitment Capacity Short Charges. QSEs and their REPs who purposely do not purchase supply before the real-time market may be subject to additional charges if ERCOT must purchase additional generating capacity. These capacity charges may be passed on to the Load customer or covered by the REPs contract [6].

B. Load Resource – Ancillary Services(AS) Market

Load resource is a Load capable of providing AS to the ERCOT System and registered with ERCOT as a Load Resource [6]. Ancillary Service – ERCOT is responsible for procuring sufficient AS to maintain adequate system reliability [6]. Ancillary service is "a service necessary to support the transmission of energy to Loads while maintaining reliable operation of the Transmission Service Provider's (TSP's) transmission system using Good Utility Practice." Ancillary services include various types of Day-Ahead capacity products to meet ERCOT's reliability requirements, as follows [8, 9]:

1) Regulation Up Reserve Service (Reg-Up) controls the power output in response to a small change in system frequency. ERCOT sends signals to increase the energy input to the grid within three to five seconds to respond to changes in system frequency.
2) Regulation Down Reserve Service (Reg-Down) is similar to Reg-Up, but all signals from ERCOT cause a decrease in energy to the grid.
3) Responsive Reserve Service (RRS) requires installing Under Frequency Relay (UFR) that opens the load feeder breaker on automatic detection of an under frequency condition. In the case of a Controllable Load Resource, the response is similar to a generator's response to a frequency change. These loads are also required to be manually interrupted within a 10-minute notice.
4) Non-Spinning Reserve Service (Non-Spin) is an Ancillary Service where Load Resources can be interrupted within 30 minutes. They can operate at a specified output level for at least one hour.

5) Controllable Load Resource (CLR) and Non-Controllable Load Resource (NCLR) are the two types of Load Resources provided in the ERCOT Nodal Market. NCLR can reduce consumption in response to a dispatch instruction from ERCOT. It would include those controlled by Under-frequency Relays (UFR) and simple Interruptible Load Resources (ILD). The UFR type Load Resources can provide Responsive Reserve Service (RRS) and Non-Spinning Reserve Service (NSRS), while the ILD type Load Resources are only allowed to provide NSRS [11]. Conversely, CLR is a Load Resource capable of controlling or increasing consumption under dispatch control (like Automatic Generation Control (AGC)) and provides Primary Frequency Response. CLR can provide Regulation up Reserve Service (Reg-Up), Regulation down Reserve Service (Reg-Down), RRS, and NSRS

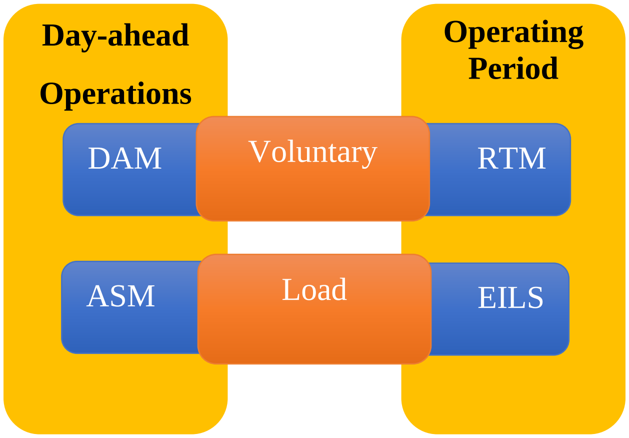

Fig. 2.2 Demand-side participation in the ERCOT Nodal market

C. Emergency Interruptible Load Service (EILS)

ERCOT procures EILS by selecting qualified Loads to make themselves available for an interruption in an electric grid emergency. EILS is an emergency load reduction service designed to decrease the need for firm Load shedding. Customers meeting EILS criteria can bid to provide the service, which is done through the customers' qualified scheduling entities (QSEs).[12]

Utility deregulation has created opportunities for both the generators and loads to participate in the auction and ancillary service markets. Several ISOs/RTOs offer demand response (or load participation) programs in the auction power market to make the auction market more flexible and realistic. With the ability to curtail electricity demand, industrial plants can participate in both the energy and ancillary service (AS) markets to increase the financial gain of the operation by improving their power consumption pattern in the process.

2.4 Responsive Reserve Service (RRS)

Load Resources controlled by high-set under-frequency relays(UFR) continue to dominate the number and capacity volume of Demand Response Resources that participate in the ERCOT Ancillary Service markets. During 2020, Market Participants registered an additional 164 Load Resources, representing 1420 MW of additional capacity. By the end of the year, there were 611 UFR-type Load Resources, with an aggregated capacity of 6926 MW, that were qualified and capable of participating in RRS. It is important to note that not all these Load Resources are at their maximum Load value at any given time, nor are they all participating in the RRS market.

The expected amount of RRS required for any given hour is listed in the Ancillary Service Plan. The required amount with any updates for the next day is communicated to the Load Serving Entity (LSE) early morning in the Day-Ahead Market (DAM). For 2020, the amounts varied from 2300 MW on a peak day during summer to 3086 MW for an off-peak hour during the fall and spring months. Protocol revisions implemented in 2018 now allow up to 60% of the total required RRS capacity to be provided by UFR-type Load Resources, subject to a constraint that requires at least 1150 MW of RRS capacity to come from Resources providing Primary Frequency Response (PFR). Before this change was made, the awards for UFR-type Load Resources were limited to 50% of the total RRS requirement at any time. The changes also applied to Qualified Scheduling

Entities (QSEs) representing LSEs and the amount that could be self-arranged to meet their hourly requirement in the DAM.

2.5 Controllable Load Resource Participation in Ancillary Services

During 2020, Market Participants continued to participate in Fast Responding Regulation Service (FRRS) using Energy Storage Resources (ESRs). Presently, these Resources are a Controllable Load Resource (CLR) when they withdraw from the grid and a Generation Resource when they inject energy to the grid. These Resources currently participate in RRS, Reg-Up, Reg-Down, and Non-Spin. As of December 2020, there were 38 ESRs in various stages of being installed and certified for commercial operation in the ERCOT System. These ESRs represent a total of 600 MW of capacity on the grid. During 2020, stakeholders and ERCOT staff made a major effort to develop new Protocols and system changes that will result in a new single device model. This report will continue to not include ESRs as part of the scope for the Annual DR report.

In 2020, three new CLRs were registered and added to the ERCOT Network Model. These CLRs consist of data centers with hundreds of servers that can be turned on and off on demand. The data centers use fast-acting control systems to respond to a frequency like the governors on a conventional thermal plant, which gives them the ability to follow SCED Base Points. These CLRs have over 100 MW of online capacity and have the ability to participate in RRS, Reg-Up, Reg-Down, and Non-Spin. This represents the first substantial amount of conventional Load to participate in the Ancillary Services market as a Controllable Load Resource.

The table below reflects the average cost of Load Resources providing RRS and the estimated total cost for each year.

Calendar Year	Average RRS Payment $/MW/hr	Total Estimated Cost $
2016	11.11	133,178,909
2017	9.78	111,693,163
2018	17.32	223,306,014
2019	25.03	339,859,297
2020	11.30	140,292,091

Table 2.1 Average cost of Load Resources providing RRS and the estimated total cost for each year

2.5.1 Limits on Demand Response Participation in Ancillary Services

The capacity to contribute to frequency response from the Load Resources controlled by high set under-frequency relays has several limiting factors. The first limitation is needed to guard against frequency overshoot during a UFR deployment. Up to 60% of RRS capacity is allowed to come from NCLRs, subject to an additional constraint needed for Primary Frequency Response during normal operations. That constraint is dictated by NERC standards and was 1150 MW up until the end of 2020. This constraint is called the Interconnection Frequency Response Obligation (IFRO) and is based on the simultaneous loss of the two largest units in the ERCOT System. On December 1, 2020, the IFRO for ERCOT changed, resulting in the minimum requirement of PFR changing from 1150 MW to 1420 MW for the calendar year 2021. The higher minimum PFR requirement of 1,420 MW will decrease the amount of capacity that can come from NCLRs during all hours of the year.

2.5.2 Improving Participation by Load Resources in ERCOT

During 2020, several initiatives were undertaken that will provide additional opportunities for Load Resources to participate in the Ancillary Services market. Those activities include:

- The implementation of Nodal Protocol Revision Request (NPRR) 863, Creation of ERCOT Contingency Reserve Service and Revisions to Responsive Reserve, will add an opportunity for Load Resources to provide Fast Frequency Response (FFR) as part of a new suite of options in RRS. In 2020, FFR was partially implemented to allow FFR to be provided by Energy Storage Resources (ESRs). The ERCOT is currently working on a project to implement the remaining components of FFR, which will allow NCLR implementation. The final phase of the NPRR 863 implementation will lead to the creation of a new Ancillary Service called ERCOT Contingency Reserve Service (ECRS). This new product will be open to Load Resources controlled by UFRs and include those that can respond to manual instruction from ERCOT Operators. ECRS is scheduled to be implemented as part of the Passport Program implementation in 2024.
- The last major initiative affecting Load Resources is Real-Time Co-optimization (RTC). NPRRs with the Protocol revisions that will implement RTC were approved by the ERCOT Board of Directors at their December 2020 meeting. This effort is planned to be implemented as a part of the Passport Program. It includes significant changes in how Loads will participate in the Ancillary Services market in Real-Time.

2.6 Emergency Response Service (ERS)

The original development and implementation of the Emergency Interruptible Load Service (EILS) in 2007 were as a Load reduction service with a 10-minute ramp requirement to be deployed in the late stages of a grid emergency. In 2012, this service was altered to accommodate certain small generators to participate. To reflect the broader participation, the service was renamed Emergency Response Service (ERS). Additional significant changes to this service occurred when the 30-minute ramp service type was implemented in 2014, alongside Weather-Sensitive ERS with both ten and 30-minute ramp requirements.

The procurement of ERS is administered in accordance with the ERS Procurement Methodology document posted to the Demand Response site on ercot.com. The risk-weighting factors are values from 1 to 100, with 100 representing the highest risk of ERCOT entering into an EEA Level 1 during that ERS Time Periods. Starting with the February through May 2013 Standard Contract Term, ERCOT implemented changes that allowed certain types of small generators to provide ERS if they are not a Generation Resource or a source of intermittent renewable generation. These ERS Generators can consist of an individual generator or an aggregation of such generators, and they participate in ERS by injecting energy into the ERCOT System.

2.7 Transmission/Distribution Service Provider (TDSP) Load Management Programs

In these programs, end-use customers agree to receive payment from a TDSP in exchange for reducing peak demand for a specified duration upon request by the TDSP. For 2020, these programs existed in the service territories for American Electric Power (AEP), CenterPoint, Oncor, and Texas-New Mexico Power (TNMP). Even though there are variations in these programs, generally, they are only available during weekdays from June 1 through September 30, from 1 p.m. to 7 p.m. The variations that exist among these programs include:

1) maximum duration (hours) of each curtailment event
2) maximum number of deployment hours during the program year
3) maximum number of deployments per month/program year 4)

4) deployment ramp time (0.5 or 1.0 hours).

Participation in these programs can change throughout the summer, but at the start of the 2020 program year, there were approximately 288 MWs participating throughout the four TDSP service territories. One of the TDSPs offers a program that is only available during the months of August and September; because of this, the total available capacity for each of these months was 308 MWs in 2020.

Through an agreement between the TDSPs and ERCOT, these Loads may be deployed by an ERCOT instruction during an Energy Emergency Level (EEA) Level 2. This agreement, however, does not prohibit the TDSPs from deploying these programs for either testing purposes or for their own use. The TDSPs did deploy their Load Management Programs during testing events at various times throughout the summer, Even though there were no EEA Level 2 events declared in 2020.

ERCOT separately analyzed the response behavior for both NOIEs and ESIIDs in competitive choice areas subject to 4CP(Coincident Peak) charges. 4CP response for NOIEs was based on estimated reductions in total NOIE Load, as determined from boundary metering after netting out NOIE-area generation. Response in competitive areas was estimated based on the TDSP metering of the customer's actual Load. In both cases, reductions were estimated for actual 4CP days and other "Near-CP" days. These Near-CP days were determined through the identification of Load reductions on days for which the ERCOT total Load was high and for which estimated Load reductions were significant.

ERCOT's practice with 4CP analysis is to base the Load reduction estimates on ESIIDs that have demonstrated a likelihood to respond to 4CP and Near-CP events. The likelihood is determined from the ESIID's response to such events over the most recent three-year period, including the summer of 2020.

In the areas of ERCOT with retail competition, customers subject to 4CP billing are independent of their REP. They largely make their own decisions on a day-by-day basis as to whether to reduce Load to avoid 4CP-based charges. Given this, the REP survey is not used directly to identify ESIIDs that take action to avoid those charges. However, the REP survey data is an important input into the 4CP analysis. It can identify ESIIDs that participate in REP deployment type products or are on Indexed pricing products. This way, ERCOT can identify days to exclude when evaluating and determining prices.

ERCOT also identified and analyzed six additional 2020 summer days which had high prices or load reductions associated with 4CP avoidance. However, at the system level, the Demand reductions for those days were below 1000 MW.

NOIE Load reduction estimates were only developed for high price days or days identified as 4CP/Near-CP days; however, NOIEs did deploy their Load reduction programs on other days.

Empty cells in the tables below are attributable to the following:

1) Deployment-based programs were only evaluated on days for which the REP or NOIE reported having deployed the program. If the REP/NOIE did not deploy their program on a specific high-price or 4CP/Near-CP day, then no Load reduction estimates for that program appear for that day.
2) In two deployment-based programs, Peak Rebate and Direct Load Control, the program was deployed, but the level of load reduction did not round to at least 1 MW.

3) In the 2019 report, Load reduction estimates were developed for TDSP Standard Offer Load Management programs and ERCOT's Emergency Response program. Columns for them are omitted from the tables for 2020 since these programs were not deployed during 2020.

Day	Day Type	Total System DR	4CP Competitive	4CP NOIE	Indexed Real-Time (IRT)	Indexed Day-Ahead (IDA)	NOIE Price Response	Peak Rebate (PR)	Other Direct Load Control (OLC)	Category Total	Overlap
8-Jun-20	4CP	1,882	1,039	841	-	6	-	-	-	1,886	4
9-Jun-20	NearCP	1,961	1,328	633	-	-	-	-	-	1,961	0
1-Jul-20	NearCP	1,148	1,072	76	-	-	-	-	-	1,148	0
2-Jul-20	NearCP	1,472	1,120	352	-	-	-	-	-	1,472	0
9-Jul-20	NearCP	1,135	865	270	-	-	-	-	-	1,135	0
10-Jul-20	NearCP	1,324	1,009	315	-	-	-	-	-	1,324	0
13-Jul-20	4CP	2,765	1,373	1,392	-	-	-	-	-	2,765	0
14-Jul-20	NearCP	1,399	607	792	-	-	-	-	-	1,399	0
6-Aug-20	NearCP, High Prices (South)	1,509	959	536	86	-	151	-	1	1,733	224
7-Aug-20	NearCP, High Prices (South)	1,498	1,042	437	99	0	161	-	2	1,741	243
10-Aug-20	NearCP, High Prices (South)	1,676	1,051	591	115	-	79	-	2	1,838	162
11-Aug-20	NearCP	1,980	1,284	697	-	-	-	-	-	1,980	0
12-Aug-20	NearCP	2,358	1,352	1,006	-	-	-	-	-	2,358	0
13-Aug-20	4CP	2,418	1,439	977	-	15	-	-	-	2,431	13
14-Aug-20	NearCP, High Prices	2,791	1,301	1,289	797	10	1,159	-	38	4,594	1,804
28-Aug-20	NearCP, High Prices	2,409	1,286	989	554	5	179	-	34	3,048	639
31-Aug-20	High Prices	1,444	-	-	514	7	889	-	34	1,444	0
1-Sep-20	4CP, High Prices (South)	2,860	1,355	1,446	65	-	240	0	41	3,147	287

Table 2.2 High Load Reduction Days 2020, at Total System-Level and Category-level – MW Reductions

Some other items of note when considering the reported values:

1) MW reductions reported are all for Hour Ending 17 to ensure consistency. In some cases, the Load reductions shown are not aligned with the high prices on that day or with the program deployment times. As a result, reductions reported here may not match those reported elsewhere for other Operating Hours.

2) Export from Settlement Only Generators is not included in this table. If a Load reduction was effectuated by operating behind the meter generators, the reduction is still treated as Load reduction in this report.

CHAPTER III

COLLECTION AND UTILIZATION OF 15 MINUTE DEMAND DATA

The demand patterns of electricity customers have become increasingly important for the market participants for power generation in the industry as the business environment has gradually changed. Introducing the market into the industry gives several participants new competition. These participants in the market need new business strategies for customer services because of new competition. Therefore, customer information becomes paramount for designing demand response systems. Demand characteristic is crucial information when analyzing customer information. Simply collecting billing data, which has been historically used for analysis, is not enough.

3.1 Uses for Demand Data

1. Demand management

   Demand management involves methods utilized to improve the power systems on the demand side. This can include increasing load efficiency by using better materials or implementing smart energy tariffs for different consumption patterns. This can even be done using sophisticated systems to control distributed energy sources.

2. Development of load profiles for manufacturers

   Standard load profiles, which are representative load and generation profiles approved by regulators, are currently used for market balancing mechanisms and network planning purposes. Standard load profiles are constructed statistically, using historical data, so their accuracy is directly related to the level of aggregation. Such profiles are representative for groups of 100 users at least; thus, they are not adapted to low voltage networks which contain a small number of users. Distribution system operators and other stakeholders require appropriate models to represent a realistic load and generation behavior in many fields, such as energy systems or local balancing mechanisms.

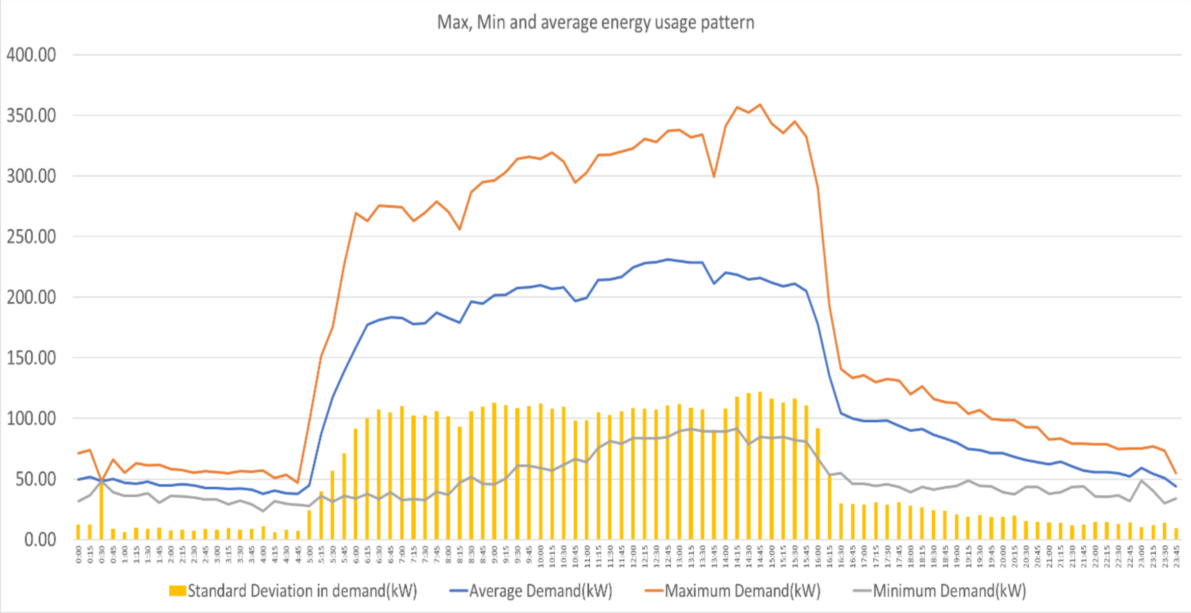

Fig. 3.1 Demand profile generated from the 15-minute demand data of metal product manufacturing plant in March 2020

3. Energy storage sizing and costing

To reduce the initial cost of battery energy storage and building of energy storage, an optimization method of battery energy storage location and sizing based on demand data will be required. It helps build the battery energy storage site and capacity model, whose objective is to improve life cost cycle, income by load shifting, and decrease line loss. The storage location and sizing are optimized using the storage life cycle cost (LCC), and storage peak profit and net loss benefit as the target. Demand data helps consider the storage charge and discharge efficiency, discharge balance, and so on, and establishes a storage location optimization model considering the demand response.

4. Sensors and IoT processes

The design of demand response systems and integration of flexibility often requires installing sensors and intelligent systems using Internet of things(IoT) processes which help adjust to changes in the environment and user requirements. Demand data helps in demand planning and optimization while allowing for changes if needed for exceptional circumstances. Calculating the average, maximum and minimum demand required over extended periods helps in the process of creating a map for designing smart systems for industrial settings.

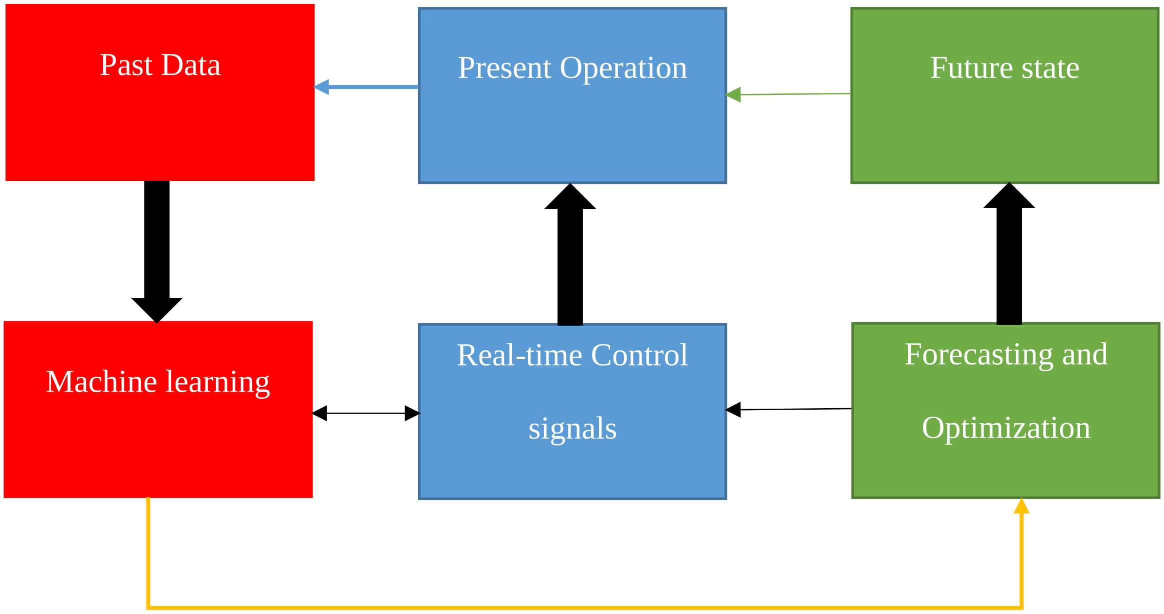

Fig. 3.2 Feedback operation of demand response at a manufacturing site

3.2 Methods for the collection of demand data:

1. Direct coordination with clients:

This method requires the team or person performing analysis to directly work with the client to provide the data for power and energy consumption over time using smart meters and recording the entries with respect to time of day. The collection of information is easier and more accurate when utilizing a smart meter that can directly log information to a computer. Additional information such as power factors and information on power generated or consumed is also useful for creating a better knowledge base during the design process. This process usually yields a .csv file that can be used to create load pattern curves that can be used to identify the power usage tendencies of the client.

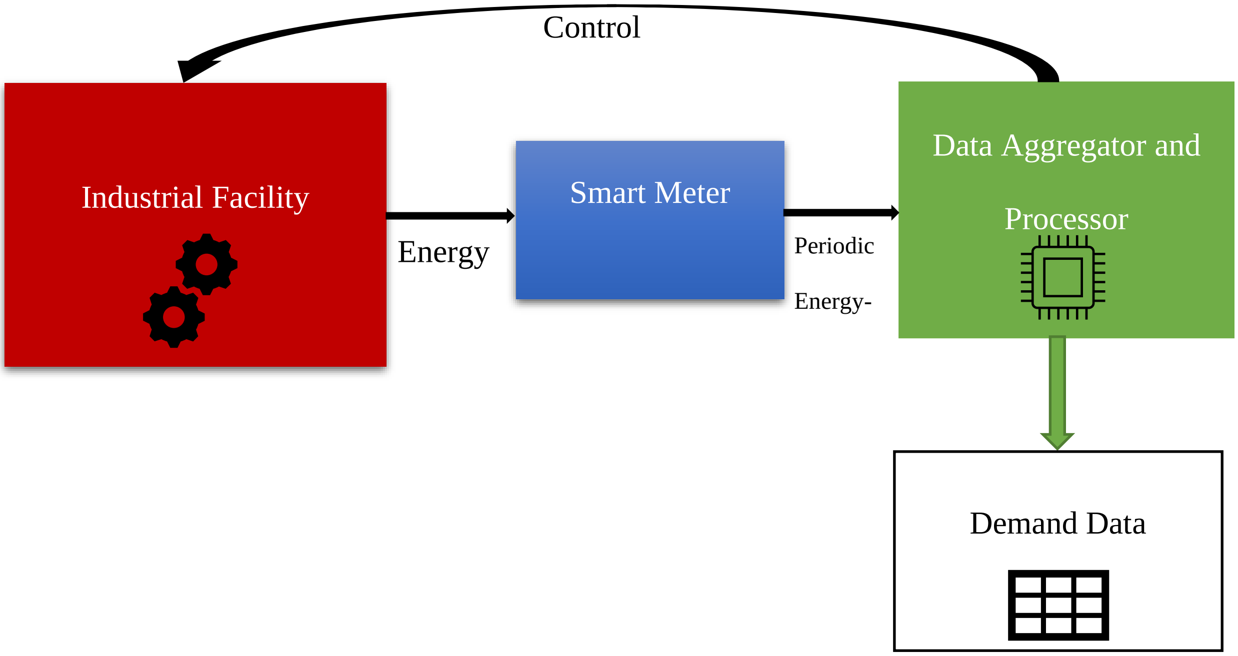

Fig. 3.3 Schematic of how demand controller and smart meter work to minimize energy cost

2. Third-party software solutions that facilitate data access:

Third-party software solutions require clients to agree to share demand data with a trusted third party that can compile the information and relay it to those using it to analyze the client if requested. Third-party organizations usually collaborate with local utilities to gather data from clients who decide to share their demand data. This helps create a better picture of industrial zones' demand patterns, proving beneficial installing renewable energy sources and creating demand response programs. Organizations that provide such solutions include the Green Button Alliance that works in the state of California.

The green button alliance provides Connect My Data(CMD), an open-data standard designed to unlock access to utility interval usage and billing data, providing easy access for software applications. This can enable utility customers to authorize third-party solutions to quickly and securely obtain interval meter data and enables an accurate and detailed level of analysis to inform energy and water management decision-making—while ensuring customer data are protected, and their privacy is maintained.

CHAPTER IV

CO_2 EMISSION FREE RENEWABLE ENERGY POTENTIAL IN TEXAS

4.1 CO_2 Emission Free Renewable Energy Sources in Texas

This section discusses the different emission-free Renewable sources used in Texas for Power Generation Purposes.

4.1.1 Hydroelectric energy

Hydropower plants capture the energy of falling water to generate electricity. A turbine converts the kinetic energy of falling water into mechanical energy. Then a generator converts the mechanical energy from the turbine into electrical energy. Hydroplants range in kW production from "micro-hydros" that generate about 5kW for a small population to giant dams like Hoover Dam that provide electricity nearly 2,000 MW for millions of people.[23]

Types of Turbines used for Generation:

Impulse Turbine

The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the downside of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications. Types of impulse turbines include:

1. Pelton
2. Cross-Flow

Reaction Turbine

A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower heads and higher flows than compared with impulse turbines. Types of reaction turbines include:

1. Propeller
2. Francis
3. Kinetic

Hydro-electricity and demand response

Some industrial processes, e.g., water pumping in drinking water storage systems, aeration in wastewater treatment plants, industrial heating, and refrigeration, are inherently flexibile, making them capable of potentially storing enough energy to respond to control signals of transmission system operator almost immediately and continuously. The implementation of micro-turbines for cross-flow hydroelectric generation utilizing kinetic energy available from water flowing in large volumes at applicable sites can prove beneficial in the implementation of Demand management in these sites. There is significant potential for hydroelectric power throughout the world. In particular, micro-hydropower, which can generate power from 5 kW to 100 kW based on size, has seen some serious interest in recent years.

Crossflow turbines are of particular interest to water treatment plants due to their cost-effectiveness and simpler installation. They can work with installations with water flows mixed with air which would damage more advanced models. Based on observations of the outflow pipe exit by IAC staff, this would also lead to a crossflow turbine as the ideal choice since the water is not leaving at the pipe's full potential output, and there are large quantities of air bubbles present as well.

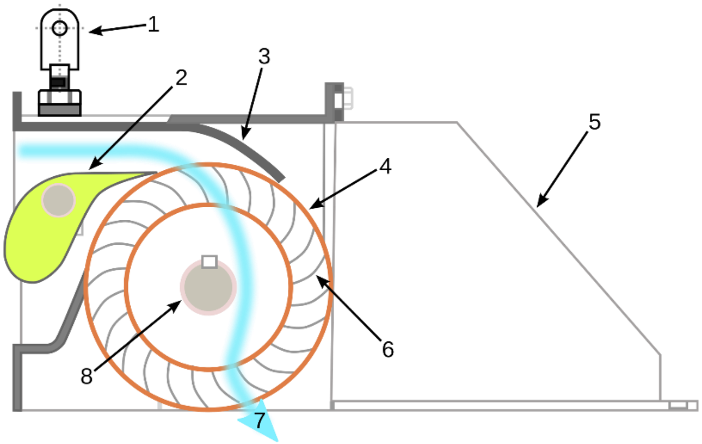

Fig. 4.1 Diagram of a Cross-flow turbine

1- air-venting valve 2- distributor 3- turbine casing (all thick grey) 4- runner 5- removable rear casing

6- blades 7- water flow 8- shaft

The power generated by turbines can be calculated using the formula:

$$P = H * Q * g * \eta * \rho$$

Where,

P = Power generated by the generator

H = head of water flowing

Q = Flow rate of water

g = acceleration due to gravity

η = Efficiency of energy conversion

ρ = Density of water(1000kg/m)

Based on the average flow rate of water(0.2534m^3/s) and head(7.9m) and using an efficiency of 80%, we can calculate the average power for a local water treatment plant.

P_{avg}=7.9*0.2534*9.81*0.8*1000= 15.71kW

Considering the water flowing through is consistent with minimal fluctuation from the average, a water treatment plant can generate up to 15.71*24*365= 137,619.6 kWh per year. This reduced energy cost can create savings of approximately $5400 per year. However, the micro-turbine generator can work economically in certain situations where there is a large volume of water flowing through it. Sites such as these include water treatment and processing plants. The large volume of water flowing through them can reclaim a portion of the power used at the site. In Texas, several water treatment plants such as these can use cross-flow turbines to reduce the power demand of the plants. Depending on the quantity and rate of water flowing through them, the resultant savings in reduced energy costs can be from $5000 to $8000 per year.

4.1.2 Wind Energy

Wind power generation means getting the electrical energy by converting wind energy into rotating energy of the blades and converting that rotating energy into electrical energy by the generator. Wind energy increases with the cube of the wind speed; therefore, wind generation plants should be installed in the higher wind speed area. [22]

A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag, and this causes the rotor to spin. The rotor connects to the generator, either directly (if it is a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to the rotation of a generator creates electricity.

Fig. 4.2 Horizontal-axis(left) and vertical-axis(right) Wind turbine types

Application settings of Wind Turbines[22]:

Land-based wind turbines, such as those shown below, have a generation range from 100 kilowatts to as large as several megawatts. Larger wind turbines are more cost-effective and are grouped into wind plants to provide bulk power to the electrical grid.

Fig. 4.3 Land-based wind

Offshore wind turbines tend to be massive and taller than 90m. Since the large components can be transported on ships instead of on roads, they do not have the same transportation challenges as land-based wind installations. These turbines can capture powerful ocean winds and generate vast amounts of energy. An example of such wind turbines is shown below:

Fig. 4.4 Offshore wind

If wind turbines of any size are installed on the customer side of the electric meter, or the installation location is at or near the place where the energy being produced will be used, It is called distributed wind.

Many turbines used in distributed applications are small wind turbines. Single small wind turbines—below 100 kilowatts—are typically used for residential, agricultural, and small commercial and industrial applications.

Small turbines can be used in hybrid energy systems with other distributed energy resources, such as microgrids powered by diesel generators, batteries, and photovoltaics.

An example of such a Wind generation application is shown below:

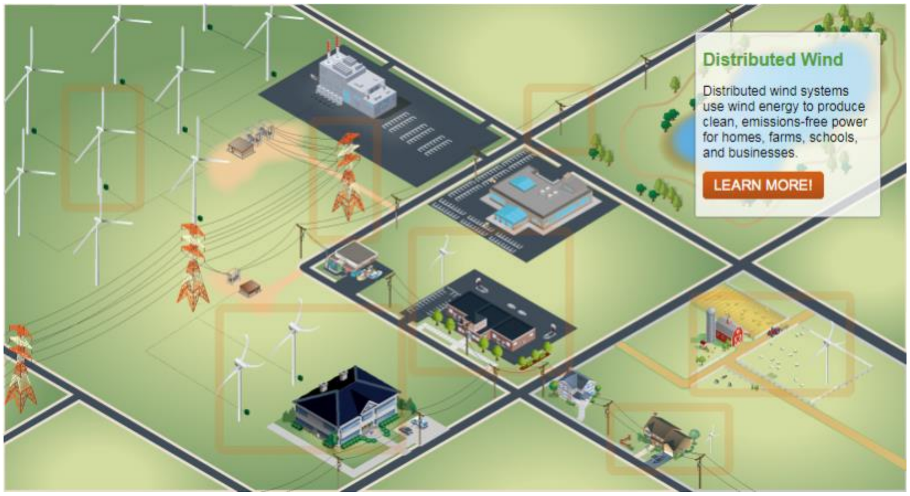

Fig. 4.5 Distributed wind

Utilization of Demand Response with Wind energy:

Large-scale integration of clean energy such as wind power brings great challenges to the operation of the integrated energy system. The wind speed scene generation is based on the historical measured wind speed, using the Autoregressive Integrated Moving Average Model and the Latin Hypercube Sampling with Random Permutation(LHSRP) method to simulate the wind speed error, the error model used is as follows[24]:

$$\Delta V(0) = 0$$

$$Z(0) = 0$$

$$\Delta V(t) = \alpha \Delta V(t-1) + Z(t) + \beta Z(t-1)$$

$$V(t) = V_f(t) + \Delta V(t)$$

Where $\Delta V(t)$ is wind speed prediction error in time period t, $Z(t)$ is random variables that obey the standard normal distribution of N(0,σ), and α and β are model parameters obtained by minimizing the mean square error of the measured wind speed data. Combining the initial wind speed sequence $V_f(t)$ and the forecast error, $\Delta V(t)$Can get the forecast wind speed in each period. Using the LHSRP method to extract N mutually independent normal distribution sequences into the error model can generate N wind speed scenarios. The system optimization goal is to minimize the overall operating cost, which includes the following: (i) outsourcing costs which includes purchasing electricity from the utility grid and purchasing fuels used, (ii) operating costs of coupling equipment (iii) battery operating costs, and (iv)load-loss penalty. The demand response constraints are as follows[24]:

$$P_{dt}^{DR} = P_{dt}^{DR,int} + P_{dt}^{DR,shif}$$

$$P_{dt}^{LD} = P_{dt}^{LDR} + P_{dt}^{DR}$$

$$P_{dt}^{LD} - P_{dt}^{DR} \leq P_{dt}^{LD,max}$$

$$0 \leq P_{dt}^{DR,int} \leq \alpha_{dt}^{P,int} . P_{dt}^{LD}$$

$$0 \leq \sum_{t=1}^{NT} P_{dt}^{DR,int} + P_{int}^{DR,max}$$

$$-\alpha_{dt}^{P,shif} . P_{dt}^{LD} \leq P_{dt}^{DR,shif} \leq \alpha_{dt}^{P,int} . P_{dt}^{LD}$$

$$\sum_{t=1}^{NT} P_{dt}^{DR,shif} = 0$$

Here,

P_{dt}^{DR}= The demand side responsive load

$P_{dt}^{DR,int}$= Interruptible load

$P_{dt}^{DR,shif}$= Transferrable load

P_{dt}^{LD}= electric load in the current period

P_{dt}^{LDR}= predicted value of electric load

$\alpha_{dt}^{P,shif}, \alpha_{dt}^{P,int}$ =percentage of power that is reduced from initial demand

The constraints can be simplified as follows: The demand-side responsive load is the sum of interruptible and transferable loads. The relationship between the predicted value of electric load and the electrical load after demand response is shown in the second formula. The electric load after demand response shall not exceed the maximum allowable electric load in the current period; the interruptible load on the demand-side is limited by a certain proportion, and the transferable load is also subject to a certain proportion, and it needs to be kept stable in the total scheduling period. The function for electric energy cost can be written as[25]:

$$\mathrm{EC}_x = \sum_{t=1}^{24} sp(t) L_x(t)$$

Where,

ECx is the electric energy cost in $

sp(t) represents the real-time price in $/kW

Lx(t) is the load in a day after demand response in kW

Here, the objective will be to keep the cost to a minimum when the wind energy source actively provides power.

4.1.3 Solar Energy (Photovoltaic generation)

Solar energy is the energy harvested utilizing solar heat or radiation. The most popular form of utilizing solar energy is electric energy generation using Photovoltaic (PV) cells. Solar power plants can be centralized or decentralized. In contrast to other types of renewable energy, this feature is one of the best features of solar power. Conventional power plants such as fossil and nuclear power are centralized power plants. Most of the other renewable power plants, especially hydroelectric power plants and geothermal power plants, are always installed in large-capacity centralized forms. Even though biomass and wind power plants can appear decentralized, these versions are not economically efficient. Solar power plants, especially photovoltaic power plants, can be made to be economically dispersed or concentrated.

Since solar energy is a clean energy source, i.e., it is neither a greenhouse gas nor requires burning material such as biomass. It is vastly available since the sun is everywhere. This makes solar energy an independent energy source. Solar radiation and temperature fluctuations are one of the worst features of solar energy that make it less reliable. Also, the fact that the sun is not available 24 hours a day is its greatest disadvantage.

4.1.3.1 Photovoltaic generation and types of PV cells. The sunlight hits the Photovoltaic cell then it transmits into the absorber layer. Light excites the charge carrier in the semiconductor material due to its energy. This excitation generates free carriers (holes and electrons). The electron moves to the n-type layer, and the hole moves to the p-type layer. In the end, the pair once again formed a connection. In short, the principle of charge generation by photovoltaic cells is to excite the charge, then separate, and finally collect. [15]

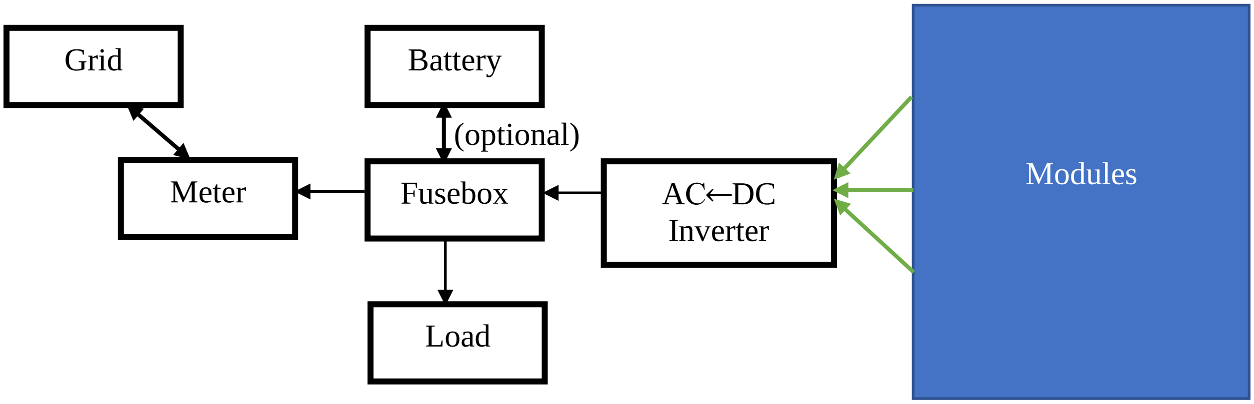

Fig. 4.6 Schematics of Grid-Connected PV Power System

As of now, various types of Solar Cells utilizing different materials that are applicable in a variety of situations are available and may be used to reduce demand at a site.

Types of commercially available PV Cells:

4.1.3.1.1 Monocrystalline silicon PV panels. These are made using cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity. The manufacturing process required to produce monocrystalline silicon is complicated and costs higher than other technologies.[16]

4.1.3.1.2 Polycrystalline silicon PV panels. Also sometimes known as multi-crystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and recrystallized silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than monocrystalline cells due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.[16]

4.1.3.1.3 Thick-film silicon PV panels. This is a variant of multicrystalline technology where the silicon is deposited onto a base material giving a fine-grained, sparkling appearance using a continuous process. Like all crystalline PV, it is normal for it to be encapsulated in a transparent insulating polymer with a tempered glass cover and then bound into a metal-framed module.[16]

4.1.3.1.3 Thick-film silicon PV panels. Amorphous silicon cells are made by depositing silicon in a thin homogenous layer onto a substrate rather than creating a rigid crystal structure. It is given an alternative name of 'thin film' PV as amorphous silicon absorbs light more effectively than crystalline silicon so that the cells can be thinner. Amorphous silicon is ideal for curved surfaces or bonding directly onto roofing materials since it can be deposited on a wide range of substrates, both rigid and flexible. However, this technology is less efficient than crystalline silicon, with typical efficiencies of around 6%, though it is easier and cheaper to produce. If space for installation is not a restriction, an amorphous product can be a good option. However, if the maximum output per square meter is required, specifiers should choose a crystalline technology.[16]

4.1.3.1.5 Other thin-film PV panels. A variety of other materials, such as cadmium telluride (CdTe) and copper indium diselenide (CIS), are now being used for PV modules. The key feature that attracts attention to these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly when compared to crystalline silicon technologies, while also typically offering higher module efficiency than amorphous silicon. Most offer a slightly lower efficiency: CIS is typically 10-13% efficient and CdTe around 8 or 9%. A disadvantage is the use of highly toxic metals such as Cadmium and the need for both carefully controlled manufacturing and end-of-life disposal. However, a typical CdTe module contains only 0.1% Cadmium, which is reported to be lower than is found in a single AA-sized NiCad battery.[16]

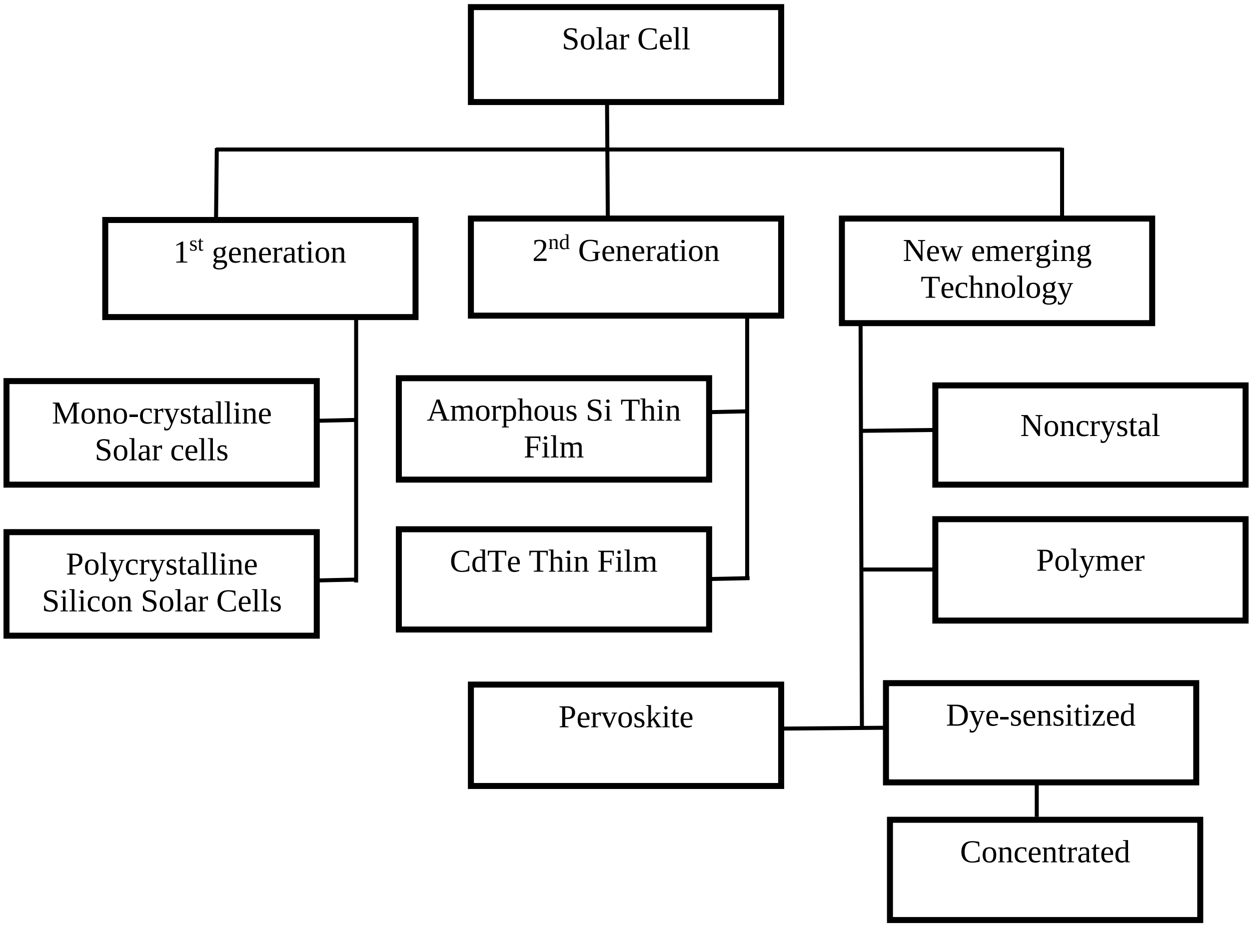

Fig. 4.7 Current and upcoming solar cell types

4.1.3.2 Solar power generation state and capacity in Texas. Solar power in Texas accounts for a small portion of total energy in the state. This includes utility-scale solar power plants as well as local distributed generation, which is mostly from rooftop photovoltaics. The western portion of the state is abundant in open land areas, with some of the country's greatest solar and wind potential.[17] Development activities in Texas are also incentivized by relatively simple permitting and significant available transmission capacity. In 2018 solar power in Texas was generated at 52 facilities with a power capacity of 1948.2MW and totaling 3348GWh of electric energy. This accounted for 0.7% of the state's electric energy while being utilized at a capacity factor of 0.196.[18]

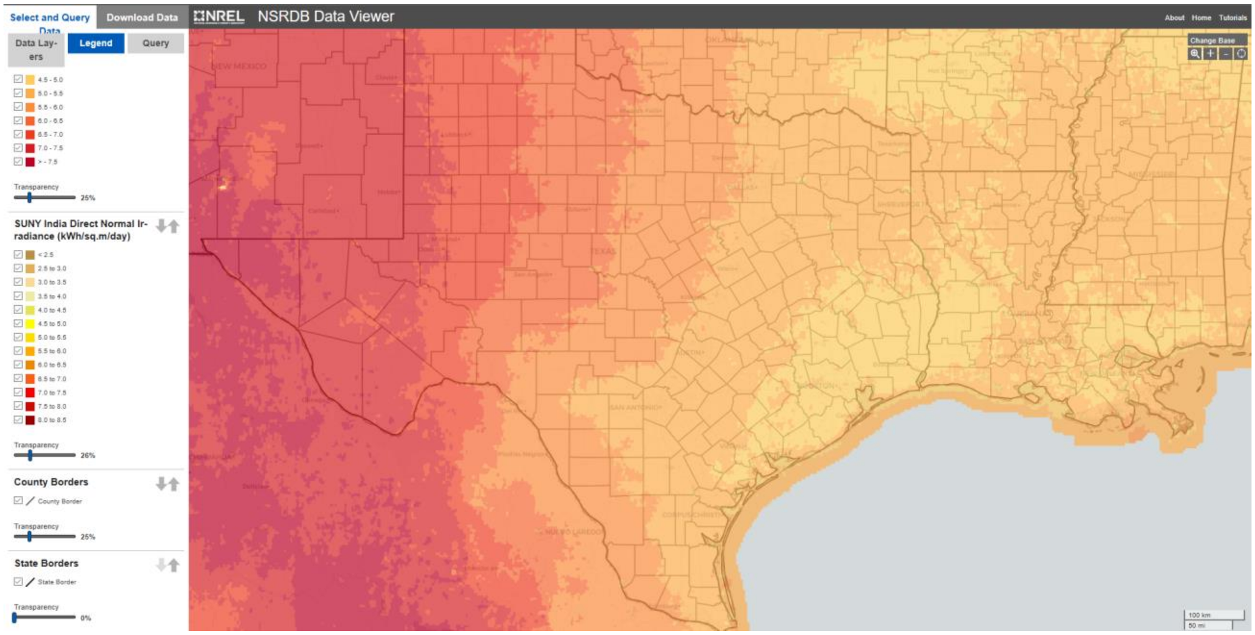

Fig. 4.8 Texas Annual Solar GHI

Using the map from NREL at [18], we can get a range on the amount of solar power that can be generated at a given area using PV modules the following formula [20]:

$$P_s = GHI * A_{pv} * \eta_{pv}$$

Where,

P_s= Solar power/energy generated(W)

GHI = global horizontal irradiance(kWh/m^2/day)

A_{pv}=Area covered by solar(m^2)

η_{pv}= percentage of Solar energy converted by PV modules used

Using available data and reasonable assumptions, we can calculate the potential for Solar power generation in a day or year in various cities in Texas. Using the assumption that 40% open area is used to place solar PV modules and based on cost, the efficiency varies from 6% to 15% to 20%; we can create the following table. The assumed percentages for the efficiency of the PV modules are taken using the cheapest, middle-of-the-road, and most expensive types of PV modules commercially available in the market for Texas.[40]

City	Area(km^2)	Average GHI (kWh/sq.m/day)	Energy generated w.r.t. PV Efficiency (MWh per day)		
			6%	15%	20%
Brownsville	220	4.89	25.82	64.54	86.06
El Paso	671	5.79	93.24	233.1	310.8
Fort Worth	899	4.80	103.6	258.9	345.2
Midland	196	5.52	25.9	64.9	86.6

Table 4.1: Potential quantities of Solar energy generation in different cities in Texas

An example calculation for the table above is given below

For El Paso,

Average GHI [40] = 5.79 kWh/sq.m/day

Area covered by PV modules A_{pv} = 671*1000,000*0.4= 268,400,000

For η_{pv} = 15% ,

P_s = GHI*η_{pv} * A_{pv} = 5.79*268,400,000*0.15 = 233,105,400kWh

4.1.3.3 Solar Power generation and its effect on Demand Management systems. The advantage of solar PV generation is the fact that photovoltaic power plants can be made to be economically dispersed or concentrated. Solar PV generation can be performed by large plants and smaller installations in industrial and residential settings. Below we can see that Solar panels simply installed can, hypothetically, reduce the power demand of an industrial site significantly. However, we can still see significant spikes in demand which can create.

When we start altering the demand by shifting it using demand response, we can further reduce demand and energy costs in the process. By analyzing pricing schemes and predicting future demands, power consumption can be raised pre-emptively. As shown in the next figure, we observe the elimination of the early morning spike by using energy when it is cheaper during the day. Even though the company may not be using less energy, the cost of the energy is reduced significantly by shifting the demand.

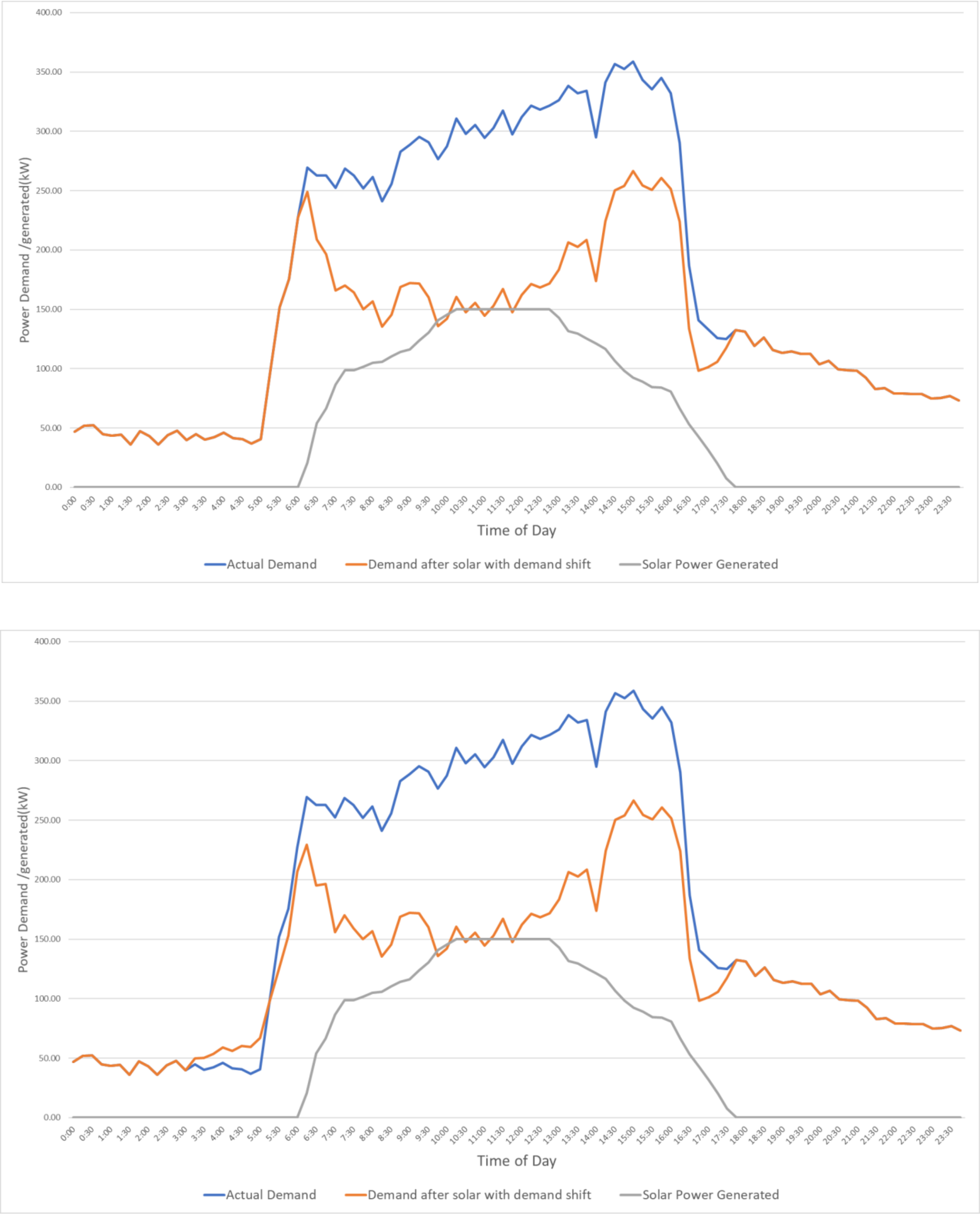

Fig. 4.3.4 Demand curves with solar installed with no shifted demand (Top) vs. Shifted demand using demand response(Bottom), Data sourced during March 23, 2020, Location: Pharr, TX

As we can see, by altering the demand, we can significantly diminish the peak demand significantly. This is done by having some functions start early when the pricing of electricity is cheaper. The lower spike results in significantly lower demand costs. Since energy is being consumed at a cheaper billing period, we also get a lower energy cost even though the amount of energy being consumed is not significantly lower. Examples of such alteration of demand would include:

1. Pre-cooling offices before 5 AM so that AC units do not need to work at full power as during the 5 AM to 7 AM and power demand is kept low during the period when machines get started up.
2. Pre-charging battery utilizing equipment such as battery-operated power tools and cleaners before 5 AM

CHAPTER V

INDUSTRIAL ASSESSMENTS

5.1 Industrial Assessment methods

Industrial Assessment is a way of analyzing and studying a facility to improve its day-to-day operations. The Industrial Assessment Center sends a team to facilities to conduct an energy assessment and assist in creating recommendations that increase energy efficiency and sustainability. The team also conducts a billing analysis on a year's worth of electricity bills to understand better how efficiently a plant is currently operating. Based on these findings, several ways for improving the facility are proposed, which aim to improve efficiency and sustainability while reducing overall electricity usage and demand. These often include removing redundant outdoor lighting, switching lighting to LED equivalents, replacing outdated equipment, and installing a photo-voltaic solar array system. These recommendations add up to tremendous savings in electricity that could benefit a facility for the long term.

The IAC team has made several official assessment recommendations that aim to have relatively low payback times. These assessment recommendations potentially lead to immense annual savings in terms of total annual electricity consumption of electrical energy and reduce peak power demand of electrical energy. The energy savings will have the potential to increase over the years as energy costs gradually increase annually. The team also proposes additional energy efficiency measures which could provide an abundance of savings if implemented.

5.2 Assessment Protocol

The following guidelines are designed to describe the process of a typical IAC energy assessment center in the performance, creation, and delivery of the primary products of the IAC program; the industrial assessment and the industrial assessment report.

Scope of Industrial Assessments:

1. The Industrial Assessment Center (IAC) is an energy center based in the engineering department of a major University and supported by the Industrial Technologies Program at the US Department of Energy.
2. The IAC team is comprised of one (or more) professors and engineering students. One of these students is designated the report lead and another the safety lead.
3. The typical IAC industrial assessment is expected to be conducted in one day.
4. The resultant Assessment Report is designed to help medium-sized manufacturers identify ways to save energy, reduce waste, and improve productivity while providing engineering students with hands-on training in manufacturing plants.

The steps used for industrial assessment are discussed below:

Step 1: Pre-Assessment Information Gathering

The client is sent a Pre-assessment Form. This form includes:

1. Size of Plant and plant layout
2. Industry type (SIC/ NAICS code) and process description
3. Production levels, units, and dollars operating hours
4. A one-year history of utility bills.
5. List of major energy-consuming equipment

Step 2: Ensure that key plant personnel are involved

1. Plant manager
2. Energy manager
3. Environmental personnel
4. Maintenance personnel

Step 3: Pre-Assessment Analysis

1. Analyze the manufacturing process
2. Chart and graph utility bills
3. Analyze utility bills for trends and errors; establish the unit cost of energy
4. Start Plant profile using QuickPEP
5. Identify key energy systems
6. Review design and other technical documentation
7. Identify possible energy saving potential recommendations using the IAC database
8. Develop Assessment Day Strategy

Step 4: Day of the Assessment

1. Introduction
    - History of the IAC program, ITP and Best Practices
    - Distribute BP tools, case studies, tip sheets
2. Description of manufacturing process and operations
    - Is this a typical day?
    - Run through process following material flow

- Discussion of inventory levels
- Questions about defects, bottlenecks, and waste materials
- Present charts and tables of utility bills

3. Plant Tour
    - Conduct in the direction of the material flow
    - Plant Manager to conduct a tour
    - Only one person will ask questions
    - Conceptual tour, no data taken
4. Meeting room debriefing
    - Discuss process, ask questions
    - Develop and plan for the afternoon
    - Create specific tasks and divide them into teams
5. Review notes and brainstorm
    - Develop a list of potential energy-saving opportunities
    - Ensure that everyone has clarity of process and potential recommendations
6. Refine the list of opportunities to be investigated
    - Decide what information needs to be gathered, measured, monitored
    - Assign teams to specific tasks
    - Make plans to meet at assigned time and place
7. Data Gathering

    Conduct Measurements, monitoring, and diagnostic testing

    - Motor systems
    - Heat processes

- Cooling processes
- Water Use and pumps
- Ventilation
- Compressed Air
- Building Systems
- Delivery and distribution systems

8. Exit Interview
    - Discuss findings with management
    - A preliminary estimate of potential savings
    - Prioritize recommendations of analysis

Step 5: Post Assessment Activities

1. Conduct engineering and financial analysis
    - Develop first-order estimates of implementation cost
    - Deliver report to the client, upload date to IAC database
2. Contents of an IAC Report
    - Executive Summary including a summary of Recommendations
    - Plant Description
    - Process Description
    - Resource Charts and Tables
    - Major Energy Consuming Equipment
    - Best Practices
    - Description of Individual Energy Saving Recommendations

3. Follow-up to Report
    - Call client two weeks to ensure delivery and answer questions
    - Call client in 6-9 months for implementation data
    - Upload data to IAC database
    - Inquire about the potential for a Case Study of the project(s)

5.3 Points of interest for Industrial Assessments

Below some of the commonly analyzed points of interest used to create assessment-based recommendations are discussed:

5.3.1 Electricity Bills

This method is the most commonly used method for assessments of a site by the assessing team. The electricity bill can give an overview of electricity consumption and provide a baseline from where improvements can be made. The data collected from the meter can help extrapolate information such as the amount of power demand variation that happens on a daily basis and parts of the day that are problematic due to having a very high demand compared to the normal demand pattern.

Even though each power company has a different method of figuring electricity costs, simple techniques can be devised to identify potential billing payment mistakes and areas for operations improvement. With the use of a computer and database software, the amount of time spent performing this task compared to analyzing each bill one at a time can be reduced. An electric bill consists of the following information:

1) General Data:
    a. Location

    - b. Power company supplying service
    - c. Account number
    - d. Meter number
    - e. Meter multiplier
    - f. Min. contracted kilowatt demand
    - g. Min. power factor without demand penalty
    - h. Rate schedule

2) Electric Data
    - a. Number of days metered
    - b. Beginning date
    - c. Ending date
    - d. Kilowatt-hours used
    - e. Kilowatt demand
    - f. Actual power factor
3) Billing Data
    - a. Usage Cost
    - b. Demand Cost
    - c. Total dollar amount
    - d. Previous meter reading
    - e. Present meter reading
    - f. Miscellaneous Fees

Once this information is in the database, the information can be displayed either in graphical form or in a report was written report form. The user also should have the ability to select data for any time period. For detecting billing mistakes, the written report form performs the best. To evaluate future price trends for budgeting, displaying electric billing information to personnel for easy reference, the graphic approach is more suitable. To locate various ways that a bill can be incorrect, a series of database reports should be generated periodically. Reports have found 95% of the mistakes in electric power bills that meet the following criteria: the current bill is 10% greater than the average of the previous three months, and the variance is greater than $100[34]. By printing monthly all bills that exceed these criteria $7500 worth of incorrect kilowatt and kWh meter reading errors and entry, errors were found in eight months from a single site. In addition, bill analysis helps identify billing mistakes such as those listed below:

1) Arithmetic errors
2) Meter reading errors(kW and kWh)
3) Meter malfunction
4) Data entry errors

Electrical Load Factor is an essential quantifier for how efficiently a site is running. It is calculated by taking the total energy (kWh) used during a specified billing period and dividing it by the product of the total energy used in that period during peak demand (kW) and the total number of hours for that period. The most optimal use of electrical equipment is represented by an ELF of 1, which indicates a 24-hour workday for an entire year at full load operation of all electrical equipment. If the load factor of a facility is below 0.5, this shows high demand with a low utilization rate. If the load factor is at or above 0.75, a facility is deemed reasonably efficient overall. Therefore we can derive that the equipment is running adequately during any peak demands. Based on the findings at a Metal Processing plant at Pharr, Texas, we can calculate its ELF as shown below.

$$ELF = \frac{Monthly\ Energy\ Consumption(kWh)}{Monthly\ Peak\ Demand(kW) * Hours\ per\ Billing\ period}$$

$$ELF = \frac{77150.77}{358.22 * 720} = 0.299$$

5.3.2 Air Flow at the site

When air compressor lines leak in a manufacturing facility, it will cause the connected air compressors to work continuously to keep the desired line pressure running throughout the working environment. When enough leaks occur over time, the facility can lose substantial money due to the increased electricity needed to run the compressor to the optimum working pressure continuously. By inspecting the compressed air systems regularly and repairing leaks when discovered, a company can easily save thousands of dollars a year which would have been spent continuously powering an air compressor. By investing some time and money into detection equipment and staff training, this issue can be mitigated as soon as an issue arises. The leaks themselves can be fairly easy to repair with a low material cost. However, larger issues in the system, such as any pneumatic rams or cylinders, will most likely have to be handled with special repair kits.

To see how preventing air leaks within the site can be beneficial, we can study the presented scenario:

A site has the following installed:

Variable	**Description**	**Value**
V_{Tank}	Total Tank Volume	61.24 ft^3

V_{Pipe}	Total Pipe Volume	662.93 ft^3
T_D	Drop down time	1.5 min
P_{atm}	Atmospheric Pressure	14.7 psi
P_D	Pressure Drop	10 psi
η_C	Specific Efficiency	0.25kW/CFM
L_E	Estimated number of leaks	25 leaks

Table 5.1: Configuration of airflow equipment at the site

With a total system volume of 724.17 ft^3 we can calculate a leakage rate using the following:

$$L_R = \frac{(P_D) * (V_{Sys})}{(P_{atm}) * (T_D)}$$

$$L_R = \frac{(10\, psi)(724.17\, ft^3)}{(14.7\, psi)(1.5 min)} = \mathbf{328.42\ CFM}$$

From this, we can derive the energy saved when stopping these leaks:

E_S=(L_R)∗(η_C)∗(O_H)∗50% $Suppression\ factor$

$$(328.42\ CFM) * (0.25\ \ kW/CFM) * (4{,}200\ \ hrs/yr) * 0.5 = 172{,}421\ \ kWh/yr$$

At a rate of $0.0457/kWh, the cost reduction introduced is

172,421*$0.0457 = $7,879.64

To calculate the peak demand reduction and demand cost reduction,

Demand Saving, $D_S = (L_R) * (\eta_C) * \left(T(in\ month)\right) * 50\%\ Supression\ factor$

$$(328.42\ CFM) * (0.25\ \ kW/CFM) * (12\, months/yr) * 0.5 = 492.63\ \ kW/yr$$

At $10.22/kW, the cost reduction introduced is $5,034.68.

From this, we can clearly see the benefits of performing such analyses. There is an introduction of large energy and annual financial savings once detected, and corrections are made. The cost of implementation can be calculated as follows:

$$C_I = C_{Det} + (L_E * C_{Leak}) + (L_E * T_I * M_C)$$

$$\$280 + (25\, leaks * 100\, \$/leak) + (25\, leaks * 1(hours/leak) * (\frac{\$15}{hour})) = \$3{,}155$$

So we can see that the costs of implementing such improvements are recuperated in savings as follows

Payback period, $T_P = \frac{Cost\ of\ implementation}{Savings\ from\ implementation/year} = \frac{\$3{,}155}{\$7{,}879.64+\$5{,}034.68} = 0.24\, yrs$

5.3.3 Equipment and installations at the site

A key part of assessing a site is finding out inefficiencies in the installations used and figuring out the places where improvements can be made. Equipment used, such as lighting fixtures and rotary belts, often go unnoticed or ignored while sustaining long periods of use, wear and tear, which increases the energy consumed to maintain output and decreases efficiency. Replacing inefficient fixtures and machinery can not only improve output but also contribute to the reduction of energy cost and improve power demand.

We can see the impact of two possible replacements which can be implemented for energy savings and demand reduction discussed below

5.3.3.1 Replacement of incandescent lamps with LEDs. The replacement of incandescent light sources with LEDs is one of the simplest and easiest changes that can be implemented. Not only will it save money based on lower energy use, but LEDs can constantly run and have longer lifespans. Additionally, the user will not have to replace them nearly as often, saving money on all the bulbs themselves as well as manpower used to replace them. Usually, the average incandescent lamp consumes 60 W per lamp. The incandescent lamps can be replaced by 12 W LED lamps which consume less power and have a longer rated life of 25,000 hours compared to the 1000 hours rated life of an incandescent lamp.[31] Since exit lamps are powered continuously, the incandescent lamps will have to be replaced four times a year. Comparatively, the LED lamps will not have to be replaced for many years. There is also the benefit of improved reliability for LEDs in environments subject to vibrations.

Using this information, we can calculate the following:

$$\text{Current energy use per incandescent lamp} = 25W * 0.001\,{}^{kW}/_{W} * 8760\,{}^{hrs}/_{yr}$$

$$= 525.6\ {}^{kWh}/_{yr}$$

$$\text{Energy use per LED lamp} = 0.001kW * 8760\,{}^{kWh}/_{yr} = 105.12\,{}^{kWh}/_{yr}$$

We can see that every lamp results in the reduction of 210.24 kWh/yr in energy consumption per year, and the power demand is reduced by 24W. The monetary savings introduced by this can be calculated as follows. Therefore, the total saving introduced in terms of energy cost and demand cost reduction is as follows:

$$REC + RDC = \left(420.48\,{}^{kWh}/_{yr} * {}^{\$0.0457}/_{kWh}\right) + (0.048kW * 12 * \$10.22/kW)$$

$$= \$25.10$$

So for every replacement of incandescent lamps with LEDs, we see a saving of $25.10. The cumulative savings increase if the number of lamps installed is made bigger, e.g., replacing ten incandescent lamps at a site results in $251.0 per year. The payback period for the installation of the LEDs made by saving is covered by 1.19 years.

5.3.3.2 Replacement of smooth V-belts with notched V-belts. The increase in efficiency between the two is only a few mere percentage points, but when applied to machines that constantly run throughout the year, the savings can be staggering. Based on our findings, if the user were to switch out their current belts for these superior quality ones, they will last longer, run more efficiently, and will not slip on the shaft due to their enhanced gripping ability.

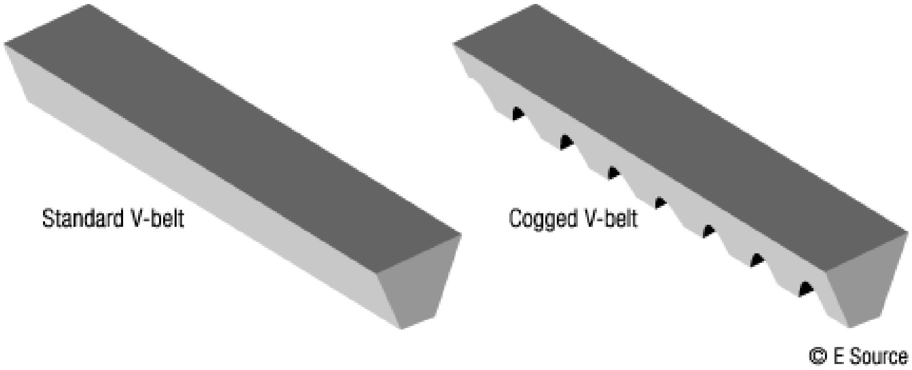

Fig. 5.1 Smooth(standard) v. Cogged V-belt cross-section

Cogged or notched V-belts are an improvement over flat belts in two distinct ways. First, notched V-belts have reduced slippage as compared to flat drive belts. Second, the notches in the belt reduce the amount of material that must be compressed or stretched around the spindle. Flat belts are stretched on the outer radius and compressed on the inner radius, diverting energy from the desired endpoint. The Department of Energy estimates that a 1-3% efficiency improvement is seen when retrofitting smooth belts with notched belts. Additionally, the lifetime of notched belts is approximately double that of standard smooth belts, with a 20-30% increase in cost.

To see the savings brought by a better belt, we can see the following calculation for a 15hp 60-ton press. The energy used by the motor is:

$$E_M = \frac{(P_M)(K_{HP2KW})(L)(D)(T_0)}{\eta_M}$$

$$\frac{(15hp)(0.746\,{}^{kW}/_{hp})(0.8)(1)(1460\,{}^{hrs}/_{yr})}{0.85} = 15{,}376.98\,{}^{kWh}/_{yr}$$

The energy used by the belt can be found as shown:

$$E_B = E_M(1 - \eta_B)$$

$$(15{,}378.98)(1 - 0.95) = 768.82\,\frac{kWh}{yr}$$

The energy used by a more efficient belt is shown

$$(15{,}378.98)(1 - 0.97) = 461.29\,\frac{kWh}{yr}$$

The energy savings introduced is 307.53kWh/yr

The Energy cost savings introduced by the new belt can be calculated:

$$307.53kWh * \frac{\$0.0457}{kWh} = \$14.05/yr$$

CHAPTER VI.

DEMAND RESPONSE IN MANUFACTURING FACILITIES

6.1 Demand Response opportunities in Manufacturing Facilities

In addition to retail demand response (DR) programs that operate outside an ISO's markets, The ISO can implement participating load, proxy demand response, reliability demand response, and non-generator resource products in the market. These are alternative models for accommodating different types of DR resources that have different operating characteristics, including (a) bidding responsive demand with a single bid curve rather than bidding and dispatching responsive demand reductions separately from the original load schedule, using a proxy generator, (b) representation in the market through a DR aggregator rather than through the load-serving entity, and (c) continuously variable operation rather than more discrete events with minimum demand reductions and run-time limitations.[26] Currently, there are two areas for facilitating the development of DR and related resources: (a) the need for and value of flexible capacity for ramping in response to changing system conditions, and (b) aligning DR resource aggregations with capacity needs and the value of the resources.

Products that non-generation resources, such as those that DR can provide, can be used for power system reliability. In fact, program designs for non-generation resources prove flexible in providing a common foundation for many types of controllable resources. In a roadmap used by the CAISO to advance DR and EE, non-polluting distributed energy resources such as microgrids, rooftop solar, electric vehicles, and energy storage facilities are further promoted and built upon.

The ISOs can use this to plan and envision these resources to contribute to the low-carbon, flexible capacity needed to maintain real-time system balance and reliability, supporting the integration of renewable energy. The roadmap describes the following goals that sites can aim for, which will help transition to cleaner, greener, environmentally-sustainable manufacturing facilities [26]:

1. Consistent assumptions for resource planning and procurement for site
2. Implementing load modifying programs results in more favorable load shapes, thus reducing resource procurement requirements and mitigating over-generation and moderating ramps.
3. Configuration of the site's operational requirements to optimally configure DR and maximize EE to be the most effective at minimizing energy costs.
4. Procured DR and EE resources that satisfy manufacturing capability, demand timing, and locational needs.
5. Improvement of the DR participation of the manufacturing site in markets; this provides operational experience and feedback for program and policy refinement.

There are three paths forwards available for provider and manufacturing facilities for collaboration for the implementation of DR and EE[26]:

- Load reshaping: Maximize DR and EE potential, so that load shape is favorably reconfigured for flatter overall system load with smooth peaks and valleys.
- Resource sufficiency: Ensure sufficient supply resources with needed operational characteristics in the right places and times, and develop policy to guide DR procurement as a supply resource.
- Monitoring: Provide feedback to record experience in understanding DR’s operational capabilities, aligning DR and EE with system and local needs, and reshaping load profiles.

6.2 Opportunities in Demand Response

The following opportunities can be used for forecasting DR accurately and timely also provide opportunities for significant improvement [27]:

6.2.1 Rescheduling facility operating hours

Most DR programs currently use a per program forecast based on ex-post load impacts or past program-level load reductions. Forecasting is made more complicated when the programs are integrated into the wholesale market. As DR continues to expand into the small and medium-sized business (SMB) space, where manufacturers and business owners' attributes are more likely to look similar to one another, DR forecasting will start to remain at the program level. This is particularly helpful in direct load control programs that use direct load control, where the load reduction per controlled device can be estimated. However, even in cases where some homogeneity can be assumed, additional variables need to be considered, including local ambient temperature and the number of days into a heatwave. Better forecasting helps the facility shift schedules to operate during part-peak hours to reduce the peak period usage and demand charges during the summer months. Prediction of Pead, Part-Peak, and Off-Peak periods will help shift production out of ‘peak’ periods during similar seasons, resulting in significantly avoided electrical costs.[32]

6.2.2 Delaying operation of machinery with advance

Currently, the load reduction attributed to a DR event for most programs is measured by comparing the load on the event day against a baseline. The baseline that has been chosen in some states, e.g., California, is the average of the hourly load from the ten business days before the event day, with the option of a pre-event morning adjustment at the participant level [28]. This baseline calculation is chosen for its simplicity in settlements with DR customers and aggregators.

However, there are limitations to this process [29]. “Similar days” prior to the event day may have slight variations, e.g., some industries may involve startup and shutdown of loads at the beginning and end of the week. Thus, Mondays and Fridays are not typical days. Another common example occurs when the event day is at the beginning of a warming trend. A higher ambient temperature on the event day may cause the load to be higher relative to the baseline. Thus, even though an overall load reduction is observed during the event, this spike can be so large that it offsets a significant portion of the actual reduction compared to the baseline. This result can even occur when using a baseline with a pre-event load adjustment. In these cases, an alternate approach may be to use an adjustment based on ambient temperature during the event. Based on studies of electrical power measurements and facility energy balance, it is estimated that delaying the operation of heavy equipment vain called for by utility companies on critical days (given one day’s advance) notice can reduce the annual electrical demand by over 600 kW.[32]

To indicate the level of savings in the manufacturing plant, various case studies have been performed. The DR and EE measures identified can save the plants over 11% in electrical energy usage and 15% in combustible fuel energy usage. As a result, over 12% of energy cost savings were found in these plants.[32]

6.3 Metrics to use when identifying renewable energy and Demand Response opportunities at a manufacturing site

To find the potential opportunities at a manufacturing site, the following metrics can be utilized[35]:

- Historical Demand ratio

  D/E $=\frac{Average\ billed\ demand}{Average\ billed\ usage}$

- Usage charges ratio

  P/U $=\frac{Average\ monthly\ demand(kW)}{Average\ monthly\ usage(kWh)}$

- % capacity used = ELF = $\frac{Average\ Monthly\ usage(kWh)}{Monthly\ average\ peak\ demand*24*30}$

Using available data on a Metal processing plant in Pharr, Texas, we can calculate the following

P/U = $\frac{358.81}{83617.24} = 0.0043$

% capacity used = ELF = $\frac{83617.24}{358.81*720} = 0.323$

From this, we can see that there is significant potential for introducing renewable energies and demand response at the manufacturing site. The goal when introducing these should be to increase the value of P/U and the Electrical load factor.

CHAPTER VII

IMPLEMENTATION OF DEMAND RESPONSE IN MANUFACTURING FACILITIES

In previous sections, different aspects of renewable energy and implementation of demand response were discussed. Based on geographical location, the kind of renewable energy source implemented, and the type of demand response best applicable can vary on a case-by-case basis. Even though Texas has vast sources for renewable energies, their popularization and implementation require sufficient investigation. The renewable energy source and DR implemented are also affected by the size of the site in terms of energy consumption, the area covered, and the equipment used. Price-based DR also reshapes loads through dynamic pricing schemes such as real-time price (RTP). It can also help mitigate the difficulties of microgrid energy management with uncertain power generation and load demand. Demand Response Programs (DRPs) are effective in reducing power demand during critical periods. DRPs with increased customer participation and system decentralization play crucial roles in enabling Distributed Generation (DG) by utilizing alternative energy sources such as wind and solar energy. When coupled with DRP, these generation resources present a sustainable system with reduced unserved energy and flexible operational characteristics.

7.1 Minimizing demand

The intended goal for implementing demand response in manufacturing sites is to choose demand and shift it during off-peak such that the demand and energy cost is kept to a minimum. The first objective to meet is to meet the operational requirement of the manufacturer. The second is to ensure minimal demand and energy consumption for the manufacturer. This can be done using a demand controlling computer working in tandem with a smart meter measuring current demand.

Considering the current situation, it is not possible for an actual implementation for the demand controller. It is, however, possible to simulate the 15-minute demand in MATLAB and optimize it within the simulation to obtain the lowest demand and energy cost.

Here the function of minimization can be defined as [35]:

$$Minimize\ :\ \sum_{m}\sum_{t} X_{m,t} * C_m + \sum_{T} W_t + Z_g$$

With constraints:

$$Subject\ to: A_{r.t} \leq B_r\ \forall t \in \{time\ periods\}, \forall \in \{resources\}$$

Where,

$X_{m,t} is\ 0\ if\ machine\ m\ is\ off$

$C_m$is the energy consumption during the time machine m is on

$A_{r,t}$is the resource utilized during the time period, t

$B_r$is the resource available

$Z_g$is the cost of investing in renewable energies technology

$W_t$is the cost of wages at the time period t

7.2 Linear Programming and Dual-Simplex algorithm

Linear programming has been utilized to simulate and optimize the 15-minute demand at the manufacturing facility. The function fmincon uses the function for demand and given constraints determined by the time of day and section of demand period for the manufacturing facility. Rather than utilizing an input of time, the 24 hours of a day have been divided into 96 15-

minute demand periods, during each of which the power consumed by hardware may vary. The linear program can be written in a simplified form as the following:

The function for the cost to be minimized can be represented as follows:

Minimize f(x) = $\sum_{i=1}^{n} x_i$

Subject to :

$$\sum_{i=1}^{n} A_i x_i \geq b_i$$

$x_i \geq 0$

In the context of minimizing demand cost,

x is a vector used to represent demand in various sections at the manufacturing facility. “n” is the number of various electric power demands available at the site. This includes but is not limited to:

I. Lighting fixtures installed at the site
II. Air Conditioners installed at the site
III. Machines installed at the site
IV. Miscellaneous equipment used at the site(e.g., computers, chargers, electrical tools, etc.)

The Dual-simplex algorithm used for minimizing demand can be visualized as shown below:

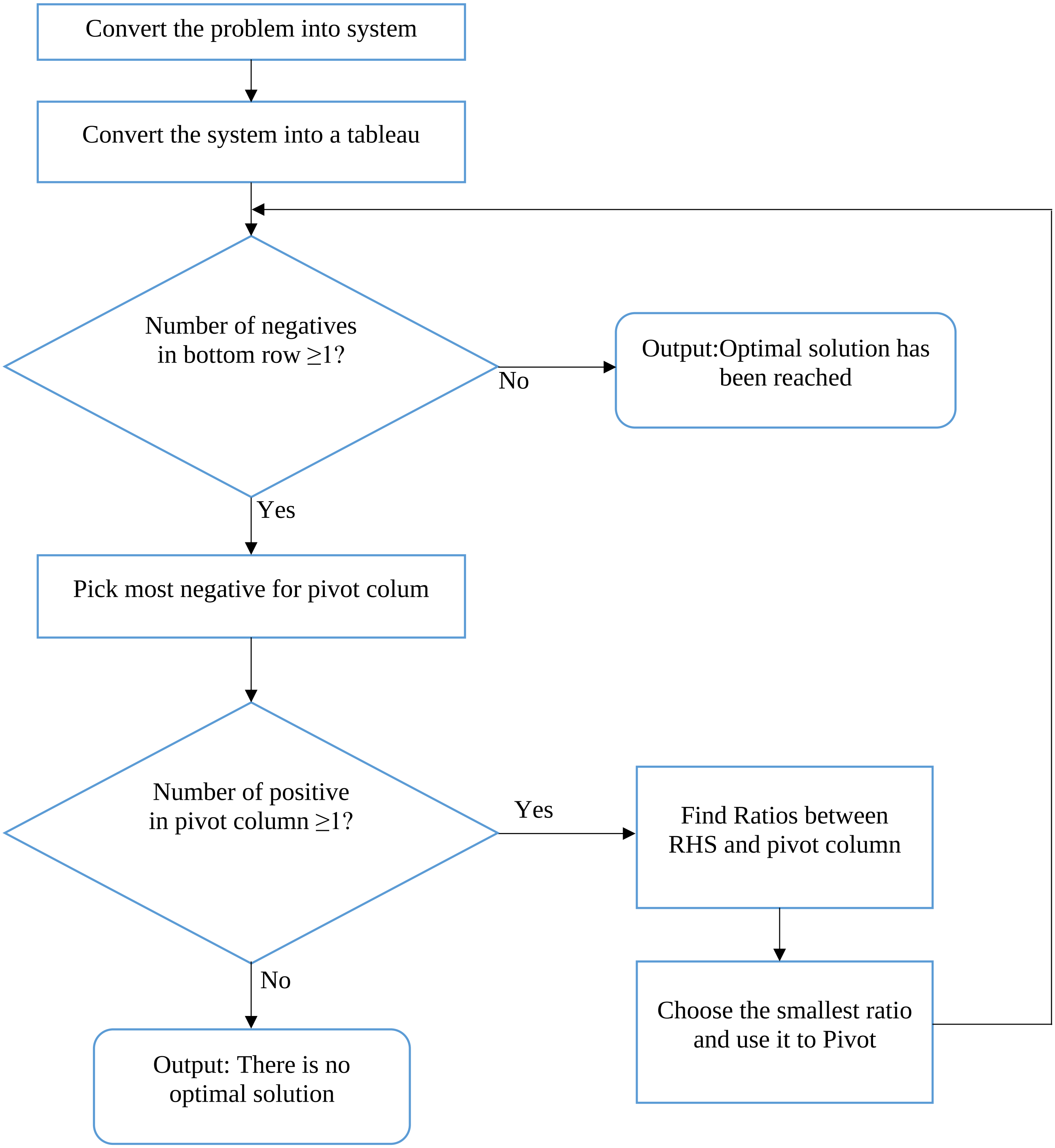

Fig. 7.1 Flowchart of Dual-simplex algorithm used

In MATLAB, linear programming and optimization algorithms are implemented for demand control using the function fmincon from the MATLAB toolbox. The function intends on finding the minimum of a constrained problem specified by

$$\min f(x)\ such\ that\ \begin{cases} c(x) \leq 0 \\ ceq = 0 \\ A * x \leq b \\ Aeq * x = beq \\ lb\ \leq x \leq ub \end{cases}$$

The rand function acts to add realistic variability in the demand when simulating the demand. This is so that the demand for every day does not need to be written, and values near what is observed in a small data sample, e.g., 2 to 3 weeks, can be simulated for calculations.

Given the limitations of the industrial assessment, the team to not be able to alter the cost of wages and the cost of investment in renewables to be fixed. The team will be able to minimize a certain section of the function. The function to be minimized by the work of the assessment team can therefore be written as:

$$Minimize : \sum_{m} \sum_{t} X_{m,t} * C_{m}$$

Where,

$X_{m,t} is\ 0\ if\ machine\ m\ is\ off$

$C_{m}$is the energy consumption during the time machine m is on

$X_{m,t} * C_{m}$Can be is replaced by the variable vector dem in MATLAB to represent the various demands across the manufacturing site and the cost associated with it. The various machines that can be on or off throughout the day include:

Air Conditioners, Pumps, Electric Heaters, Rollers, Cutters, etc.

The simulated and optimized demand for a day in 15-minute intervals for a single iteration is shown below

STOD	Demand(kW)	STOD	Demand(kW)	STOD	Demand(kW)	STOD	Demand(kW)
0:00	47.32	4:00	46.73	8:00	242.80	12:00	319.80
0:15	48.21	4:15	44.23	8:15	251.80	12:15	318.72
0:30	43.99	4:30	45.98	8:30	224.35	12:30	318.20
0:45	46.96	4:45	45.33	8:45	269.80	12:45	320.41
1:00	46.59	5:00	46.65	9:00	278.80	13:00	319.14
1:15	47.23	5:15	46.90	9:15	287.80	13:15	318.24
1:30	47.71	5:30	152.80	9:30	296.80	13:30	323.78
1:45	44.09	5:45	137.92	9:45	305.80	13:45	322.53
2:00	47.43	6:00	170.80	10:00	277.74	14:00	323.99
2:15	45.67	6:15	156.71	10:15	323.80	14:15	327.05
2:30	45.96	6:30	164.95	10:30	332.80	14:30	326.23
2:45	45.52	6:45	197.80	10:45	341.80	14:45	324.85
3:00	44.07	7:00	185.25	11:00	350.80	15:00	326.45
3:15	45.84	7:15	215.80	11:15	314.36	15:15	330.81
3:30	47.64	7:30	224.80	11:30	316.70	15:30	326.34
3:45	44.49	7:45	233.80	11:45	316.92	15:45	326.48

STOD	Demand(kW)	STOD	Demand(kW)
16:00	331.96	20:00	45.44
16:15	331.16	20:15	48.90
16:30	329.97	20:30	48.53
16:45	332.11	20:45	48.52
17:00	47.12	21:00	48.55
17:15	47.39	21:15	45.33
17:30	45.48	21:30	47.36
17:45	45.42	21:45	46.35
18:00	47.59	22:00	42.69
18:15	47.42	22:15	44.76
18:30	47.78	22:30	48.32
18:45	46.71	22:45	45.92
19:00	47.59	23:00	47.83
19:15	45.22	23:15	45.66
19:30	46.65	23:30	46.22
19:45	48.42	23:45	44.57

Table 7.1: Simulated and minimized 15-minute demand at the manufacturing site

Such simulation results will vary every time it is run but will tend to output values that demonstrate a similar pattern to what is observed here.

MATLAB Code used to simulate and minimize demand throughout the day:

```
clear;
close all;
clc;
day_dem = [];
  %initializing demand values
  lightsr1 = 0;
  lightsr2 = 0;
  lightsr3 = 0;
  demAC1 = 0;
  demAC2 = 0;
  demAC3 = 0;
  demmach1 =0;
  demmach2 =0;
  demmach3 =0;
  %setting demand for low demand night time 00:00 - 5:30
for i = 1:22
  f = @(dem)(dem(1) + dem(2) + dem(3) + dem(4)+ dem(4)+ dem(5)+ dem(6)+
dem(7)+ dem(8)+ dem(9)+ dem(10)); %define function for minimization
  lb = [12*((0.8-0.6)*rand+0.6), 12*((0.8-0.6)*rand+0.6), 12*((0.8-
0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-
0.6)*rand+0.6), 0,0,0,30*((0.8-0.6)*rand+0.6)]; %lower bound
  ub = [12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8),
10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8),
0,0,0,30*((1-0.8)*rand+0.8)]; %upper bound
  A = []; %coefficients for linear inequality constraints
  b = []; %constants for linear inequality constraints
  Aeq = []; %coefficients for linear equality constraints
  beq = []; %constants for linear equality constraints
  dem0 = [9.6,9.6,9.6,8,8,8,0,0,0,24]; %initial guess
  [dem,fval] = fmincon(f,dem0,A,b,Aeq,beq,lb,ub);  %fmincon function to
perform constrained optimization
  lightsr1 = dem(1);
  lightsr2 = dem(2);
  lightsr3 = dem(3);
  demAC1 = dem(4);
  demAC2 = dem(5);
  demAC3 = dem(6);
  demmach1 =dem(7);
  demmach2 =dem(8);
  demmach3 =dem(9);
  demmisc = dem(10);
  totaldem =
lightsr1+lightsr2+lightsr3+demAC1+demAC2+demAC3+demmach1+demmach2+demmach3;
  day_dem = [day_dem totaldem];
end
  %setting demand for daytime part-peak period 5:30 -10:30
for i = 0:22
```

```
  f = @(dem)(dem(1) + dem(2) + dem(3) + dem(4)+ dem(4)+ dem(5)+ dem(6)+
dem(7)+ dem(8)+ dem(9)+ dem(10)); %define function for minimization
  lb = [12*((0.8-0.6)*rand+0.6), 12*((0.8-0.6)*rand+0.6), 12*((0.8-
0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-
0.6)*rand+0.6), (30+3*i)*((1-0.8)*rand+0.8) ,(40+3*i)*((1-0.8)*rand+0.8),
(30+3*i)*((1-0.8)*rand+0.8),30*((0.8-0.6)*rand+0.6)]; %lower bound
  ub = [12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8),
10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8),
(30+3*i)*((1-0.8)*rand+0.8) ,(40+3*i)*((1-0.8)*rand+0.8), (30+3*i)*((1-
0.8)*rand+0.8),30*((1-0.8)*rand+0.8)]; %upper bound
  A = []; %coefficients for linear inequality constraints
  b = []; %constants for linear inequality constraints
  Aeq = []; %coefficients for linear equality constraints
  beq = []; %constants for linear equality constraints
  dem0 = [9.6,9.6,9.6,8,8,8,30+3*i ,40+3*i, 30+3*i,24]; %initial guess
  [dem,fval] = fmincon(f,dem0,A,b,Aeq,beq,lb,ub);  %fmincon function to
perform constrained optimization
  lightsr1 = dem(1);
  lightsr2 = dem(2);
  lightsr3 = dem(3);
  demAC1 = dem(4);
  demAC2 = dem(5);
  demAC3 = dem(6);
  demmach1 =dem(7);
  demmach2 =dem(8);
  demmach3 =dem(9);
  demmisc = dem(10);
  totaldem =
lightsr1+lightsr2+lightsr3+demAC1+demAC2+demAC3+demmach1+demmach2+demmach3;
  day_dem = [day_dem totaldem];
end
%setting demand for daytime peak period 10:30 - 16:00
for i = 0:22
  f = @(dem)(dem(1) + dem(2) + dem(3) + dem(4)+ dem(4)+ dem(5)+ dem(6)+
dem(7)+ dem(8)+ dem(9)+ dem(10)); %define function for minimization
  lb = [12*((0.8-0.6)*rand+0.6), 12*((0.8-0.6)*rand+0.6), 12*((0.8-
0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-
0.6)*rand+0.6), 90+0.25*i ,90+0.25*i, 90+0.25*i,30*((0.8-0.6)*rand+0.6)];
%lower bound
  ub = [12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8),
10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8),
90+0.25*i ,90+0.25*i, 90+0.25*i,30*((1-0.8)*rand+0.8)]; %upper bound
  A = []; %coefficients for linear inequality constraints
  b = []; %constants for linear inequality constraints
  Aeq = []; %coefficients for linear equality constraints
  beq = []; %constants for linear equality constraints
  dem0 = [9.6,9.6,9.6,8,8,8,0,0,0,24]; %initial guess
  [dem,fval] = fmincon(f,dem0,A,b,Aeq,beq,lb,ub);  %fmincon function to
perform constrained optimization
  lightsr1 = dem(1);
  lightsr2 = dem(2);
  lightsr3 = dem(3);
  demAC1 = dem(4);
  demAC2 = dem(5);
  demAC3 = dem(6);
  demmach1 =dem(7);
  demmach2 =dem(8);
```

```
  demmach3 =dem(9);
  demmisc = dem(10);
  totaldem =
lightsr1+lightsr2+lightsr3+demAC1+demAC2+demAC3+demmach1+demmach2+demmach3;
  day_dem = [day_dem totaldem];
end
  %setting demand for low-demand end-of-day 16:00 - 00:00
for i = 1:28
  f = @(dem)(dem(1) + dem(2) + dem(3) + dem(4)+ dem(4)+ dem(5)+ dem(6)+
dem(7)+ dem(8)+ dem(9)+ dem(10)); %define function for minimization
  lb = [12*((0.8-0.6)*rand+0.6), 12*((0.8-0.6)*rand+0.6), 12*((0.8-
0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-0.6)*rand+0.6), 10*((0.8-
0.6)*rand+0.6), 0,0,0,30*((0.8-0.6)*rand+0.6)]; %lower bound
  ub = [12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8), 12*((1-0.8)*rand+0.8),
10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8), 10*((1-0.8)*rand+0.8),
0,0,0,30*((1-0.8)*rand+0.8)]; %upper bound
  A = []; %coefficients for linear inequality constraints
  b = []; %constants for linear inequality constraints
  Aeq = []; %coefficients for linear equality constraints
  beq = []; %constants for linear equality constraints
  dem0 = [9.6,9.6,9.6,8,8,8,0,0,0,24]; %initial guess
  [dem,fval] = fmincon(f,dem0,A,b,Aeq,beq,lb,ub);  %fmincon function to
perform constrained optimization
  lightsr1 = dem(1);
  lightsr2 = dem(2);
  lightsr3 = dem(3);
  demAC1 = dem(4);
  demAC2 = dem(5);
  demAC3 = dem(6);
  demmach1 =dem(7);
  demmach2 =dem(8);
  demmach3 =dem(9);
  demmisc = dem(10);
  totaldem =
lightsr1+lightsr2+lightsr3+demAC1+demAC2+demAC3+demmach1+demmach2+demmach3;
  day_dem = [day_dem totaldem];
end
```

The following MATLAB code can be used to simulate the demand across the day for a Metal forming Company's manufacturing facility. The simulation takes the 15-minute demand data throughout the week and simulates the solar and wind power generated during those days. Using the simulated demand data, we can obtain a simulated quantity for the following:

1. 15-minute power demand throughout the day
2. Maximum demand for everyday
3. Maximum demand for every week
4. Maximum demand for the month

5. The energy that would have been consumed without any renewable energy sources present

Using the simulated solar and wind profile, we can then also calculate

6. The actual 15-minute demand throughout the day after it has been reduced using renewable energy sources installed at the facility
7. Maximum reduced-demand for every week
8. Maximum reduced demand for the month

Using these values, the program then calculates:

9. The reduction in demand for the month
10. The reduction in energy used for the month
11. The reduction of demand and energy cost
12. The total savings created by the implementation the renewable energy sources for the whole month
13. The total savings introduced per year

The code is shown below:

```
clc;
clear;
close all;
cost_redy = [];
for j = 1:12
  maxwdem = [];
  amaxwdem = [];
  aenergyconm = 0;
  energyconm =0;
  for i=1:4
    tod = 1:1:96;%15 min intervals throuout the day
    windcap = 0;
    acdem_mon = [ 71.12 73.73 48.45 66.05 55.14 62.98 61.13 61.90 58.06 57.44
55.14 56.37 55.76 54.83 56.52 55.91 56.83 50.99 53.45 47.00 97.54 151.60
175.56 227.48 269.26 262.96 275.56 274.94 274.33 262.96 270.03 278.94 270.80
255.74 286.92 294.91 296.45 303.20 314.26 316.11 314.11 319.49 312.11 294.45
```

```
302.90 317.34 317.80 320.26 323.02 330.85 328.09 337.30 338.22 332.08 334.08
299.21 341.14 356.66 352.36 358.81 343.30 335.46 344.98 332.24 290.30 192.77
141.00 133.32 135.63 129.79 132.40 131.17 120.11 126.41 115.97 113.36 112.59
103.83 106.75 99.68 98.61 98.46 92.46 92.46 82.79 83.56 78.95 79.10 78.49
78.80 74.96 75.11 75.11 76.95 73.26 54.83]; % demand across monday
    winp =[windcap*((0.8-0.5)*rand(1,96)+.5)]; % wind power throughout the
day
    solp = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9.86 25.81 42.45 60.53
91.63 100.28 107.15 109.90 110.13 112.32 112.54 115.87 119.47 120.41 125.72
129.92 132.59 141.01 148.63 150 150 150 150 150 150 150 150 150 150 150 150
150 150 150 147.52 142.80 138.10 133.02 121.23 112.10 105.29 101.38 96.47
95.82 92.12 75.65 60.54 48.64 36.44 22.98 8.77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0].*((1-0.8)*rand(1,96)+.8);% solar power generated
throughout the day
    netdem_mon = acdem_mon - winp -solp;
    aenergycon_mon = sum(acdem_mon)*0.25;
    energycon_mon = sum(netdem_mon)*0.25;
    acdem_tue = [71.12 73.73 65.12 66.05 55.14 62.98 61.13 61.90 58.06 57.44
55.14 56.37 55.76 54.83 56.52 55.91 56.83 50.99 53.45 47.00 40.55 71.42
159.59 180.63 218.88 256.51 275.56 270.80 274.33 254.05 264.65 278.94 270.80
253.59 265.73 286.92 294.91 296.45 301.98 314.26 309.96 314.11 319.49 312.11
279.86 282.16 309.35 317.80 308.58 313.04 330.85 328.09 323.02 322.56 329.93
323.33 299.21 328.40 313.50 302.44 301.52 302.44 293.68 296.91 284.77 235.47
161.74 115.81 110.90 99.84 99.99 109.36 98.61 99.68 96.77 97.54 98.15 92.62
87.24 85.09 83.10 81.41 81.41 81.25 75.26 63.59 55.45 69.58 58.06 61.13 58.98
58.52 56.22 61.90 54.22 56.22];%demand across tuesday
    winp =[windcap*((0.8-0.5)*rand(1,96)+.5)]; % wind power throughout the
day
    solp = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9.86 25.81 42.45 60.53
91.63 100.28 107.15 109.90 110.13 112.32 112.54 115.87 119.47 120.41 125.72
129.92 132.59 141.01 148.63 150 150 150 150 150 150 150 150 150 150 150 150
150 150 150 147.52 142.80 138.10 133.02 121.23 112.10 105.29 101.38 96.47
95.82 92.12 75.65 60.54 48.64 36.44 22.98 8.77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0].*((1-0.8)*rand(1,96)+.8);% solar power generated
throughout the day
    netdem_tue = acdem_tue - winp -solp;
    aenergycon_tue = sum(acdem_tue)*0.25;
    energycon_tue = sum(netdem_tue)*0.25;
    acdem_wed = [54.68 53.30 50.99 50.69 52.84 52.07 56.37 49.00 47.31 50.84
50.38 45.00 32.87 33.79 32.26 39.94 32.56 36.71 35.48 28.72 33.94 102.45
138.08 158.21 215.65 259.58 272.18 274.94 272.33 261.73 270.03 278.78 266.19
247.76 260.96 286.31 273.87 286.77 303.20 306.58 316.11 303.82 294.45 301.21
276.17 276.48 301.52 311.19 320.26 323.02 319.02 311.96 337.30 335.77 320.72
321.64 285.08 298.90 325.17 334.69 345.14 322.25 320.41 317.95 307.66 272.64
192.77 137.62 129.18 135.63 129.79 125.95 124.57 120.11 114.74 103.98 96.61
90.32 83.40 76.64 72.80 70.81 73.57 71.27 65.12 70.35 69.12 65.28 52.84 53.45
55.76 52.68 47.31 52.53 51.15 51.15];%demand across wednesday
    winp =[windcap*((0.8-0.5)*rand(1,96)+.5)]; % wind power throughout the
day
    solp = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9.86 25.81 42.45 60.53
91.63 100.28 107.15 109.90 110.13 112.32 112.54 115.87 119.47 120.41 125.72
129.92 132.59 141.01 148.63 150 150 150 150 150 150 150 150 150 150 150 150
150 150 150 147.52 142.80 138.10 133.02 121.23 112.10 105.29 101.38 96.47
95.82 92.12 75.65 60.54 48.64 36.44 22.98 8.77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0].*((1-0.8)*rand(1,96)+.8);% solar power generated
throughout the day
    netdem_wed = acdem_wed - winp -solp;
```

```
    aenergycon_wed = sum(acdem_wed)*0.25;
    energycon_wed = sum(netdem_wed)*0.25;
    acdem_thu = [31.79 37.48 28.11 39.01 36.25 37.32 38.40 30.56 41.01 35.48
34.71 33.02 37.17 29.03 34.56 29.34 32.10 31.95 30.10 30.10 29.49 94.31
126.72 131.33 139.47 158.21 158.21 162.35 151.60 161.12 159.59 167.42 172.18
160.97 173.57 174.64 166.81 180.32 183.09 182.17 182.78 186.93 175.87 172.95
159.44 160.97 171.11 167.73 168.19 174.95 187.70 189.85 181.40 166.96 170.96
183.40 193.69 159.90 103.06 78.80 84.63 83.86 84.94 82.18 80.64 66.82 53.60
54.83 45.92 46.23 44.39 45.77 43.62 39.01 43.31 41.47 43.01 45.31 44.39 48.69
44.24 44.08 39.17 37.48 43.47 37.78 39.01 43.62 43.93 40.55 42.08 40.70 42.39
42.70 39.78 38.70];%demand across
    winp =[windcap*((0.8-0.5)*rand(1,96)+.5)]; % wind power throughout the
day
    solp = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9.86 25.81 42.45 60.53
91.63 100.28 107.15 109.90 110.13 112.32 112.54 115.87 119.47 120.41 125.72
129.92 132.59 141.01 148.63 150 150 150 150 150 150 150 150 150 150 150 150
150 150 150 147.52 142.80 138.10 133.02 121.23 112.10 105.29 101.38 96.47
95.82 92.12 75.65 60.54 48.64 36.44 22.98 8.77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0].*((1-0.8)*rand(1,96)+.8);% solar power generated
throughout the day
    netdem_thu = acdem_thu - winp -solp;
    aenergycon_thu = sum(acdem_thu)*0.25;
    energycon_thu = sum(netdem_thu)*0.25;
    acdem_fri= [40.40 36.71 39.01 45.62 44.70 37.78 40.70 39.17 36.40 35.63
37.94 33.64 36.86 37.32 40.70 38.24 33.94 39.47 38.40 38.86 40.86 36.10 31.33
35.94 33.94 37.94 33.48 40.70 32.56 33.33 32.56 39.63 37.17 54.83 57.29 53.91
46.69 45.77 50.53 63.28 62.67 59.14 56.98 61.74 66.66 63.74 75.72 81.25 79.26
85.55 83.56 83.56 84.78 89.55 91.24 92.62 88.93 89.09 91.70 94.77 95.84 97.38
95.84 94.00 92.00 93.23 97.84 98.92 95.84 94.00 92.31 93.85 90.32 93.54 88.16
89.70 84.78 84.17 84.17 80.79 83.40 84.02 80.33 73.57 63.74 64.82 67.28 68.04
65.58 67.58 66.51 59.60 57.60 57.14 48.69 54.83];
    winp =[windcap*((0.8-0.5)*rand(1,96)+.5)]; % wind power throughout the
day
    solp = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9.86 25.81 42.45 60.53
91.63 100.28 107.15 109.90 110.13 112.32 112.54 115.87 119.47 120.41 125.72
129.92 132.59 141.01 148.63 150 150 150 150 150 150 150 150 150 150 150 150
150 150 150 147.52 142.80 138.10 133.02 121.23 112.10 105.29 101.38 96.47
95.82 92.12 75.65 60.54 48.64 36.44 22.98 8.77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0].*((1-0.8)*rand(1,96)+.8);% solar power generated
throughout the day
    netdem_fri = acdem_fri - winp -solp;
    aenergycon_fri = sum(acdem_fri)*0.25;
    energycon_fri = sum(netdem_fri)*0.25;
    acdem_sat= [44.70 43.78 36.86 37.78 37.94 39.01 33.33 36.86 39.32 32.26
29.80 36.86 35.79 32.26 29.18 35.79 30.26 32.72 27.65 33.48 27.65 33.02 27.49
31.49 33.33 37.32 34.40 27.80 28.72 35.63 33.18 37.02 31.02 37.63 39.94 42.39
49.00 52.07 52.22 53.91 60.06 59.44 67.28 76.34 72.04 76.49 78.64 79.10 83.86
83.10 89.86 90.62 91.08 85.25 82.48 77.26 80.18 81.87 87.09 88.47 88.32 86.32
87.40 92.77 92.77 90.62 81.25 78.95 80.48 81.25 80.18 81.56 86.78 85.55 83.86
81.56 80.94 78.03 78.80 78.49 81.25 81.41 78.03 58.06 64.20 53.45 59.60 56.52
56.98 50.38 49.46 43.93 54.06 47.31 43.47 52.68];
    winp =[windcap*((0.8-0.5)*rand(1,96)+.5)]; % wind power throughout the
day
    solp = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9.86 25.81 42.45 60.53
91.63 100.28 107.15 109.90 110.13 112.32 112.54 115.87 119.47 120.41 125.72
129.92 132.59 141.01 148.63 150 150 150 150 150 150 150 150 150 150 150 150
150 150 150 147.52 142.80 138.10 133.02 121.23 112.10 105.29 101.38 96.47
```

```
95.82 92.12 75.65 60.54 48.64 36.44 22.98 8.77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0].*((1-0.8)*rand(1,96)+.8);% solar power generated
throughout the day
    netdem_sat = acdem_sat - winp -solp;
    aenergycon_sat = sum(acdem_sat)*0.25;
    energycon_sat = sum(netdem_sat)*0.25;
    acdem_sun= [48.69 45.62 43.16 38.09 46.23 45.16 43.47 40.70 41.78 35.79
35.02 38.86 35.94 37.78 37.78 30.10 31.49 38.55 35.79 33.79 40.24 37.02 33.18
31.33 29.64 35.33 27.95 32.56 24.42 34.10 38.09 36.56 32.72 30.26 32.41 38.09
45.62 51.61 48.23 54.37 54.37 53.91 67.58 71.58 69.73 74.19 81.41 81.71 85.40
90.47 89.24 83.56 85.25 86.94 95.38 94.00 97.07 90.47 95.84 94.00 98.00 98.30
101.07 95.38 94.77 90.16 95.84 96.46 102.91 98.15 96.61 93.70 92.00 88.78
89.24 88.47 88.93 80.94 81.56 79.72 78.49 76.49 79.87 74.03 68.35 64.20 57.90
64.51 64.36 57.29 55.60 59.90 52.68 54.53 43.31 45.16];
    winp =[windcap*((0.8-0.5)*rand(1,96)+.5)]; % wind power throughout the
day
    solp = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9.86 25.81 42.45 60.53
91.63 100.28 107.15 109.90 110.13 112.32 112.54 115.87 119.47 120.41 125.72
129.92 132.59 141.01 148.63 150 150 150 150 150 150 150 150 150 150 150 150
150 150 150 147.52 142.80 138.10 133.02 121.23 112.10 105.29 101.38 96.47
95.82 92.12 75.65 60.54 48.64 36.44 22.98 8.77 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0].*((1-0.8)*rand(1,96)+.8);% solar power generated
throughout the day
    netdem_sun = acdem_sun - winp -solp;
    aenergycon_sun = sum(acdem_sun)*0.25;
    energycon_sun = sum(netdem_sun)*0.25;
    amaxmon = max(acdem_mon);
    amaxtue = max(acdem_tue);
    amaxwed = max(acdem_wed);
    amaxthu = max(acdem_thu);
    amaxfri = max(acdem_fri);
    amaxsat = max(acdem_sat);
    amaxsun = max(acdem_sun);
    amaxwdem =[amaxwdem max([amaxmon amaxtue amaxwed amaxthu amaxfri amaxsat
amaxsun])];
    maxmon = max(netdem_mon);
    maxtue = max(netdem_tue);
    maxwed = max(netdem_wed);
    maxthu = max(netdem_thu);
    maxfri = max(netdem_fri);
    maxsat = max(netdem_sat);
    maxsun = max(netdem_sun);
    maxwdem =[maxwdem max([maxmon maxtue maxwed maxthu maxfri maxsat
maxsun])];
    aenergyconw =aenergycon_mon + aenergycon_tue + aenergycon_wed +
aenergycon_thu + aenergycon_fri + aenergycon_sat + aenergycon_sun;
    aenergyconm = aenergyconm+ aenergyconw;
    energyconw =energycon_mon + energycon_tue + energycon_wed + energycon_thu
+ energycon_fri+ energycon_sat + energycon_sun;
    energyconm = energyconm+ energyconw;
  end
  amaxmdem = max(amaxwdem);
  maxmdem = max(maxwdem);
  adem_cost = amaxmdem*10.22;
  aenergy_cost = aenergyconm*0.0457;
  dem_cost = maxmdem*10.22;
  energy_cost = energyconm*0.0457;
```

```
  dem_red = amaxmdem - maxmdem;
  energy_red = aenergyconm - energyconm;
  acost = adem_cost+aenergy_cost;
  cost_redm = (dem_red*10.22)+(energy_red*0.0457);
  cost_redy = [cost_redy cost_redm];
end
yearly_cost_red = sum(cost_redy);
```

Therefore, the two codes simulate the function for minimization and generate values for when the demand is minimized, such as the initial and actual cost of using the system over the span of a year.

Using this, we can observe the following savings when simulating demand over a long period.

Month of the year	Savings introduced($)
January	2627.70
February	2610.30
March	2633.00
April	2722.90
May	2606.70
June	2659.30
July	2623.80
August	2666.43
September	2672.61
October	2595.81
November	2594.86
December	2614.17
Total	31627.65

Table 7.2: Monthly and Total savings introduced by the 150kW Solar generation and demand shifts estimated by simulation

7.3 Role of Industrial Assessments

Even though the implementation of demand response and renewable energy can bring are significant improvements to a manufacturing site, a lack of information often leads to them not being implemented. To find whether or not renewable energies can be implemented at the site, the following method can be followed[35]:

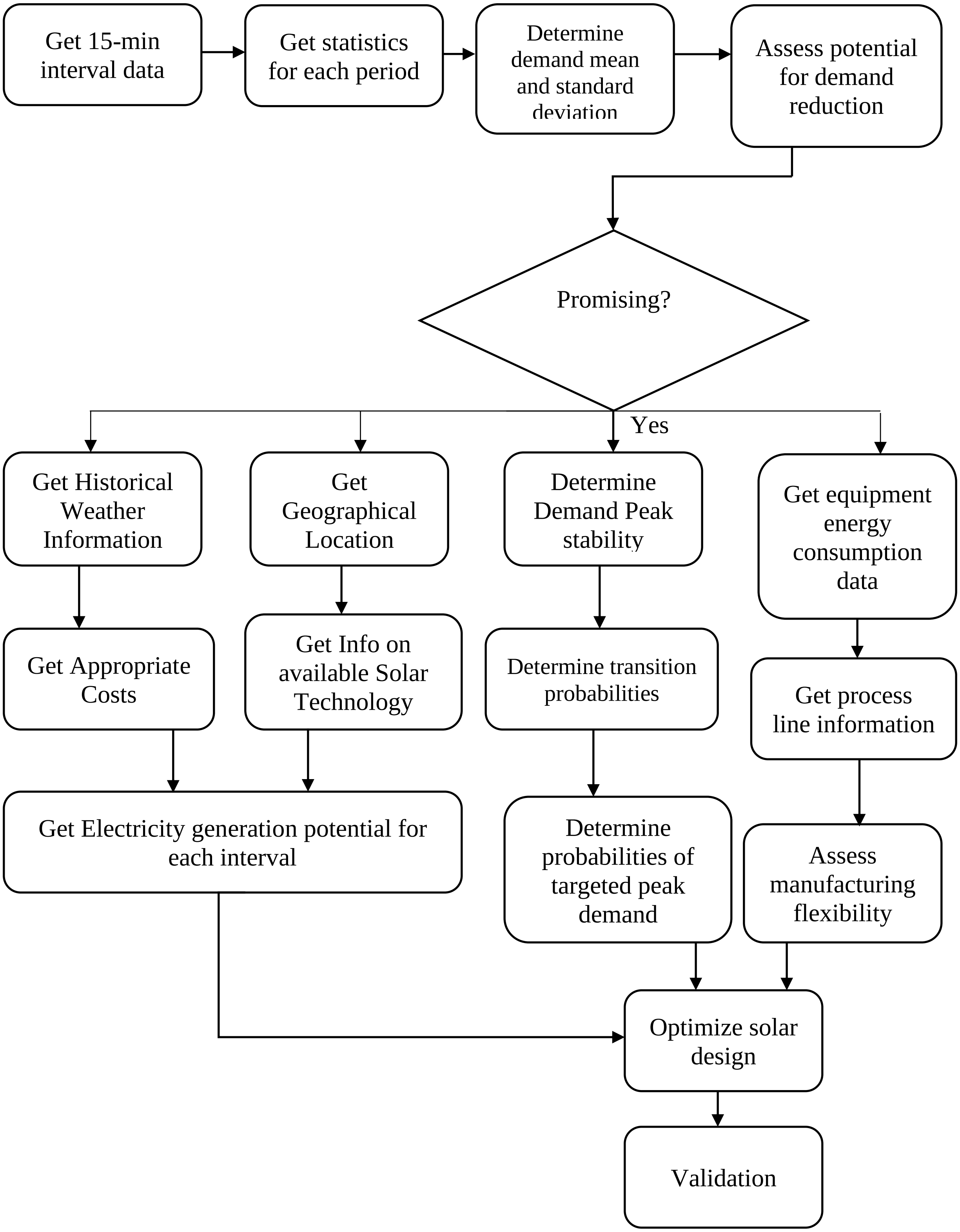

Fig. 7.2 General Approach for implementation of renewable energy generation at the manufacturing site for the Industrial Assessment team

Since demand profiles can vary between different manufacturers and times of the year, the program can be altered to fit the manufacturers' processes on a case-by-case basis. The programs shown previously for demand simulation, minimization, and finding the savings can be changed after performing the steps described in the “Assessment protocol” section of Chapter 5 by an industrial assessment team. The savings and payback from the implementation of demand response and renewable energies can be calculated for a Metal processing plant in Pharr, Texas, as shown below:

Capacity of Solar Generation Kit(kW)	Price at checkout($)
50	60,537.50
100	118,992.50
150	154,715

Table 7.3: Prices of Solar Kits as seen at [36]

Installed solar generation capacity: 150 kW (PV)

Base Price of all included materials: $142,000

Tax: $11,715

The labor cost of installation:

$$C_{ins} = M_{Tax} * I_{Rate}$$

$$\$142{,}000 * 0.1 = \$14{,}200$$

Cost of installation of solar generation unit with demand controller unit[36]

Equipment cost + labour cost of installation

$$\$154{,}715.00 + \$14{,}200 = \$168{,}915$$

Actual cost of solar generation unit after 26% federal tax credit Tax credit received:

$\$168{,}915 * (\frac{100\%-26\%}{100\%}) = \$124{,}997.1$

Cost of implementing demand shift[37,38]:

- Recharge batteries during off-peak demand period[37] = $0
- Use power during off-peak periods [38] = $10,000

Actual electrical demand charged through the year, without 150kW solar installation:

Month	**Demand(kW)**	**Cost($)**
January	355.56	3633.82
February	356.24	3640.77
March	357.64	3655.08
April	359.37	3672.76
May	358.89	3667.86
June	358.81	3667.04
July	361.82	3697.80
August	362.62	3705.98
September	359.75	3676.65
October	356.52	3643.63
November	354.61	3624.11
December	352.51	3602.65
		Total: $43888.15

Table 7.4: Actual electrical demand charged through the year, without 150kW solar installation

Actual electrical demand charged through the year, with 150kW solar installation and demand shift implementation:

Month	**Demand(kW)**	**Cost($)**
January	262.56	2683.36
February	265.07	2709.02
March	268.35	2742.54
April	267.35	2732.32
May	268.04	2739.37
June	267.71	2736.00
July	268.59	2744.99
August	268.97	2748.87
September	266.77	2726.39
October	264.79	2706.15
November	263.95	2697.57
December	266.31	2721.69
		Total: $32688.26

Table 7.5: Actual electrical demand charged through the year, with 150kW solar installation and demand shift implementation(obtained using simulation)

Energy consumed through the year, without 150kW solar installation: 925809.19 kWh

Cost of Energy consumed through the year, without 150kW solar installation:

Energy consumed throughout the year * Cost per unit electric energy =

925809.19 kWh *$0.0457/kWh = $42309.48

Energy consumed through the year, with 150kW solar installation and demand shift implementation(calculated using simulation):

480579.36 kWh

Cost of Energy consumed through the year, with 150kW solar installation and demand shift implementation:

Energy consumed throughout the year * Cost per unit electric energy =

480579.36 kWh *$0.0457/kWh = $ 21962.47

Previous electricity cost:

Cost of electrical demand charged through the year(without 150kW solar installation) + Cost of Energy consumed through the year(without 150kW solar installation) =

$43888.15 + $42309.48 = $86197.63

Estimated savings introduced by shifting demand (recharge batteries during off-peak demand period and use power during off-peak periods) [37,38](source: ARC 2.3137(KG0036) and ARC 2.3132(TA0009)) :

- Recharge batteries during off-peak demand period[37] = $4912.00/yr
  Energy cost reduction when using power during off-peak periods [38] = $210/yr

Electricity cost after the introduction of 150kW solar generation unit and introduction of demand shift:

Cost of electrical demand charged through the year(with 150kW solar installation and demand shift implementation) + Cost of Energy consumed through the year(with 150kW solar installation) - Savings introduced by shifting demand(recharge batteries during off-peak demand period + use power during off-peak periods)[37,34] =

$32688.26 + $21962.47- $(4912+147.37) = $49,591.36

Savings per year:

Previous electricity cost - Electricity cost after introduction of 150kW solar generation unit and demand response = \$86197.63 - \$49,591.36= \$36,606.27

Payback period :

$$\frac{Cost\ of\ installation}{Savings\ per\ year} = \frac{\$134{,}997.1}{\$36{,}606.27/yr} = 3.69\ years$$

Shown above is a calculation of the costs and savings introduced to a Metal processing plant in Pharr, Texas, if it were to implement a solar generation unit of capacity 150kW and shifted parts of its demand during the early morning, which is an off-peak period. Calculations made here are subject to change on a case-by-case basis since all manufacturers are not identical and will have different operational needs. For example, a water processing plant would have a different demand profile throughout the day. It would also have the opportunity to introduce a micro-hydropower generator that can reclaim power from the water flowing through the plant. This would result in the MATLAB algorithm being altered and would also need to account for the power being generated by the micro-hydro power generator when calculating the cost of the generator and the savings brought by the generator in the process[40]. A smaller manufacturing facility may not have the space needed to implement a 150kW solar generation unit. Therefore the size and cost of the solar generation will have to be re-adjusted in the algorithm. These considerations and alterations can be done by a member of the industrial assessment team who has knowledge regarding the operation of MATLAB.

After altering the MATLAB algorithm to include the power generated and demand reduced by a 15kW turbine generator at a site where there is sufficient water flowing through it, we can observe the following:

Average flow rate of water at the site: 0.2534m^3/s

Head: 7.9m

Conversion efficiency: 80%

P_{avg}=7.9*0.2534*9.81*0.8*1000= 15.71kW

Energy generated: 15.71*24*365= 137,619.6 kWh per year.

Cost of implementation, based on prices at [39]: \$8667+ 40*\$15$/hr$ = \$9267

Energy cost reduction: 137,619.6 * \$0.0457/kWh = \$6289.21

Demand cost reduction: 15.71*12*\$10.22/kW = \$1926.67

Payback period for hydro turbine installation at water treatment plant:

$$\frac{Cost\ of\ installation}{Savings\ per\ year} = \frac{\$9267}{\$6289.21 + \$1926.67} = 1.13 years$$

From the initial calculations of simulations, we can observe that a relatively short payback period can be seen in the implementation of demand shift, solar generation units, and/or small hydro turbines. Simulated results indicate a reduced cost for the user. They show significant benefit for implementing demand response in shifting demand to off-peak periods at the manufacturing site alongside the installation of renewable energy sources such as solar.

7.4 Guide for Future Users to alter MATLAB algorithm to simulate of demand of industrial site

Since every manufacturer will have their own operational requirements, the values used in the simulation will vary between sites. The number of machines, lights, and miscellaneous equipment will have to be accounted for, and the information regarding power demand for each of them will help design the simulation to provide accurate estimations. These estimations help create better assessment recommendations which can yield greater savings for the user. The methods to be used when altering the algorithms that will simulate the site's demand and estimate power savings from the implementation are described as given in the sections below

7.4.1 How to alter MATLAB Code used to simulate and minimize demand throughout the day

7.4.1.1 Using available 15-minute demand data. As discussed in Chapter 3, 15-minute demand data is a useful tool to design the simulation. The data can be used to identify the off-peak, part-peak, and peak periods throughout the day. These periods can be defined as follows:

1. Off-peak: These are the parts of the day when demand is the lowest. Here only lights and a few pieces of machinery like ACs, chargers, computers, etc., are kept on, but core manufacturing-related equipment is kept off.
2. Part-peak: This is usually the start of the day for the site. The demand here starts to rise from the level it is during off-peak periods and gradually rises to peak-period levels.

3. Peak-period: This part of the day is where the majority of power consumption occurs at the site. The demand remains mostly steady or rises and falls by small amounts throughout the day.

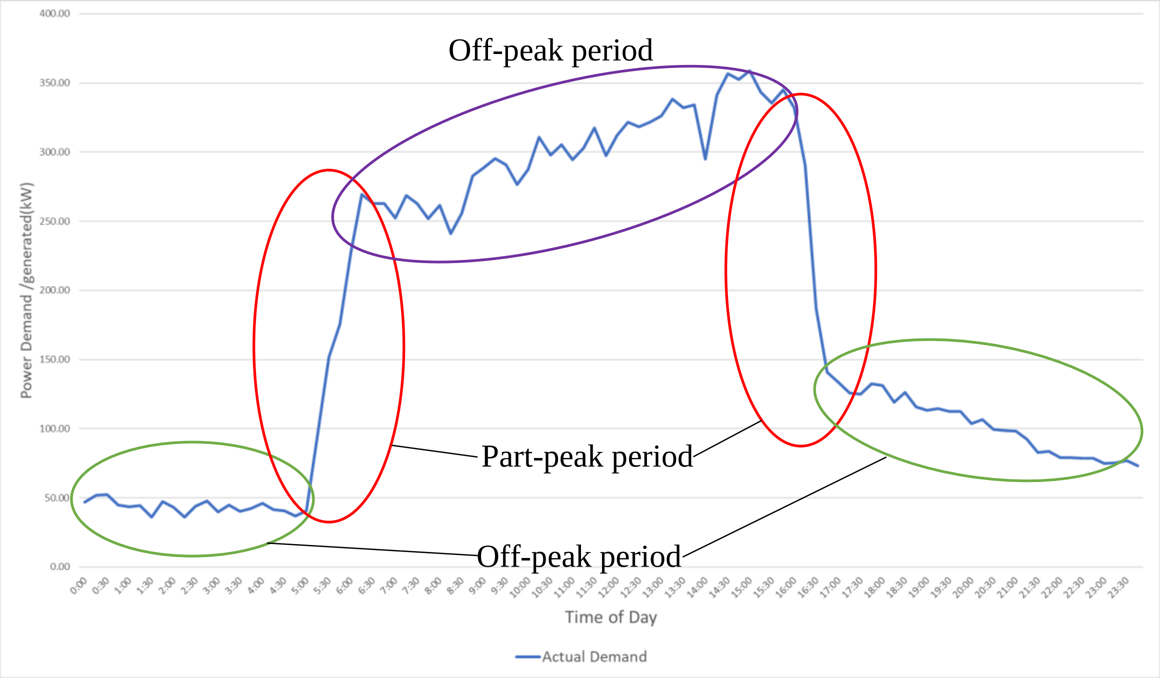

Fig. 7.3 Off-peak, part peak, and Peak-periods identified throughout a day

As shown in the figure above, the off-peak periods are the sections circled with green circles, Part peak uses red circles, and peak-period uses violet circles. After these periods have been identified, the day can be divided into 96 15-minute periods. Once the periods are identified, the demand of each piece of equipment or group of equipment throughout the day at the site can then be found using the steps mention in the next section.

7.4.1.2 Using machinery and site equipment information. Once the peak periods are identified, the following types of loads need to be listed:

1. Groups of lighting equipment.
2. Machinery that operates on electricity at the site

3. Air Conditioners or Heaters used for climate control at the site
4. Miscellaneous equipment used at the site(e.g., computers, chargers, etc.)

Information on the types of demands at the site can be collected by either monitoring the site throughout the day or inquiring operational staff regarding the daily operation on which machinery is operated throughout the day at certain peak periods. The information can then be utilized to formulate the upper and lower bounds used in the matrices lb and ub. The number of elements in these matrices is determined by the number of individual large power demands(e.g., high-powered machinery and ACs) and groups of small power demands(e.g., lighting, chargers, and miscellaneous electronics). dem is a 1*n matrix where every element of the matrix is one of the demand groups or large power demands. ub(upper bound) and lb(lower bound) for optimized demand are also of identical dimensions. The values of upper and lower bound are determined as functions of time or values which vary between a portion of the maximum demand a certain load may get to, e.g., lights can vary from 100% - 80% to 80% - 60% depending on the user's requirement and large machinery may gradually gain demand through the off-peak period and slowly gain demand during peak period. Operations at the site will vary between days, so the upper and lower bounds will need to be altered accordingly.

7.4.2 How to alter MATLAB code used to provide estimations of savings and reduction

The second MATLAB code that has been proposed utilizes previously available data and the simulated demand data alongside the generated renewable energy profile throughout the day. The previous code needs to be run a number of times for demands of every day to create the 1*96 matrices acdem_mon, acdem_tue, acdem_wed, acdem_thu, acdem_fri, acdem_sat, and acdem_sun. The solp matrices used are identical everywhere in the program, but the values used in the matrices will vary according to the capacity of the solar installation installed and the location of the installation. Demand and energy cost calculations in the program will need to be altered since the cost of energy and demand may vary between locations.

7.5 Potential Additional Benefits

7.5.1 Reduction in Greenhouse Gas Emissions

As we can see in the calculations shown in the previous section, we can reduce the electric energy consumed by a manufacturing facility through the implementation of this technology. The reduction of electrical energy consumed from power plants using combustible and non-renewable energy sources is also observed in the process. We can use the following data to estimate the reduction in the emission of certain greenhouse gasses from the reduction of energy consumption.

Greenhouse gas	**Emission(per kWh)**
CO_2	0.417kg
NO_x	0.00191kg

Table 7.6 Emission Rate of certain Greenhouses gasses [41]

From the simulations and calculations made in the previous section,

Energy consumption reduced using solar generation and demand response: 925809.19 kWh - 480579.36 kWh = 445,229.83 kWh

Assuming around 17.53% of the electricity is generated from non-emissive sources (e.g., solar, wind, hydro, etc.)[42-44], we can make the following estimate:

$$Energy\ consumed\ that\ is\ generated\ using\ emmisive\ sources:$$

$$445{,}229.83kWh * \frac{100-17.53}{100} = 367{,}181.04\ \text{kWh}$$

Emissions reduced:

CO_2 Emissions reduced: $367{,}181.04kWh * 0.417kg/kWh = \ 153{,}114.49kg = \ 153.1\, Tonnes$

NO_x emissions reduced: $367{,}181.04kWh * 0.00191kg/kWh = \ 701.32kg = \ 0.701\, Tonnes$

7.5.2 Improvement of Load factor

Since the demand and energy consumed are reduced, we also see an improvement in the Electrical Load Factor at the site. With demand response implemented and the demand minimized, we can calculate the estimated ELF as follows:

Previous load factor calculated at section 5.3.1: 0.299

Average monthly demand: 266.53 kW

Average Energy consumed per month, after the introduction of 150kW solar generation unit and demand response: 74251.70kWh

Average monthly ELF after the introduction of 150kW solar generation unit and demand response:

$$\frac{Average\ monthly\ energy\ consumed(kWh)}{Max\ Demand(kW) * 720} = \frac{74251.70}{266.53 * 720} = 0.387$$

% increase of ELF = $\frac{0.387-0.299}{0.299} * 100 = 29\%$

Therefore, we observe that there are still significant opportunities available for renewable energies to be installed. The further the average monthly demand is reduced, the greater the value of ELF will be for the manufacturing site. An additional point to note is that, on average, nearly 34203.42kWh of the 74251.70kWh consumed is generated using the solar generation kit installed. This means that energy and demand costs are significantly reduced, and further investments can be made for future improvements.

CHAPTER VIII

CONCLUSION

As shown in this work, the implementation of demand management methods that decrease the electricity at manufacturing sites can bring significant benefits to a manufacturing site. Demand profiles and the size and type of renewable energy implemented can vary between sites. We have observed that a large PV generation unit is well-fitting for a large site covering a large area. In contrast, a site with significant quantities of water flowing through it can utilize a micro-hydro turbine to reclaim part of the energy used to make it flow through it, e.g., at a water treatment plant. Outside of the benefit of reduced costs, we also observe other benefits presented by shifting demands and installing energy sources at the site; we also see a significant contribution to reducing emissions.

8.1 Demand curves before and after implementation of Demand Response and Solar generation

Using the MATLAB code for simulating the daily demand and minimizing it, and introducing solar generation at a metal processing plant at Pharr, TX, the following comparison can be made:

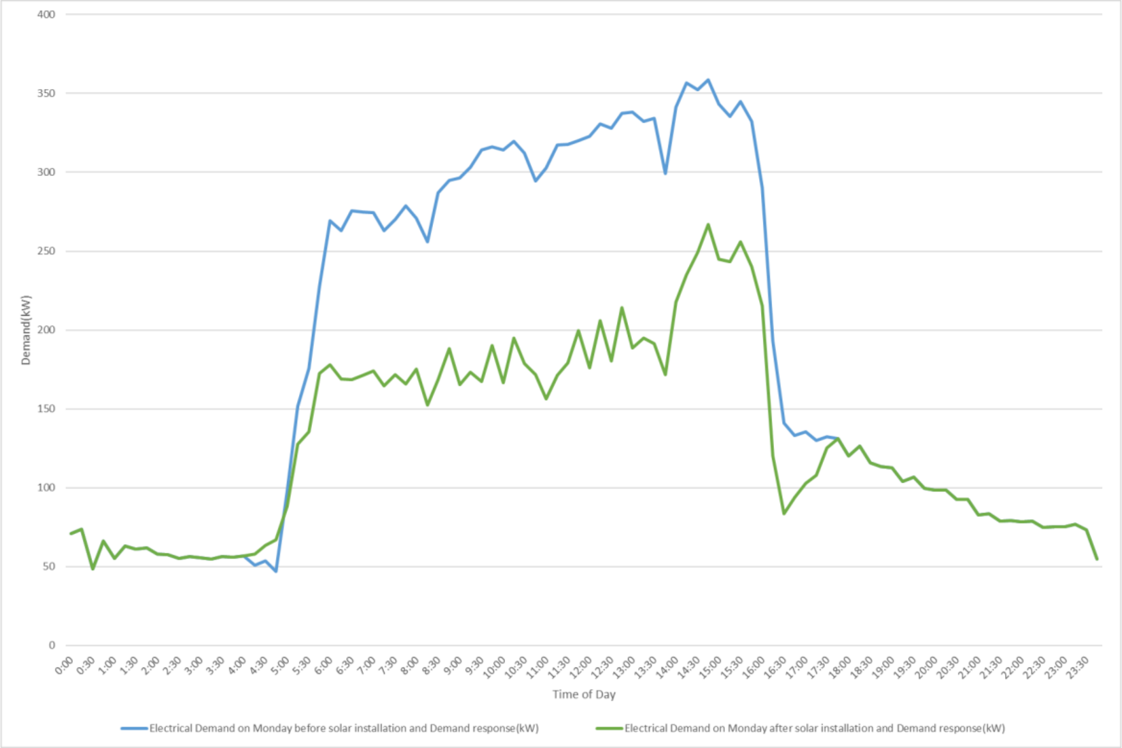

Fig. 8.1 Electrical Demand on Mondays before(blue) and after(green) solar installation and Demand response(kW)

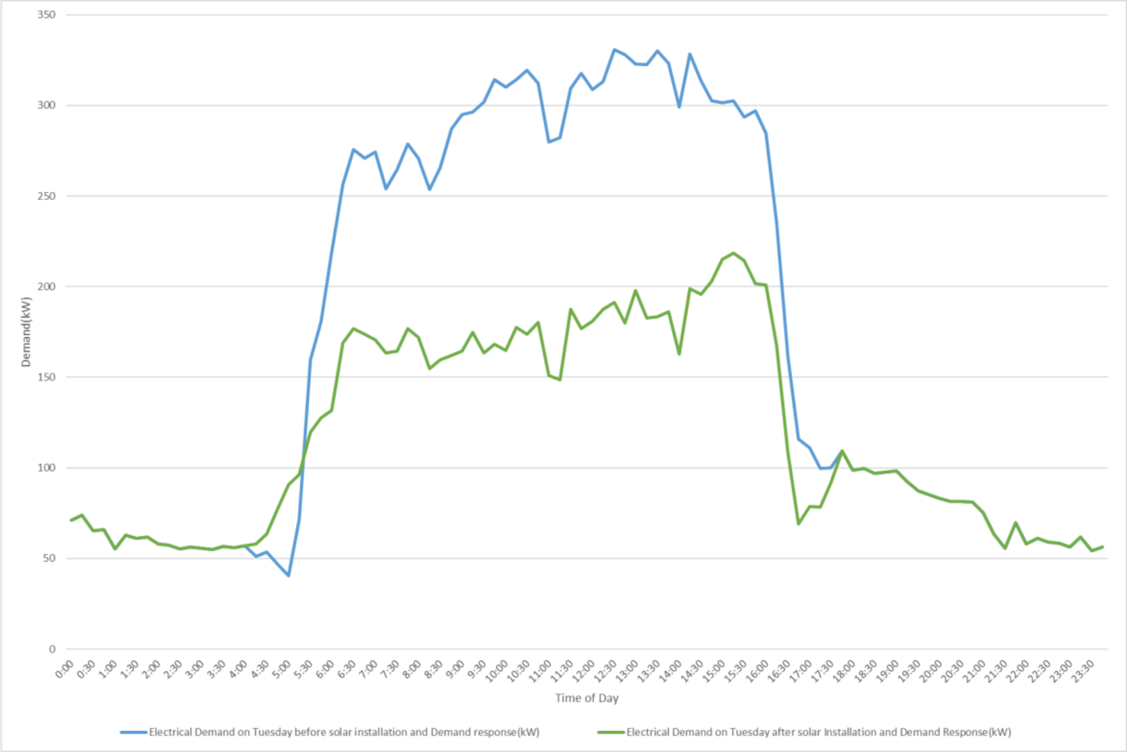

Fig. 8.2 Electrical Demand on Tuesdays before(top) and after(bottom) solar installation and Demand response(kW)

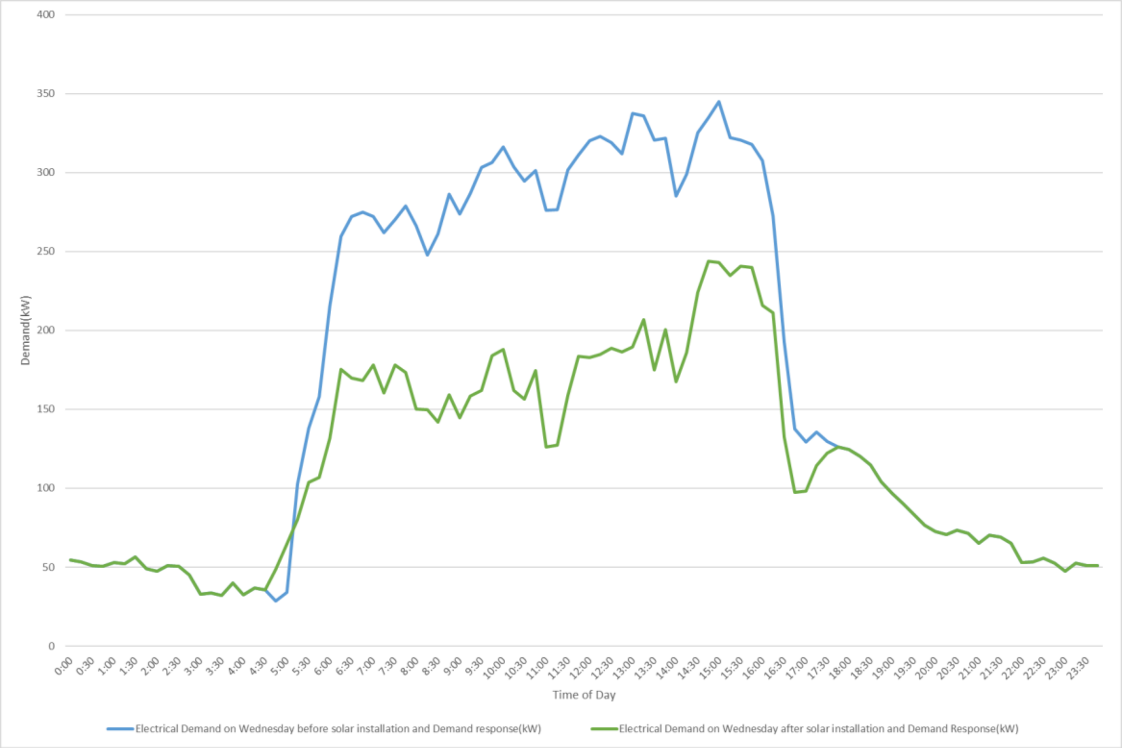

Fig. 8.3 Electrical Demand on Wednesdays before(blue) and after(green) solar installation and Demand response(kW)

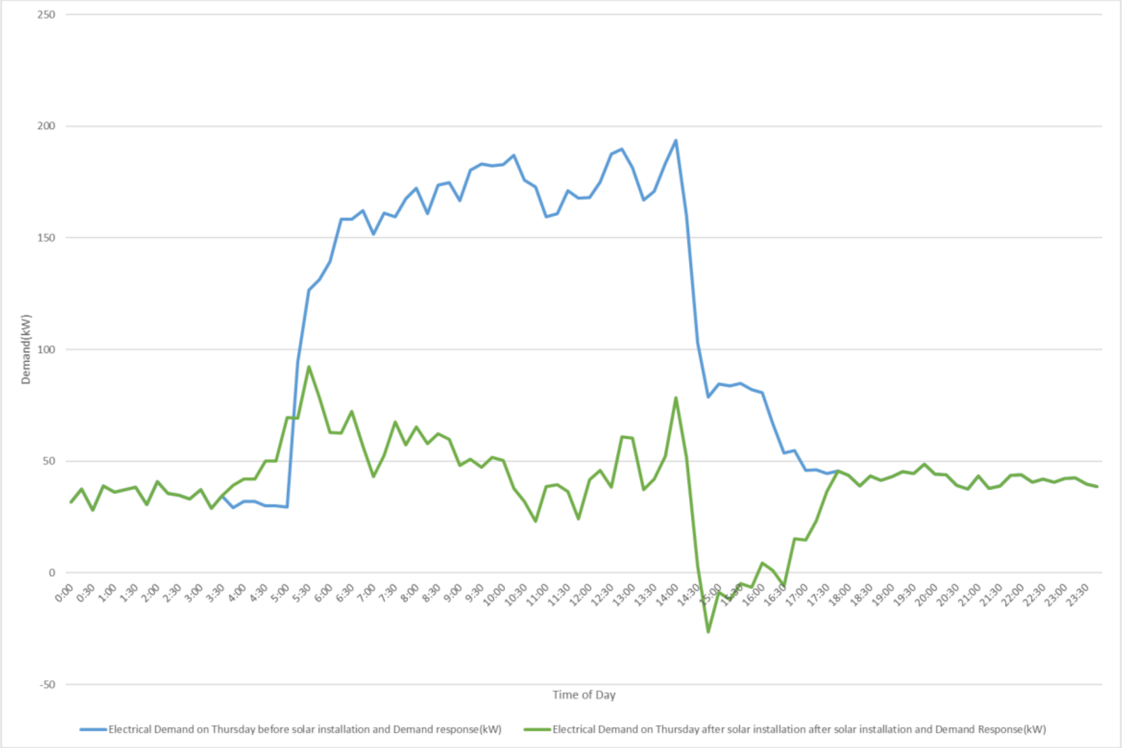

Fig. 8.4 Electrical Demand on Thursdays before(blue) and after(green) solar installation and Demand response(kW)

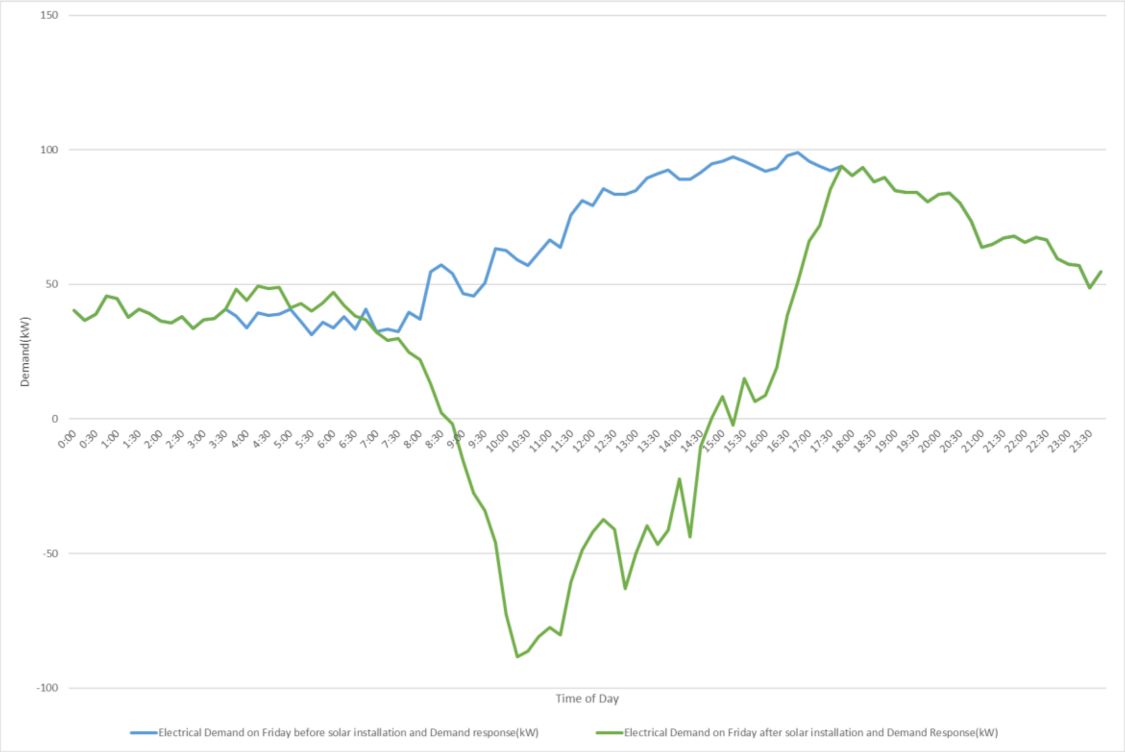

Fig. 8.5 Electrical Demand on Fridays before(blue) and after(green) solar installation and Demand response(kW)

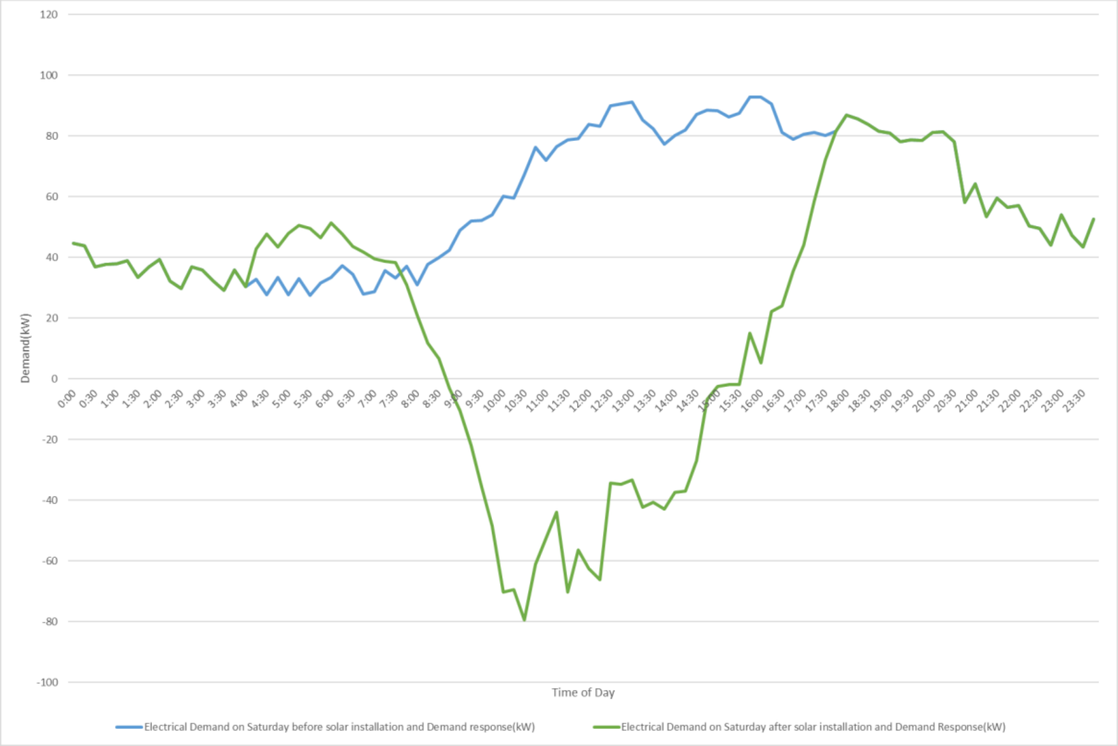

Fig. 8.6 Electrical Demand on Saturdays before(blue) and after(green) solar installation and Demand response(kW)

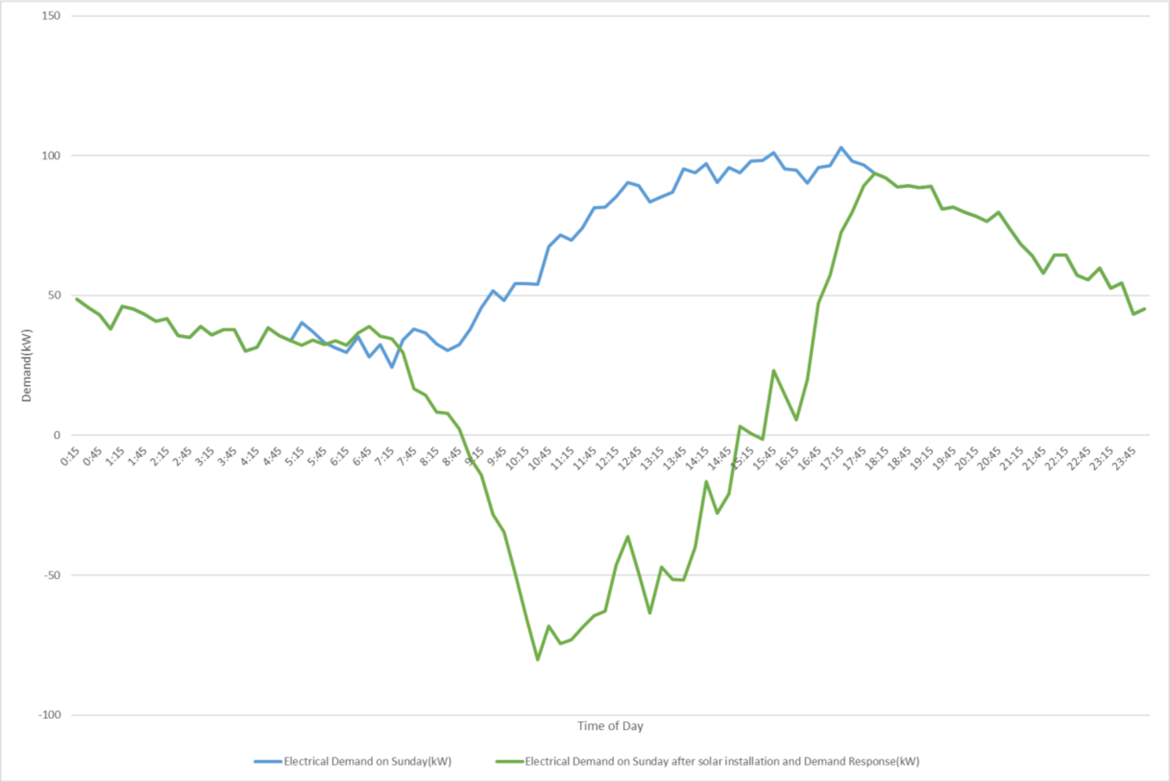

Fig. 8.7 Electrical Demand on Sundays before(blue) and after(green) solar installation and Demand response(kW)

As shown in the figures in the previous pages, we observe a reduction in the maximum demand of the manufacturing facility. Additionally, the reduction of demand throughout peak periods is also observed. Demand can also be reduced further in the future by upgrading the installed capacity of solar generation at the site.

8.2 Implementation of Demand Response at a manufacturing site

The following schematic can be followed to implement the demand controller at a manufacturing site for the implementation of demand response:

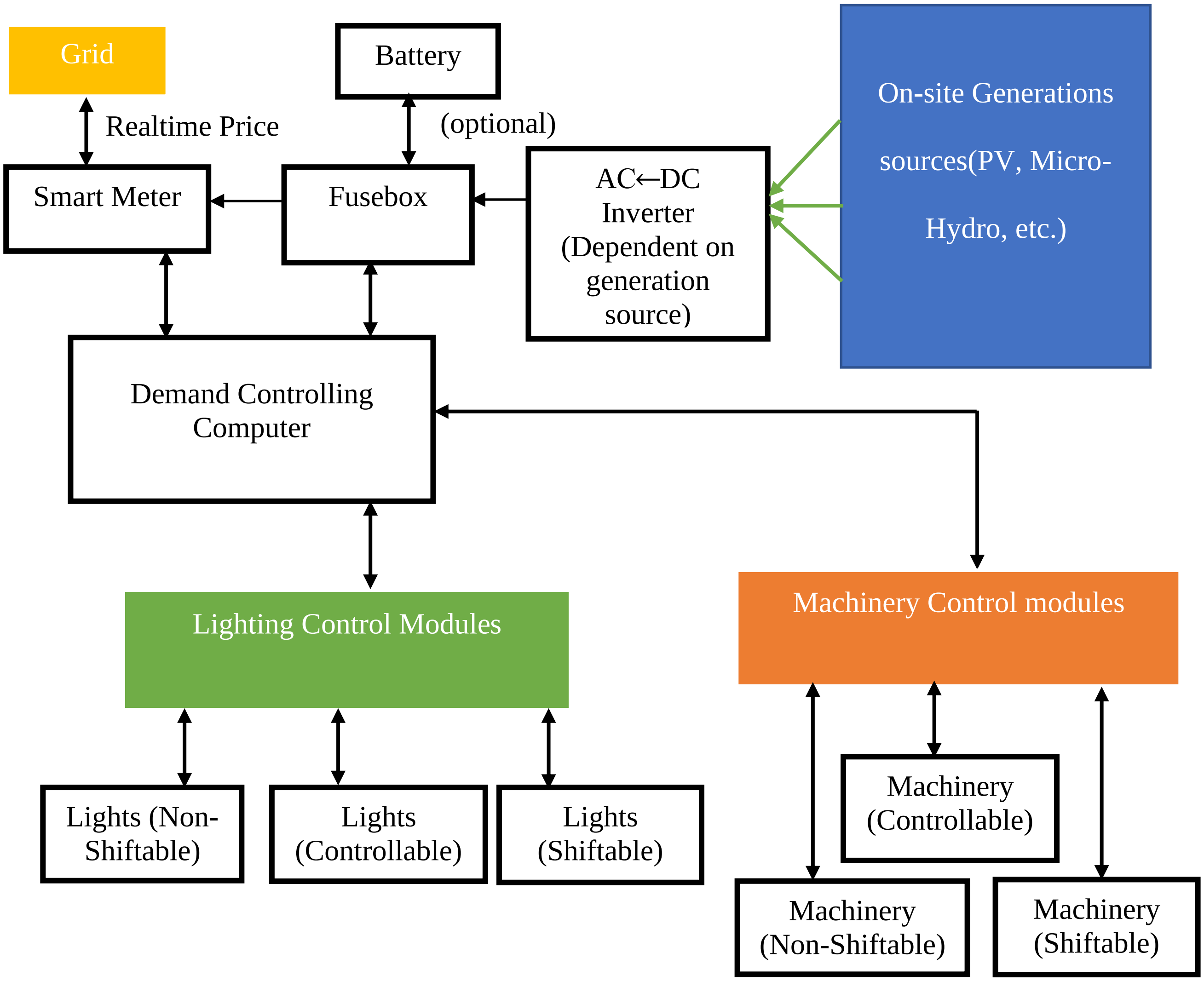

Fig. 8.8 Conceptual architecture of the proposed DR management system

The system can be divided into two layers. The Electromagnetic Compatibility (EMC) layer consists of the grid, smart meter, fuse box, and power generation and storage resources available at the site. The field layer consists of the Lighting and machinery controlling modules and the lighting and machinery themselves. The function of the EMC layer is to act as the "brain" of the facility. At regular intervals, the EMC layer receives information regarding the operational requirements for the manufacturing sites. It provides the distribution of demand throughout the site to provide the minimum cost to the manufacturer. The vector for 15-minute demand data is generated at the smart meter. The demand controlling computer sends the input to the controlling modules after calculating the demand for minimum cost to meet operational requirements. The controlling modules ensure that the machinery is operating at the demand as what is fixed by the computer and provides feedback to make sure the input received is compatible with the connected machinery so that they may not malfunction or halt operation.

8.3 Importance of Cybersecurity

To enable this future energy management system, the manufacturer must revise their cybersecurity measures and its role to safeguard against future attacks that attempt to destroy or disable the manufacturing processes, or otherwise, that happen at the site. Cybersecurity must transition into an essential embedded design of current operations. The challenges faced by cybersecurity for the proposed system can be listed as follows:

1. It is difficult to shift scarce cybersecurity resources from a reactive fire-fighting mode into a proactive fire prevention mode. However, a collaborative research style between local manufacturers and researchers can make a collective engagement that shifts the burden from a few to many resources to creatively consider all possible options to problem resolutions.
2. An additional challenge is brought by organizational resistance to cybersecurity changes, and weak security cultures within the facility compound this resistance. These issues are manageable but take time for education and support changes in technologies processes and even work skills.

Cybersecurity measures are not easily measured for success or failure, other than the existence or absence. Without standard performance metrics, it is difficult for manufacturers to quantify their overall impact. The arguments for the investment are weakened by a lack of hard numbers that demonstrate a projected value.

8.4 Future areas for research and development

While the proposed system indicates major savings for the manufacturing sites where it can be installed, more research regarding the proposed energy management system is required. Actual data on the physical implementation will give more reliable data that can be used to further improve the design of the proposed DR management system. From the calculations made in Chapter VII, we observed that the ELF had been raised with the implementation of the Solar generation unit. A significant portion of the energy consumed at the site is generated using the proposed solar generation unit. However, an ELF of 0.387 indicates the potential for more renewable generation sources to be introduced and the possible reduction of energy consumption if further studies are performed. For the purposes of this thesis, we have successfully utilized the methods used during industrial assessments to simulate and minimize the demand across a manufacturing site and, as a result, have been able to introduce and improve demand response strategies at manufacturing sites which results in a significant reduction in the cost for the user in the term. Though the initial cost of implementation may prove large, the calculated payback period indicates significant long-term benefits can be provided by introducing demand response and solar generation at the manufacturing site.

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55Bv%255D%3Dt%26ozt_aP%255Bd%255D%3D4&bL=clight&cE=0&lR=0&mC=30.600093873550072%2C-97.4322509765625&zL=7 , Last visited on 29 June 2021

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APPENDIX

APPENDIX

LIST OF ABBREVIATIONS

ABBREVIATION USED	**FULL FORM**
AGC	Automatic Generation Control
ARC	Aggregators of Retail Customers
AS	Ancillary Services
CAISO	California Independent System Operator
CLR	Controllable Load Resource
CP	Coincidental Peak
CPP	Critical Peak Pricing
CSP	Curtailment Service Providers
DADRP	Day-Ahead Demand Response Program
DAM	Day-Ahead Market
DDR	Demand Response Resource
DG	Distributed Generation
DNI	Direct Normal Irradiance
DR	Demand Response
DSM	Demand Side management
EDPR	Emergency Demand Response Programs
EDR	Economic Demand Response

EDRP	Emergency Demand Response Program
EE	Energy Efficiency
EILS	Emergency Interruptible load Service
ELF	Electrical Load Modifier
EMC	Electromagnetic Compatibility
ERCOT	Electric Reliability Council of Texas
ESIID	Electric Service Identifier
EUC	End-Use Customers
FRRS	Fast Responding Regulation Service
GHI	Global Horizontal Irradiance
IAC	Industrial Assessment Center
ICAP	Installed Capacity
IEC	International Electrotechnical Commission
ILD	Interruptible Load Resources
IOT	Internet of Things
ISO	Independent System Operator
LED	Light Emitting Diode
LHSRP	Latin Hypercube Sampling with Random Permutation
LMR	Load Modifying Resources
LSE	Load Serving Entities
MATLAB	MATrix LABoratory
MIS	Market Information System

MISO	Midwest Independent Transmission System Operator
MP	Market Participant
NAICS	North American Industry Classification System
NCLR	Non- Controllable Load Resource
NERC	North American Electric Reliability Corporation
NOIE	Non-Opt In Entity
NSRS	Non-Spinning Reserve Service
PDR	Proxy Demand Resource
PLP	Participating Load Program
PV	Photo-voltaic
QSR	Qualified Scheduling Entity
REG-UP	Regulation Up Reserve Service
REP	Retail Electric Provider
RRS	Responsive Reserve Service
RTM	Real-Time Market
RTO	Regional Transmission Operator
RTP	Real-time pricing
SB	Senate Bill
SCADA	Supervisory Control And Data Acquisition
SCR	Special Case Resources
SIC	Standard Industrial Classification
SMB	Small and Medium-sized Business

TDSP	Transmission and Distribution Service Provider
TOU	Time of Use
UFR	Under Frequency Relay
VPP	Virtual Power Plant

BIOGRAPHICAL SKETCH

Monsur Habib was born in Dhaka, Bangladesh, to his father, Retd. Cdr. A K M Ahsan Habib and mother Wahida Habib. He attended high school at Chittagong Grammar School from where he completed his O-level examinations and completed his A-level examination under private tutorship. Monsur first step into electrical engineering was completing his Bachelors in Science from the Islamic University of Technology at Dhaka, Bangladesh, in 2018. He graduated in 2021 with his Master's in Electrical engineering at the University of Texas Rio Grande Valley. He is currently looking for further research opportunities in demand management and demand response. You can contact him via email at monsur.habib07@gmail.com.