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Evaluation of Electric Vehicles charging patterns with DSM for residences (with and without Building Integrated Photovoltaic) in the distribution network

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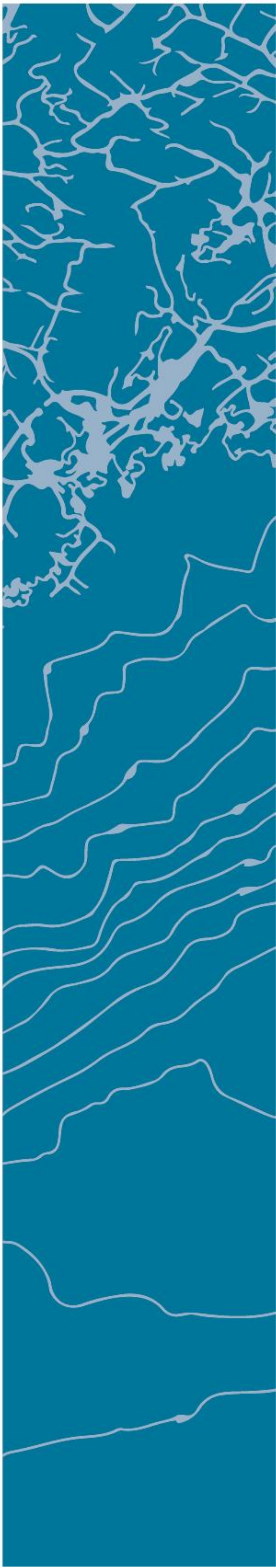

Abstract

The wide development of electric vehicles (EVs) in transportation meets the sustainable targets with a shift in attitude towards climate change and reduction of GHG (Green House Gas) emissions. Currently, Norway is the forefront of using electric vehicles by having more than one million electric vehicles by the middle of 2016 and expected to increase further in the future. The transition to electric vehicles has many benefits, but it also poses to the power system network.

To explore the impact of increasing penetration of EVs in Norway on power system, an existing low voltage power system network with consumer consumption data provided from “Sogn og Fjordane Energi” and EV consumption data from Nissan Leaf battery specifications have been used in this project. The simulations are analysed the 24 hour based monthly average load data for 20 houses with 5 PV (Photovoltaic) usage consumption houses. The uncontrolled simultaneous charging patterns of EVs on distribution side could cause considerable effects such as voltage fluctuations, thermal stress on the lines and potential to affect the life of distribution components.

The objective of this project is to illuminate the problems of uncontrolled charging patterns of different users and Smart Load Management (SLM) is introduced for coordinating the charging pattern of EVs for different users on a monthly period. The existing low voltage power system network with different user profiles and Nissan Leaf EVs are analysed to reschedule the charging pattern to achieve the minimum power consumption hours while operating within network limit constrains. The effect of transformer and distribution line overloading are delayed the charging time in the smart charging algorithm to achieve the best results.

As well as, Demand Side Management (DSM) method is used to coordinate the charging pattern of EVs by shifting EVs to minimum power consumption time periods and by shifting noncritical user consumption loads to minimum tariff time periods for without BIPV residences and by shifting PV electricity generation time periods for with BIPV residences using forecasted last year user consumption of each hour on existing distribution network. It will be observed the considerable energy cost saving by using the proposed DSM charging pattern under demand limits as well as TOU tariffs.

MATLAB software is used to simulations of uncoordinated and coordinated smart charging as well as economic analysis. The impact of uncoordinated and coordinated EV charging will be discussed with respect to network stability and user satisfaction.

Keywords: *Electric Vehicles (EVs); Constrains; Building Integrated photovoltaic (BIPV); Smart Load Management(SLM); Demand Side Management(DSM); optimal charging pattern; economic analysis*

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Abbreviations

AC	**A**lternating **C**urrent
BEV	**B**attery **E**lectric **V**ehicle
BIPV	**B**uilding **I**ntegrated **P**hoto**V**oltaic
DC	**D**irect **C**urrent
DLC	**D**irect **L**oad **C**ontrol
DOD	**D**epth **O**f **D**ischarge
DSM	**D**emand **S**ide **M**anagement
DR	**D**emand **R**esponse
EV	**E**lectric **V**ehicle
EVSE	**E**lectric **V**ehicle **S**upply **E**quipment
GHG	**G**reen **H**ouse **G**as
HEV	**H**ybrid **E**lectric **V**ehicle
ICE	**I**nternal **C**ombustion **E**ngine
LV	**L**ow **V**oltage
PV	**P**hotovoltaic
RTP	**R**eal **T**ime **P**ricing
SOC	**S**tate **O**f **C**harge
SLM	**S**mart **L**oad **M**anagement
ToU	**T**ime **o**f **U**se
VAT	**V**alue **A**dded **T**ax

Chapter 1

1 Introduction

This chapter provides the motivation of the project and the problem statement to emprise the requirement of the coordinated charging strategies. Thereafter objectives, goals and limitations are discussed. Literature review and problem solutions are also included in this chapter. Finally, an outline describing the structure of the upcoming chapters is provided.

1.1 Motivation

Norway is the forefront in using Electrical Vehicles (EVs) and continues to expand its EV market without hesitations due to its benefits to climate goals, by providing the attractive incentives such as lower annual vehicle registration and taxes, reducing parking cost with charging capabilities. Further, it is expected exponential increment in EV market by having more than one million electric vehicles and nearly 28% EV market share in Norway from the middle of 2016. The EV market share in 2016, has reached more than 100 times, compared to 2010 [1]. Norway, being the worldwide leader, in EV market, makes the development more and more towards e-mobility. The rapid evolvement of EV technology is the better solution to minimize the production of tailpipe emissions that harmful to the environment. The huge potential customer group for EVs in Norway are willing to embrace zero emission technology today to achieve the carbon neutrality to 2030 as ratified the Paris agreement on climate change in June 2016 [2]. Since 1990, Norwegian EV policies and incentives have built economically feasible and user attractive EV market to achieve the best place on world market in terms of the number of EVs to the population [3].

The clean and environmentally friendly electricity generation in Norway creates low cost electricity and high penetration of electrical vehicles usage has increased with the feasibility of development in renewable energy power sector. The renewable energy source, i.e. hydropower, provides major power in Norway. Hydropower is still the mainstay for producing electricity in low cost and will continue to play vital role in the future. Among the renewable energy power generation, Norway has a limited resources in solar energy.

The increment of EV market have been affected to the electricity network and some locations in Norway where the electricity network is especially weak, the penetration of EVs present an immediate challenge. The high penetration of EVs, especially when plugged in simultaneously, might become a problem in power supply stability and quality. The coordinated EV charging pattern will avoid the power peaks and the zero emission target can be successfully achieved. If there is no coordination charging method of EVs, most users would probably plug in their vehicles to charge when they arrive to home and it would cause a peak demand consumption times due to the peak on base loads at that time. It has been made the difficulties to distribution network due to the uncoordinated charging schemes specially in peak hours. The smart coordination of EV demand creates an improvement of distribution network and reduces the power system investment.

1.2 Problem Statement

The impact of EVs on distribution network primarily effects on the distribution feeder losses, voltage unbalanced, and the transformer-aging factor [4]. Mainly, the uncoordinated EV power consumptions and random charging patterns significantly cause considerable effects on distribution network causing voltage fluctuations, decreased power quality, thermal stress on the lines and potential to affect the life of distribution components.

This project focused specifically on the impacts of electric vehicles on two key components of power distribution systems: a residential service transformer, and feeder line cables. The proposed charging algorithms are developed assuming that the four main user profile-charging behaviors and all usage EVs are Nissan Leaf. Analysis of the impact of uncoordinated charging pattern and coordinated smart charging patterns in a distributed network is very important especially for power system stability and power quality. The smart charging patterns are possible to shift the charging pattern from maximum power consumption time to minimum power consumption time. Further, Matlab algorithms are used to implement the coordination of EVs by considering the concept of DSM by shifting non-critical loads to off-peak hours for without BIPV residences and to PV generation hours for with BIPV residences.

1.3 Objectives

This thesis will analyze the impact of electric vehicles in a low voltage distribution network with respect to power quality and the role of charging schedules of EVs. The residences with and without BIPV will be explored to identify the impact of EV adoption with their user profile using system as it is, smart charging approaches and demand response-charging programs.

Mainly, this project will be solved through the following objectives.

- **Objective 1 – Uncoordinated charging (charging pattern as it is)**
  Analysis the uncoordinated EV power consumption and identify the impact of distribution network (charging pattern as user profiles).

- **Objective 2 - Smart charging (Smart Coordinated)**
  Development of coordinated EV charging pattern for Smart Load Management (SLM) algorithm for shifting charge hours of EVs to minimum power consumption hours by considering low voltage distribution network constrains.

- **Objective 3 – DSM schedule charging (DSM Coordinated)**
  Development of EV charging patterns as well as shifting non-critical loads to off-peak or PV generation hours based on the fixed demand limit applies to all power consumers (with and without BIPVs) connected to the low voltage distribution network. These patterns are proceeded through the load shifting algorithms based on demand side management (DSM).

1.4 Key assumptions and limitations

To develop the optimum charging algorithms, the existing distribution network located in Sogn og Fjordane is countered and the following assumptions are taken in to account.

- The selected distribution network may slightly vary with real conditions and situations.
- The user power consumption and Photovoltaic (PV) generation in Sep-2015 to Aug-2016 are estimated to identify the user behaviors on that area and it is considered to develop the charging patterns based on that observed data.
- The BIPV systems are interfaced with the available utility and taken as no power storage system.
- Nissan leaf battery specifications are used as EV characteristics and the battery has linear charging capability.

To satisfy the model assumptions, the following limitations are encountered.

- Only symmetrical three phase loads are accounted in the simulation.
- The EV loads and user consumptions are simulated as active power.
- Introduction of new EVs with different characteristics may affect the network power quality and energy management methodology.
- The average hourly based power consumptions are used for simulations and the consumption can vary with real conditions of maximum and minimum to that values.

1.5 Literature Review

In recent years, several researchers studied that high penetration of EV usage without coordination of charging impacts on the distribution network [5, 6]. Thus, it seems to be coordination charging is an effective method to prevent distribution congestion and this project is focused on the different coordination charging methods in order to minimize grid disturbances and maximize customer satisfaction. In order to approach the project objectives, the different literature design considerations and applications are reviewed.

The short master thesis “Intelligent Energy Management of Electric Vehicles in Distribution Systems”, which analyzes a Danish electrical network, developed the intelligent charging and discharging algorithms attending to economic criteria using specific software and programming languages, such as Matlab and GAMS [7]. The similar type of Load Management System (LMS) was concluded using different scenarios with an increasing share of EVs in a section of a rural grid model of Freiamt, Germany [8]. The energies journal publications have done various methods to establish an optimal load pattern for EV charging-based reliability. The paper have developed and implemented the optimization algorithm using a Genetic Algorithm (GA), where thermal line limits, the load on transformers, voltage limits and parking availability patterns were taken. The result was indicated a smart charging schedule for EVs leads to a flattening of the load profile, peak load shaving and the prevention of the aging of power system elements [9].

In reference [10] , the highest energy consumption day load values in 24-hour simulation period were used to implement the smart charging strategies. In this hypothetically built wind turbine and different EV adaptation presentations were integrated to design smart charging model. According to [11], the Norwegian electric network with the impact of EV increment was built to establish a charging management method using DIgSILENT and Matlab software. Further, the different EV charging control strategies were discussed in [12], to identify the best-suited method for control of PEVs to smart grids. Those designs and applications have reviewed to obtain the awareness of the development of algorithms and design configuration of this project.

1.6 Problem Solution

In this work, the above-mentioned charging strategies will be achieved through the analysis of typical Norwegian low voltage distribution network and user behaviors. The development of smart charging algorithms and coordination charging of EVs based on DSM will be done in Matlab software. These control strategies for different EV adaptations have been tested in low voltage distribution network and the energy cost saving under TOU (Time of Use) tariff mechanism is used for the economic analysis.

1.7 Thesis Outline

The thesis report is organized in chapters and subsections to demonstrate the background and method to analyze the coordinate and uncoordinated charging of EVs to an existing residential low-voltage system. The following chapters are arranged for that purpose.

Chapter 1: This chapter consists of a brief introduction of the thesis and the objectives are presented. The limitations of the project and literature related to this project is briefly reported.

Chapter 2: This describes the background and theories related to the project. The overview of EVs, characteristics of distribution network, BIPV systems and Demand Side Management (DSM) methods are explained.

Chapter 3: This provides the system scenarios with relevant concepts and components to the project. All the simulation data, equations and constrains that are used to implement the model are given.

Chapter 4: The load management program methods and algorithms are outlined in this chapter. Further, the simulation model methods are explained for better understanding of project solution criteria. The electricity pricing mechanisms are provided to evaluate the electricity bill calculation.

Chapter 5: The simulation results of different charging scenarios are presented and discussed. Then the scheduling of the EVs are analyzed with the electricity bill savings with tariff charges.

Chapter 6: This last section summarizes the main results obtained from simulation. Finally the recommendations for future work is suggested.

Appendix A: The data of tables referred in simulation and results are attached.

Chapter 2

2 Background and Theory

This chapter describes the overview of the electric vehicle technology with battery characteristics and the growth of EVs in Norway. The main aspects of Norwegian distribution network systems and the impact of EVs on power system network are discussed. Further, Demand Side Management (DSM) methods with tariff methods will be presented to the give worthy understanding of this project background.

2.1 Electrical vehicles

With the increment of price of oil in the recent past, the transportation sector is employing a number of new technologies to enhance the energy security by reducing dependence on oil. The electrical vehicles (EVs) perform an important role in shifting to more sustainable mobility to vehicle industry by reducing pollution as well as reducing dependence on oil. Battery Electrical Vehicle (BEV) is any kind of vehicle which uses an electric motor for propulsion powered by rechargeable battery packs rather than a gasoline engine. This type of vehicles stores all its energy in rechargeable batteries that are powered from a power grid. The controller gets that battery power and delivers it to the motor whenever it needs. Most BEVs have a theoretical range of 160-240km between recharges, but the practical range is small. However, these vehicles may be powered by gasoline engines as well as by electrical motors, leading it to take part of the hybrid technology. This type of hybrid electrical vehicles (HEVs) run partly on electricity and partly on some other fuel (gas or diesel). Vehicles that can at times run solely on electricity, and can be plugged in to charge their batteries, are called plug-in hybrid electric vehicles (PHEVs) [13].

Overall, EV has more advantages than the disadvantages. The main advantages are reduction of CO_2 emission which lead to reduction in global warming and unhealthy people. In addition, EVs are becoming popular all over the world due to avoiding dependence on the limited oil resources. The main problem is a recharging battery pack for long distances and need to charge for four to eight hours depending on the kind of EV types. This EV battery packs are heavy, expensive, may need to be replaced and take up considerable space of the vehicle. By increasing the number of charging spaces and fast charging facilities of the country can be helpful to minimize the difficulties of EV usage [14]. Moreover, EV users have a great benefit to charge using any electricity outlet, including outlets in home garage, on the walls of workplaces, etc rather than finding a gas or fuel station as Internal Combustion Engine (ICE) vehicle users.

2.1.1 EV charging technology

The EV charging technology provides the crucial link between the battery of EV and the electrical source that will recharge those batteries using the Electrical Vehicle Source Equipment (EVSE). EVSE units are commonly referred to as charging station and it delivers electric energy from electric source to charge an EV battery as shown in Fig. 2.1. The EVSE connect to an electric power source, that provides the alternating current (AC) or the direct current (DC) supply to the electric vehicle that is needed to charge the vehicle's traction batteries. EVSE charging capacity options are important to consider a direct bearing on how fast the batteries can be recharged. The physical connection between the EVSE and EV inlet is EV connector that uses the EV internal battery charger to convert the EVSE AC supply to DC needed to charge the car's traction batteries.

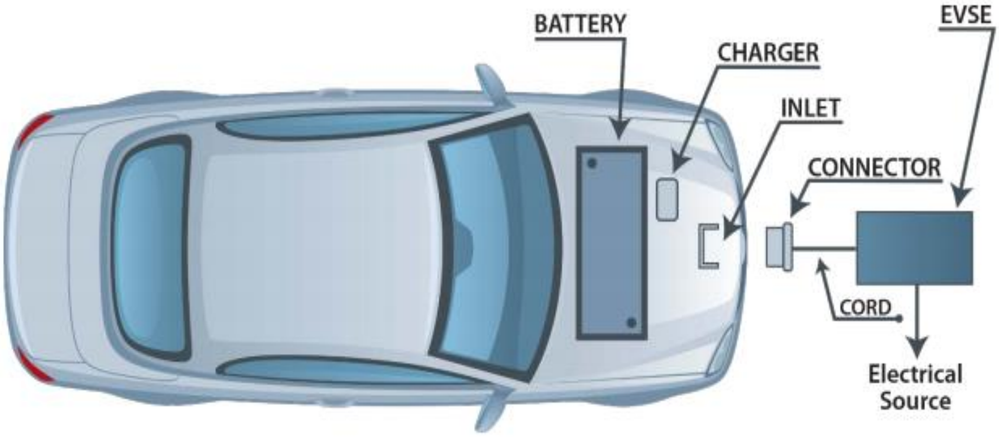


Figure 2.1: EVSE unit connection to EV charging [15]

Power electronics are used to manage the power and are dependent on car model and type of electric motor. In most cases, pulse width modulation (PWM) technology is used to control the voltage supplied from the battery. Transistors, such as insulated-gate bipolar transistors (IGBTs), are chopping the voltage so that desired frequency is achieved. The desired frequency is dependent on how much power the car user requires. An inverter is used to convert battery supplied DC voltage to AC voltage, and a DC/DC boost converter used to increase the voltage.

2.1.2 EV batteries

There are several types of batteries, but Lead-Acid, Nickel-Metal Hydride and Lithium-ion are best suited for EVs. The most used battery type for EV is Lithium-ion battery and its exact chemistry varies from the different manufactures. It has a highest power to weight ratio of the three compared batteries, low self-discharge and high energy efficiency [16].

The charging of EVs with battery characteristics are essential to perform an optimal charging and a long lifetime of the battery. One of the important states of the battery is called a state of charge (SOC). An accurate SOC estimation provides benefits on battery's longevity, performance and reliability. However, a battery is an electrochemical storage source and this chemical energy cannot be directly accessed. This issue makes the estimation of the SOC of a battery remains very complex and is difficult to implement, because battery models are limited and there are parametric uncertainties. In general, the SOC of a battery is defined as the ratio of its current capacity ($Q(t)$) to the nominal capacity (Q_n). The nominal capacity is given by the manufacturer and represents the maximum amount of charge that can be stored in the battery [17].

The various mathematical methods are classified to estimation of SOC of the battery. In addition, manufacturers are doing research to improve the battery technology both physically and economically. Normally the SOC is given percentage value that indicates 0% for fully empty battery and 100% for fully charged battery. The inverse of SOC is the measure of depth of discharge (DoD). It describes how deeply the battery is discharged. DOD can be treated as how much energy that the battery delivered [18].

$$DoD = 1 - SOC \tag{2.1}$$

$$E_{\ c} = DoD \times P_{b,max} \tag{2.2}$$

$where\ DoD: Depth\ of\ Discharge\ ;\ SOC: State\ of\ Charge;$
$E_c: Energy\ to\ charge\ the\ battery\ ;\ \ P_{b,max}: maximum\ battery\ power$

In this project the charging and discharging will be assumed linear to simplify the simulations with use of lithium-ion battery technology.

2.1.3 EV status in Norway

The development of EVs in transportation sector is important to country with the view of reducing environmental impact by low carbon dioxide emission. The increment of EVs can be caused the distribution network parameters due to the high charging capacity of EVs. Currently, Norway is the forefront in using electrical vehicles and continues to expand its EV market without hesitations due to its benefits. The status of EVs in Norway remains one of the world’s most important countries to follow within e-mobility. The government of Norway has motivated the EV usage to reduce the GHG emissions of its transportation sector. The clean and environmentally friendly electricity generation in Norway creates low cost electricity and it has encouraged EV users to become economically smart and ecologically friendly condition.

Since 1990, Norwegian EV policies and incentives have built economically feasible and user attractive EV market to achieve the best place on world market in terms of the number of Electrical Vehicles to the population. Economic incentives such as exemption from vehicle taxes (VAT, registration tax) have secured the possibility to sell Electrical Vehicle competitively. Most of electric cars entering the Norwegian EV market are BEVs due to the Norwegian incentives of the large exemption from registration taxes and VAT to BEVs over PHEVs. The successful non-fiscal incentives, free parking and charging and access for EVs to bus lanes has begun to improve the EV usage in country. Modifying and introducing new incentives caused reduction on EV prices and enlarged the EV purchasing rate in Norway [19].

The sales of EVs in Norway create the exponentially increment over last few years due to the attractive policies for purchasing and using EVs. The evolution of EV market shares different kind of EV models with consumer satisfaction, requirement and the market status of the vehicle. With the entry of new car models and the emerging battery technologies, allow to travel in longer distances and the cost of owning an EV is also becoming more advantage in terms of distance compared to the conventional vehicles.

According to Fig. 2.2, the current situation in end of December 2016 shows that close to 100,000 BEVs and about 35000 PHEVs registered in Norway. It shows that the market share for BEVs was 15.7% and 13.4% for PHEVs, 29.1% in total for 2016 in Norway. It is predictive that there is no longer use petrol and diesel for road transportation in 2050 and the proportion of zero emission EVs has increased to 100% in 2050.

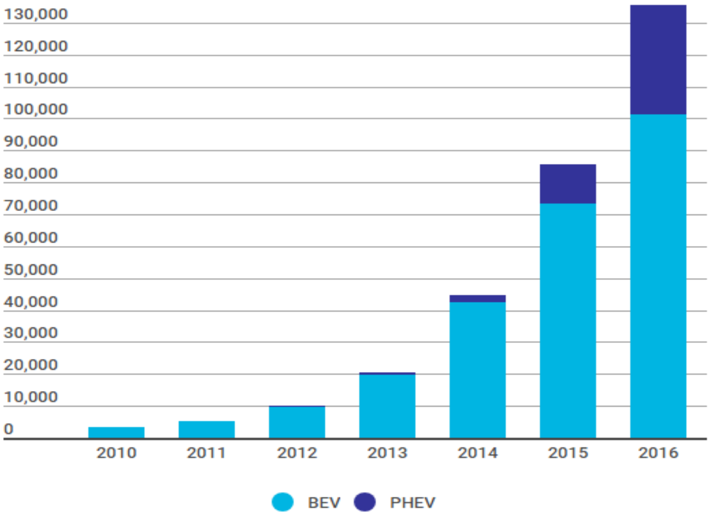


Figure 2.2: The Electric Vehicle fleet in Norway (updated 31/1/2016) [20]

2.1.4 Impact of EV charging to distribution network

Analysis shows that, the charging of EVs directly impact on the distribution grid because these vehicles consume a large amount of electrical energy and this demand of electrical power can lead to extra-large and undesirable peaks in the electrical consumption. The large charging power, high charging frequency and sinusoidal distortion caused by EV chargers can be affected to power quality with power losses and voltage deviations [21]. Without coordination of the charging, the vehicles are charged instantaneously when they are plugged in and it may lead to grid problems.

Today, there are no incentives for the customer in Norway to move load away from peak hours [22]. However, the coordinated charging to shift peak hour charging will proposed to minimize the power losses and to maximize the main grid load factor. In this project, voltage deviations and distribution network component overloading are minimised. The proposed method emphasises planned distribution network power quality improvements that are possible by using uncoordinated charging to coordinated charging.

2.2 Norwegian Distribution Network

In electricity generation, Norway is a heavy producer of renewable energy, due to the mainstay electricity production of hydropower. Hydropower plants are covered 99% of electricity production and it will continue to pay a vital role in the future with low cost production capability. There is also large potential in wind power, offshore wind power and wave power as well as bio-energy production. Further, it has limited resources in solar energy.

The distribution network is the part of the power grid that transmit and distribute electric energy all the way to end users. The high voltage distribution network in Norway consists with nominal voltage of 11kV or 22kV from the substation (the regional grid) to the local transformer and low voltage lines with 230V to households and 420V for enterprise and industry. The network may consist with overhead lines or underground cables [23]. The Norwegian electricity prices differs from one region to another, and this can also vary on an hourly basis and between seasons and years.

Norwegian Water Resources and Energy Directorate have been intended to cover the regulations to ensure the adequate supply in the Norwegian power system and efficient operation, expansion and development of the power system. These regulations are used to reduce the short and long interruptions. According to [24], Norwegian regulations of supply in power system defines regulations for voltage frequency, slow variations in the voltage rms, temporary overvoltages and voltage changes, harmonic and inter-harmonic voltages and transient overvoltages.

Some of the regulations of supply in power system relevant to this project are concluded as below for the system design.

- **§ 3-2. Voltage frequency:**
  System operator must ensure that the voltage frequency is normally kept within 50 Hz ± 2% with the provisions of the Nordic system operation agreement.

- **§ 3-3. Slow variations in voltage RMS value:**
  The distribution network operator shall ensure that slow variations in voltage RMS value is within a range of ± 10% of nominal voltage, measured as an average over a minute, in connection point in low voltage network.

- **§ 3-4. Temporary overvoltages, under voltages and voltage changes:**
  Norwegian Water Resources and Energy Directorate may order to implement measures to reduce the temporary overvoltages and voltage dips. For 24kV voltage, the overvoltage must not exceed the limit of 5% of nominal voltage.

- **§ 3-6. Voltage asymmetry:**
  The network companies shall ensure that degree of voltage asymmetry do not exceed 2% in connection points, measured as an average of ten minutes.

- **§ 3-10. Transient overvoltages:**
  The regulations implement to reduce the scope or consequences of transient overvoltages.

2.3 Building Integrated Photovoltaic (BIPV) system

Among the renewable energy resources, solar energy is the most abundant, inexhaustible and clean energy technology. Photovoltaic (PV) is an effective method of energy producing on site, directly from the sun, without concern for energy supply or environmental harm. Building integrated photovoltaics (BIPV) are photovoltaics (PV) modules integrated into the building envelope and hence replacing traditional parts of the building envelope, such as roofs or facades. BIPVs have a great advantage compared to non-integrated systems because there is neither need for allocation of land nor stand-alone PV systems.

Further, BIPVs can be reduced the total building material costs and achieved significant savings from mounting costs. The different kind of BIPV productions are rapidly growing due to its simply generation of electricity from sunlight, with no pollution [25]. Furthermore, it is important to identify the long term durability BIPV productions by fulfilling the user electricity consumption requirement.

There are four main options for building integration of PV cells such as on sloped roofs, flat roofs, facades and shading systems. The BIPV system serves as a building envelope material and power generation simultaneously and it reduces the electricity costs as well as provides the savings in materials and labor. The BIPV systems often have lower overall costs than PV systems requiring separate, dedicated and mounting systems. The complete BIPV system includes the PV modules, a charger controller, a power storage system (generally comprised of the utility grid in utility –interactive systems or a number of batteries in stand-alone systems), backup power supplies and appropriate support and mounting hardware. The BIPV systems can either be interfaced with the available utility grid or they may be designed as stand-alone, off-grid systems [26]. This method is also helpful to savings of power production of utility as well as lower electricity bills for users because of reducing peak demands (peak shaving).

2.4 Demand Side Management (DSM)

The rapidly increasing of new infrastructures, new electric equipments such as huge rise in use of air conditioners, heaters and EVs increase the electricity usage and the growth of electricity demand. It mainly effects to the energy supply utility and the usage of electricity must be manage to reduce the pressure of energy supply utilities specially on peak usage in demand. Residential load is the largest contributor for the increment in peak demand and it depends on the life style of the people, the types and appliances that they are using. Additional, the residential loads depend on the weather factors in the country as heaters are mostly used in coldest countries and air conditioners are used in tropical countries.

Demand Side Management (DSM) is the method of planning, implementation and monitoring of distribution network utility activities designed to influence customer use of electricity [27]. The DSM related to residential consumers encourage the customer to control their electricity usage and to know the behavior of their main electric appliances with the utility demand limits. During the peak period, the electric system becomes more stressed and the reliability of the whole system is damaged but regardless of that, the utility must supply that demand to balance the supply and user demand. In recent past adding more generation was the solution to peak demand. Currently, the DSM various programs are introduced to implement by utility companies in order to control the energy usage at the customer point of view.

Typically by using DSM programs, the available energy can be more efficiently utilized without implementing new electricity utilization facilities. As a result, the electricity usage time pattern and magnitude of the electricity load can be controlled to reduce the peak demand. DSM uses a different technologies and policy measures to reduce the electricity consumption through economical benefits. The advancement of renewable energy technologies such as wind and solar systems coupled with microgrid technology is considerably important for DSM technologies to stabilize the long-term cost and improve stability of utility.

2.4.1 Basic load shaping techniques

The DSM techniques taken by the utility companies to alter the load shape can be clarified into six basic categories on the situation of existing electricity generation. The basic load shaping methods are peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape (Figure 2.3). The combination of the mentioned techniques enables to load shape by controlling the energy consumption at the customer side.

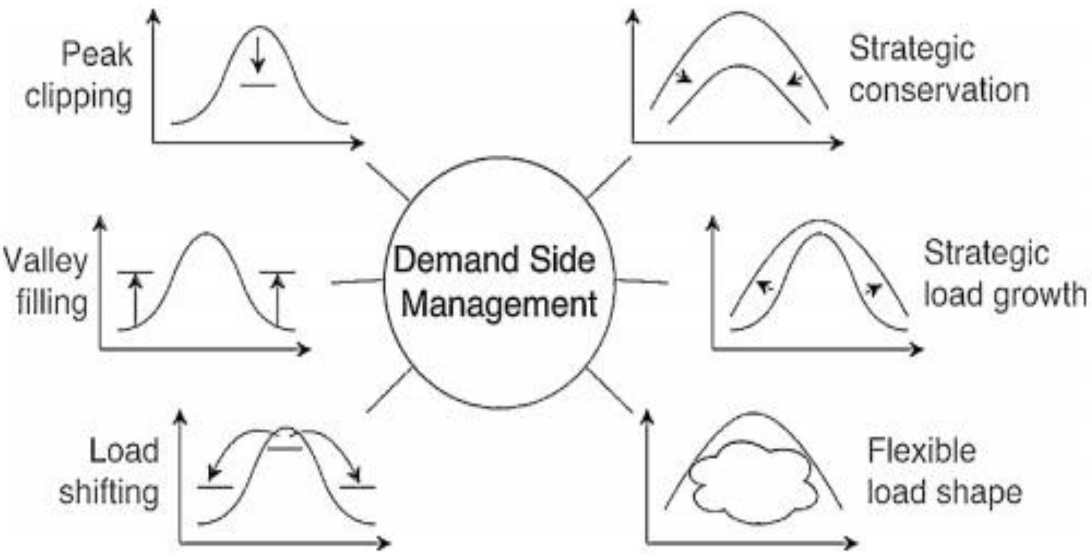


Figure 2.3: DSM load shaping techniques [28]

- **Peak Clipping:** Using direct load control, it reduces the system peak loads by disconnecting consumer appliances at the critical situations. This can be used to reduce capacity requirements, operating costs and dependence on critical fuels.

- **Valley Filling:** This is another type of load management strategy to filling loads during off peak periods. Due to the low cost in off-peak hours, this method helps to reduce the average price of electricity.

- **Load Shifting:** Load shifting is also one of the classical forms of load management taken by the utilities, which shifts loads from peak to off-peak periods without changing overall consumptions. This method combines the benefit of peak clipping and valley filling by moving existing loads from on peak hours to off peak hours.

- **Strategic conservation:** The strategy is used to change the load shape from various targeted conservation activities. The change modifies the load shape involving a reduction in consumption as well as a change in the pattern of use. It is not traditionally used by utilities as a load management option as it reduces the sales not as accomplished with peak reduction.

- **Strategic load growth:** It refers to a general increase in electricity sales beyond valley filling and the spontaneous effects of economic growth. Examples of strategic load growth include electrification, substitution for primary fuels, commercial and industrial process heating and automation and other means for increase in energy intensity in industrial and commercial sectors [29].

- **Flexible load shape:** This involves allowing customers to purchase some power at lower than normal reliability. The customer's load shape will be flexible, depending on the real-time reliability conditions.

2.4.2 Demand Response (DR)

Demand Response (DR) is a specific concept in DSM to improve system stability at the critical situations. According to Federal Energy Regulatory Commission, Demand Response (DR) is defined as: "*Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*" [30]. The control and modification patterns of electricity usage enables to satisfy the available utility power generation. Through various DSM methods, the utilization of renewable energy resources along with energy management maximizes the utility stability and reliability with the cost savings as well as user satisfaction.

- **Direct Load Control (DLC):**

In order to control the residential load consumption, there should be a communication between the utility and the consumers based on the agreement between both parties. The real time data can be transmitted between the consumer and electric supplier with the possibility of two way communication. The direct load control (DLC) is the residential load management method to control the operations and energy consumptions of selected appliances in a household remotely. The DLC demand response method does not provide flexibility in managing loads and it is clearly necessary to an automation energy management for more flexibility control.

The smart pricing is an alternative method to DLC, where customers can manage their loads individually and voluntarily, for example by reducing their consumptions at peak hours. The various pricing schemes like Real Time Pricing (RTP), Time of Use (ToU) etc. In RTP, the price of electricity varies at different hours of the day and it helps to encourage customers to manage their loads in order to reduce their own energy cost. In TOU, the price of electricity varies at periods of the day with the usage of consumption.

- **Autonomous appliance scheduling:**

The another method of DSM for a grid connected household with photovoltaic energy is autonomous appliance scheduling. In this method, past customer electricity consumption behavior is analyzed and according to this past energy consumption pattern of the particular customer is converted to appliance scheduling which is then used to autonomously regulate the energy use [29]. In this method the manual participation of customers in demand respond is not possible and due to full automation this DSM method is in process of success.

2.4.3 Benefits of DSM

The concept of DSM is focused in response to the system reliability that improved the energy efficiency with cost effectiveness. The utility and its customers cooperatively participating in DSM will result the benefits to the customer, utility and society as a whole. The benefits of DSM are varied, as summarized in Table 2.1 below.

Table 2.1: DSM benefits to customer, society and utility [27]

Customer benefits	**Society benefits**	**Utility benefits**
Satisfy electricity demands	Reduce environmental degradation	Lower cost of service
Reduce / stabilize costs	Conserve resources	Improve operating efficiency, flexibility
Improve value of service	Protect global environment	Reduce capital needs
Maintain/improve lifestyle and productivity	Maximize customer welfare	Improve customer service

Chapter 3

3 System scenarios

This chapter presents all the system details related to the project. The selected low voltage distribution network details, user consumption data with different EV charging profiles are described. The typical network constrains and electricity price mechanisms are considered for the smart charging scheduling and cost saving analysis on the developed energy management system.

3.1 Distribution network

The distribution network to be analyzed in this project is an older residential area in Sogn og Fjordane in Norway. All distribution network data needed for simulation were provided by “Sogn og Fjordane Nett AS (SFE)”. The provided information consists the detailed map, the single line diagram, the cable characteristics and transformer details in that distribution area.

3.1.1 The network diagram

The detailed map of the system is shown in Figure 3.1. The red line represents the high voltage line and green color box shows the transformer in that area. The feeder nodes and cable types are marked with blue in low voltage lines. It is comprised mainly 20 residential houses which are marked with nine-digit tags, framed in black boxes in this distribution network system.

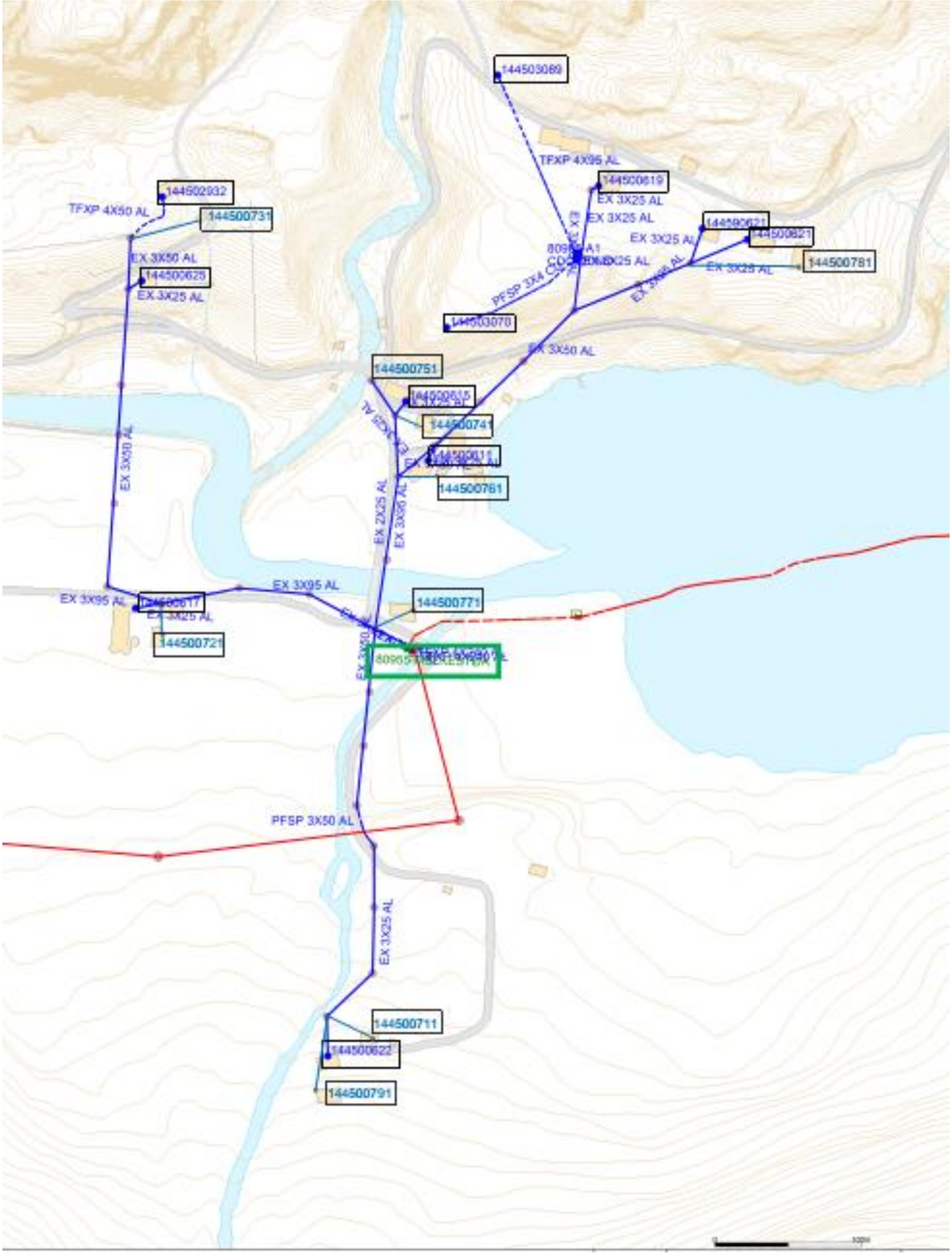


Figure 3.1: Low voltage distribution network in "Sogn og Fjordane" area, where all 20 residences are marked with tags in black boxes

3.1.2 Single line diagram

The relevant single line diagram for the low voltage distribution is sketched as shown in Figure 3.2. All the details in Figure 3.1 represents in the single line diagram. The twenty network subscribers' loads are indicated the house mark with house number. The five residences with BIPV system are indicated with solar panel and other without BIPV residences are not included a solar panel in this diagram.

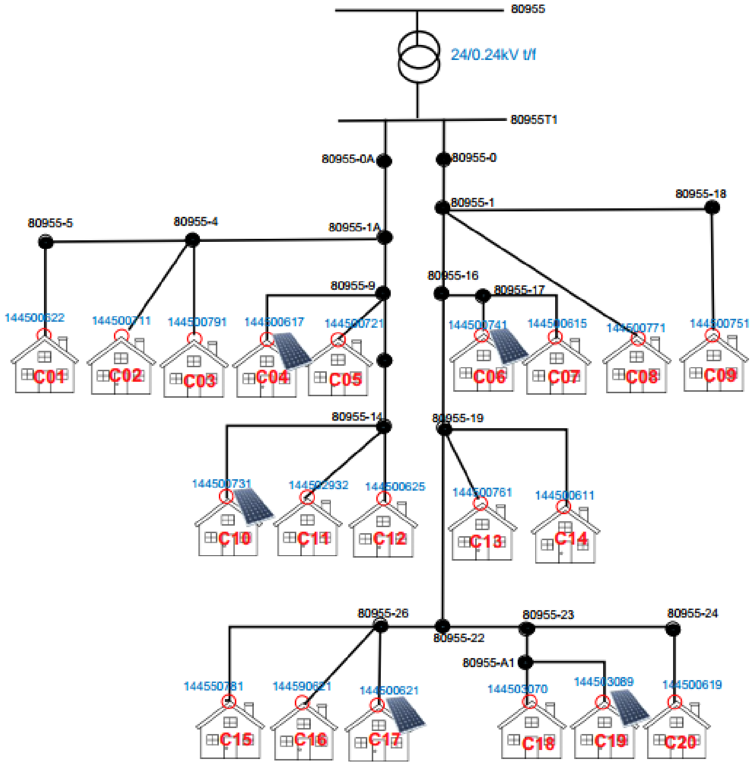


Figure 3.2: The single line diagram of the detailed map with indicating BIPV houses

3.1.3 Transformer

The distribution network system consist with a 2-Winding 24/0.24kV step down transformer. It is an IT system with nominal voltage of 230 V. The transformer supplies 20 residences and is connected in wye-wye, which is the most common connection for distribution transformers. All transformer data is listed in Table 3.1. Due to internal losses, the low voltage output of the transformer is 238 V. The values gives a power factor close to Cos φ=0.9, which is what SFE use in their load flow analysis in Norway [10].

Table 3.1: Transformer data for the low voltage distribution network

Transformer data	
Rating	150 kVA
Rated Voltage HV	22 kV
Rated Voltage LV	0.24 kV
Phase	3 phase
Frequency	50 Hz subject to fluctuation of ± 5%
Vector group	Yy0

3.1.4 Feeder lines

The feeder lines in distribution network is another bottleneck of each house as distribution transformer. The feeders will overload if all connected houses consume a large amount of power at the same time. The specifications for each line connected from feeder to the 20 residences are presented in Table 3.2. The distribution system consists with different cable types to connect from transformer to residences as tabulated in Appendix A: Table A1 and Table A2. The total feeder line impedances are calculated by adding all the resistance and reactance values from transformer to each resistance as indicated in Figure 3.1. In addition, the maximum current capacity of each cables are tabulated.

Table 3.2 : Cable specifications from feeder to residence in low voltage distribution network

House No:	**Network Subscriber**	**Cable**	**Type**	**Length (km)**	**Resistance (ohm)**	**Reactance (ohm)**	**Max. current (A)**
C01	144500622	EX 3X25 AL	Overhead	0.0129	0.1884	0.0129	115
C02	144500711	EX 3X25 AL	Overhead	0.0129	0.1884	0.0129	115
C03	144500791	EX 3X25 AL	Overhead	0.0268	0.3216	0.0220	115
C04	144500617	EX 3X25 AL	Overhead	0.0015	0.0216	0.0015	115
C05	144500721	EX 3X25 AL	Overhead	0.0017	0.0227	0.0017	115
C06	144500741	EX 3X25 AL	Overhead	0.0012	0.0144	0.0095	115
C07	144500615	EX 3X25 AL	Overhead	0.0011	0.0156	0.0011	115
C08	144500771	EX 3X25 AL	Overhead	0.0018	0.0216	0.0024	115
C09	144500751	EX 3X25 AL	Overhead	0.0016	0.0192	0.0013	115
C10	144500731	EX 3X25 AL	Overhead	0.0420	0.0266	0.0033	115
C11	144502932	TFXP4X50AL	Ground	0.0410	0.0263	0.0032	150
C12	144500625	EX 3X25 AL	Overhead	0.0009	0.0132	0.0009	115
C13	144500761	EX 3X25 AL	Overhead	0.0021	0.0300	0.0021	115
C14	144500611	EX 3X25 AL	Overhead	0.0008	0.0120	0.0008	115
C15	144500781	EX 3X25 AL	Overhead	0.0044	0.5304	0.0036	115
C16	144590621	EX 3X25 AL	Overhead	0.0021	0.0300	0.0021	115
C17	144500621	EX 3X25 AL	Overhead	0.0034	0.0504	0.0034	115
C18	144503070	PFSP3X50AL	Ground	0.1030	0.0661	0.0103	115
C19	144503089	TFXP4X95AL	Ground	0.1350	0.0432	0.0101	220
C20	144500619	EX 3X25 AL	Overhead	0.0005	0.0072	0.0005	115

3.2 Load Analysis

The load consumption of each residences is mainly divided into two categories: household load and EV load data for the simulation purpose.

3.2.1 Household load

In this distribution network, there are twenty residences with five single-family houses with BIPV system and other fifteen houses without BIPV system. The household load consumption data with and without BIPV installed residences are related to Skarpnes Smart house project data, is chosen for load analysis. This monthly basis average actual data is relevant to the period of September-2015 to August-2016. The consumption data changes with the user profiles, climate for the selected area, time and month of the year.

- **Household consumption of residences with BIPV system**

Among the twenty residences in the distribution network, the five residences named as C04, C06, C10, C17 and C19 are developed with roof mounted building integrated Photovoltaic (BIPV) system. Those houses have been occupied and started collecting energy consumption and production with power quality data. The Sparknes smart village project housing load demand is used to those houses monthly average power consumption on the period of September-2015 to August-2016. The energy outputs of those five houses for a year are given in Figure 3.3 to Figure 3.7.

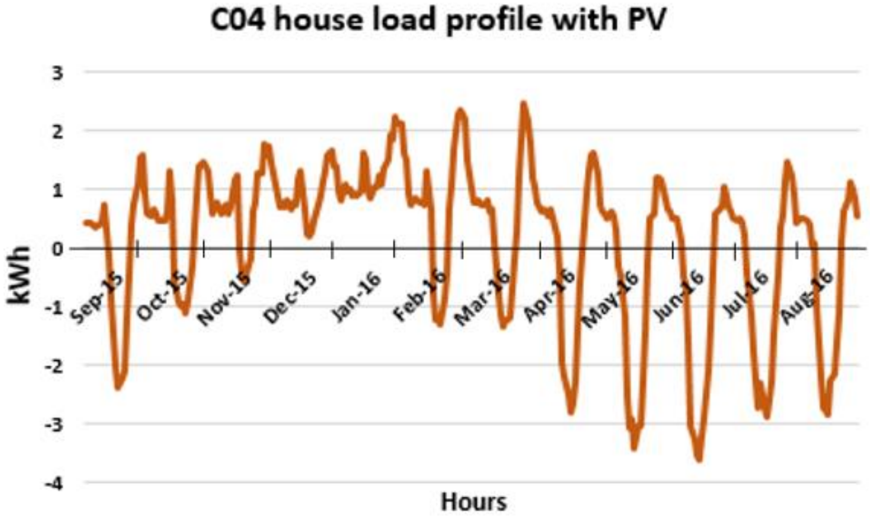


Figure 3.3: Average monthly load profile of C04 house with BIPV system for Sep-15 to Aug-16 period

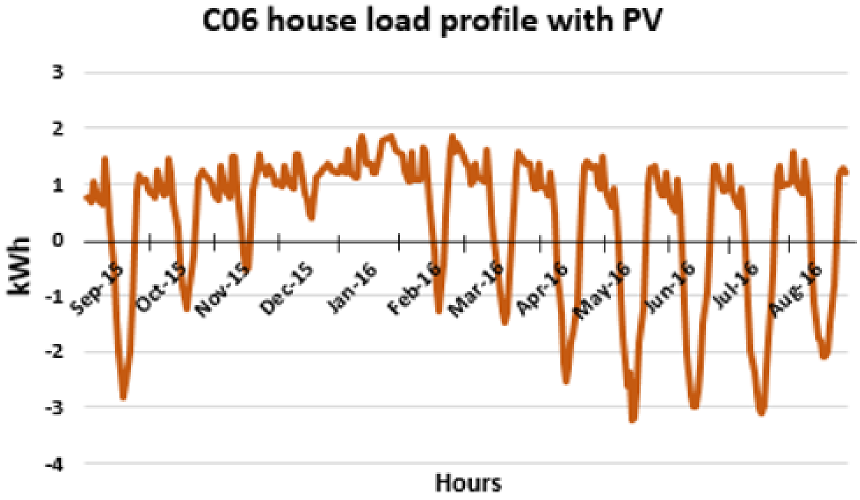


Figure 3.4: Average monthly load profile of C06 house with BIPV system for Sep-15 to Aug-16 period

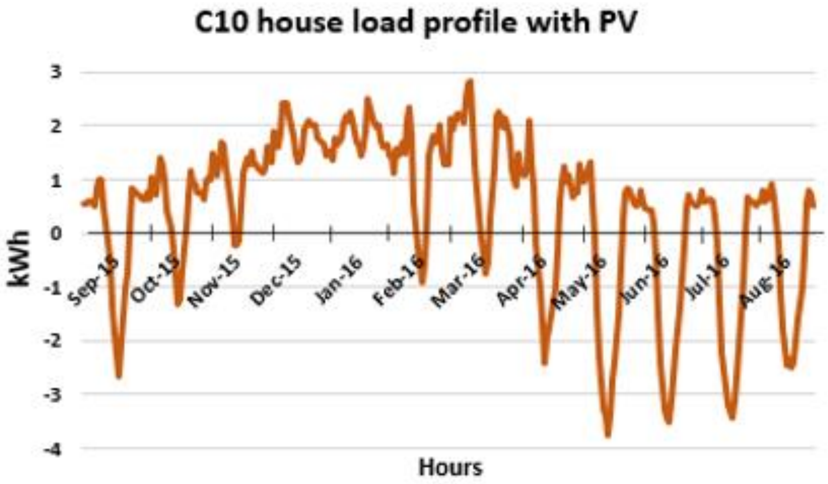


Figure 3.5: Average monthly load profile of C10 house with BIPV system for Sep-15 to Aug-16 period

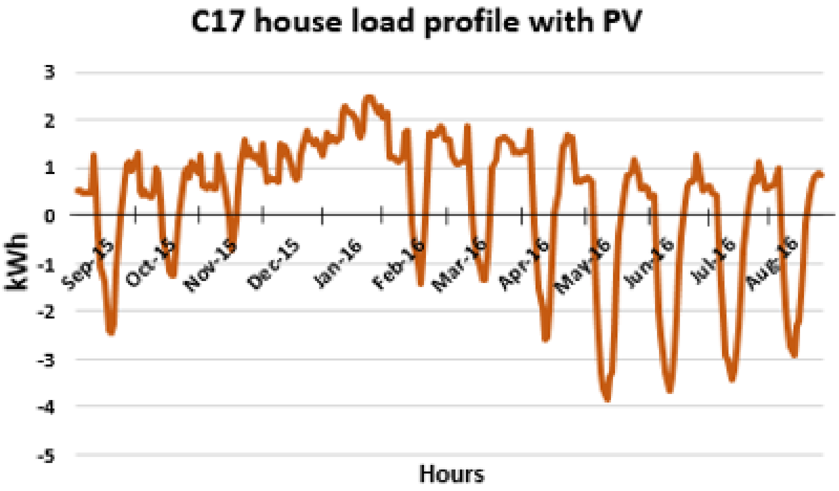


Figure 3.6: Average monthly load profile of C17 house with BIPV system for Sep-15 to Aug-16 period

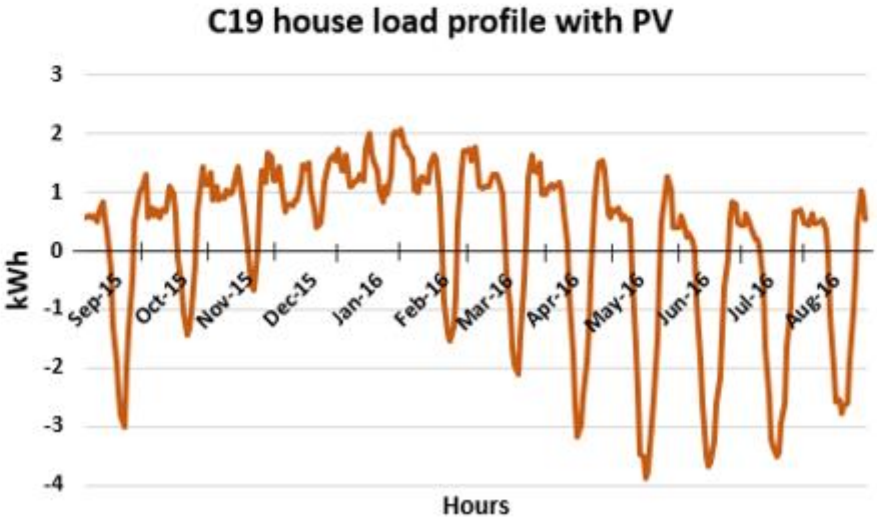


Figure 3.7: Average monthly load profile of C19 house with BIPV system for Sep-15 to Aug-16 period

- **Household consumption of residences without BIPV system**

The monthly average load consumption for fifteen residences as indicated in Figure 3.1 without BIPV system is plotted in Figure 3.8. The average load consumption for all those residences are assumed to be same as the detailed hour based consumption data given in Sparknes project.

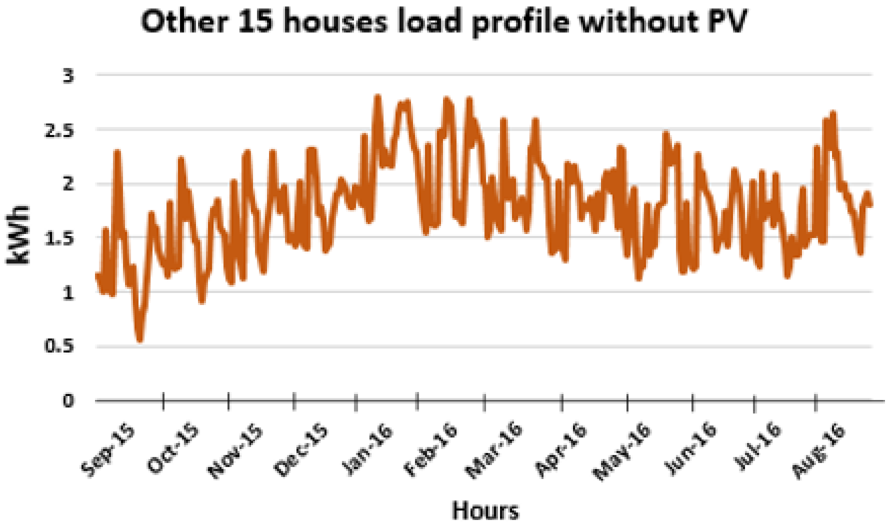


Figure 3.8: Average monthly load profile of other 15 houses for Sep-15 to Aug-16 period

3.2.2 EV Consumption

The additional loads in the form of EV consumption will be challenged to the distribution network and it will be sensitive to the system by increasing consumption. The total load of residence is modeled with power consumption of each house with the EV consumption. To establish the EV consumption, different EV user profiles with their daily charging patterns and charging strategies are selected.

- **EV User profile**

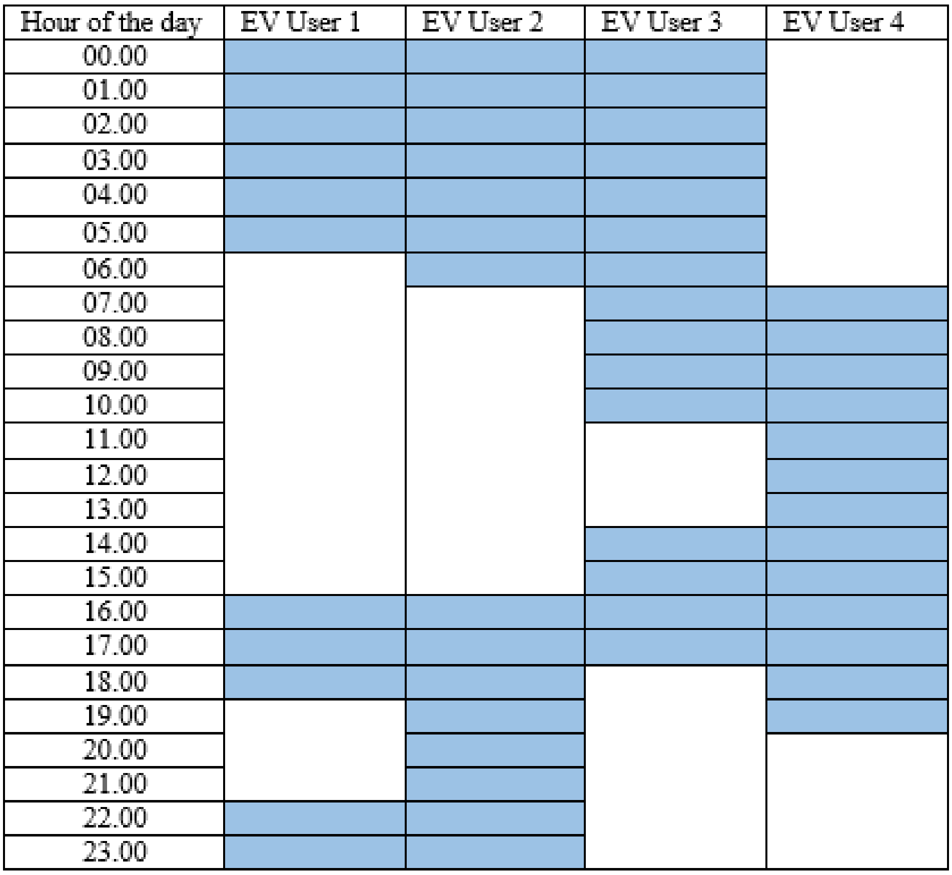
The four main EV user profile categories such as normal family, single user for EV, unemployed user and night worker are selected in this project to analysis the EV charging scenarios. These user profiles are proposed using their behavior of load usage and possible charging hours of their day today works.

Table 3.3: EV user profile characteristics

EV user profile		**EV connection**	**Probabilities (%)**
EV User 1	Normal family with frequently and unpredictable EV usage	16.00 to 19.00 and 22.00 to 06.00	40
EV User 2	Single user for EV	16.00 to 07.00	30
EV User 3	Unemployed user	14.00 to 18.00 and 00.00 to 11.00	20
EV User 4	Night worker	07.00 to 20.00	10

Different probabilities for which EV users are in this distribution network is set as 40 percent for EV User1, 30 percent for EV User2, 20 percent for EV User3 and 10 percent for EV User4. Hence, the total 20 residences are divided with eight normal family residence user types, six single user EV residence user types, four unemployed user types an two night worker in this distribution network.

The EV connection and disconnection time of different user profiles are used to implement the minimum power consumption hour charging during that time period. Normally EVs could be charged any place a standard outlet is present. Therefore in this analysis, the batteries of vehicles are assumed to be charged at home which is relevant to their EV connection time of user profile as Table 3.3. It is assumed that only one vehicle per household can be charged at once. It is important to mention these user profiles for charging algorithms. Figure 3.9 shows graphically the different connection and disconnection times of the four user profiles described in Table 3.3.



Hour of the day	EV User 1	EV User 2	EV User 3	EV User 4
00.00	🟦	🟦	🟦	
01.00	🟦	🟦	🟦	
02.00	🟦	🟦	🟦	
03.00	🟦	🟦	🟦	
04.00	🟦	🟦	🟦	
05.00	🟦	🟦	🟦	
06.00		🟦	🟦	
07.00			🟦	🟦
08.00			🟦	🟦
09.00			🟦	🟦
10.00			🟦	🟦
11.00				🟦
12.00				🟦
13.00				🟦
14.00			🟦	🟦
15.00			🟦	🟦
16.00	🟦	🟦	🟦	🟦
17.00	🟦	🟦	🟦	🟦
18.00	🟦	🟦		🟦
19.00		🟦		🟦
20.00		🟦		
21.00		🟦		
22.00	🟦	🟦		
23.00	🟦	🟦		

Figure 3.9: EV user connections for each hour (blue colour indicated the EV connection hours)

- **EV specifications**

Among the EV market share in Norway, Nissan Leaf is the mostly common used model [31]. It is an advanced, practical and a usable battery powered car yet. For this project, all electric vehicles are assumed to be Nissan Leaf and its specifications will be used in simulations as tabulated in Table 3.4.

Table 3.4: Nissan Leaf EV specifications for simulation purpose

Battery capacity	24kWh
Battery type	Laminated lithium-ion
Energy consumption per km	0.12 kWh/km
Charging power	3.3kW /6.6kW
Maximum SOC (%)	100
Minimum SOC (%)	0
Charge efficiency (%)	93
Transportation efficiency (%)	86.5

- **EV charging hours**

According to the Nissan Leaf battery specifications, EV has a 24kW maximum battery capacity at fully charged and it is charged in 3.3 kW power using the SAE J1772 socket in residences. According to the linear charging characteristics, SOC values can be used to calculate the energy value to charge the battery using equation 2.2. Moreover, the charging hours can be calculated by using the relevant energy value taken from SOC as equation 3.1.

$$h_c = \frac{E_c}{P_c \times \eta_c} \tag{3.1}$$

From equation 2.2;

$$h_c = \frac{(1 - SOC) \times P_{b,max}}{P_c \times \eta_c}$$

$where\ \ h_c: Number\ of\ Charging\ hours\ ;$ $E_c: Energy\ to\ charge\ the\ battery\ ;$

$SOC: State\ of\ Charge;$ $P_{b,max}: Maximum\ battery\ power;$

$P_c: EV\ Charging\ power;$ $\eta_c: Charge\ efficiency$

These two main equations are implemented to calculate the charging hours in this project Matlab file. As the example, the battery level of 66% of SOC value and charging power of 3.3 kW of EV gives the hour-based value of 3 hours as calculated below.

$$h_c = \frac{(1-SOC)\times P_{b,max}}{P_c \times \eta_c} = \frac{(1-0.66)\times 24kWh}{3.3\ kW \times 0.93}$$

$$Charging\ hours = \quad h_c = 2.66\ h = 2hours\ 40min = 3\ hours$$

Its therefore, a fully depleted Leaf battery can be recharged within seven hours using 240V charging outlet [31]. In this project, the initial SOC value of 0.66 for all EVs will be used to calculate charging hours and implemented to optimization of the load management.

3.3 Distribution System Constrains

The distribution network constrains are very important considerations for the distribution network in country and the reducing affect to distribution component overloading. The method of load flow calculation helps to find out the voltages and currents in distribution network It is useful to optimize economic cost and stability limit. The regulation limits are described in section 2.2 and it is used to manage these constrains.

- **Current limit**

Current flowing through the distribution lines must be lower than the cable conductivity to eliminate the cable overloading.

$$I_b \leq I_z \; [A] \tag{3.2}$$

where $I_b = load\ current\ ,\ I_z = cable\ conductivity$

The cable conductivity values of each conductor are given in Table 3.2 and load currents can be calculated as follows.

$$I_b = \frac{P}{\sqrt{3}\, V_n\ cos\varphi} \; [A] \tag{3.3}$$

where $P = load\ power$; $V_n = nominal\ voltage$; $cos\varphi = power\ factor$

- **Voltage limit**

LV network in Norway have a nominal line to neutral voltage of 230V. The actual voltage has to be within a range of ± 10% of nominal voltage. The residence voltage must be within this range.

$$V_{min} \leq V_{residence} \leq V_{max} \; [\mathrm{V}] \tag{3.4}$$

where, $V_{min} = 207$; $V_{residence} = residence\ voltage = 230$; $V_{max} = 253$

Voltage at residence can be calculated using the voltage difference between the transformer output voltage and feeder line voltage. The feeder line voltage (delta_V) is calculated using the total feeder line resistance(R) and reactance values (X) from transformer to residence (Appendix A: table A1 and Table A2).

$$V_{residence} = V_{transformer} - \ delta\_V \tag{3.7}$$

where $V_{transformer} = 238\ [V]\ \ (section\ 3.1.3)$

$$delta\_V = \sqrt{3}\{(R \times I_b \times cos\varphi) + (X \times I_b \times sin\varphi)\}$$

- **Power limit of transformer**

Total consumer power loads must be lower the transformer capacity to eliminate the transformer overloading.

$$\textstyle\sum_{0}^{k=20} P_{load} \leq P_{transformer} \; [\mathrm{kW}] \tag{3.8}$$

where $P_{load} = All\ power\ consume\ loads = househols\ loads\ +\ EV\ charging\ loads$;

$P_{transformer} = Transformer\ capacity = Apparent\ power[VA] \times\ cos\varphi$

- **Demand limit**

The distribution network may be implement a demand limit for all the residences to reduce the overloading of the distribution network components as well as to increase the user satisfaction with economic benefits.

$$P_{total\ load} \leq\ Demand\ limit \; [\mathrm{kW}] \tag{3.9}$$

where $P_{total\ load} = househols\ loads\ +\ EV\ charging\ loads$

3.4 DSM controlling strategies

The DSM controlling strategies are very useful to achieve the different DSM techniques and it enhances the system reliability. According to the past energy consumption patterns, the particular customer consumption can be scheduled in this DSM controlling. It has been depicted through user energy consumption behaviors, the BIPV generations in residences and the demand limitations to fulfill the success of DSM method.

3.4.1 User energy consumption analysis

In many countries, the residential sector consumption plays a major role in the electricity demand of distribution network. The users tend to improve their life-style by using more and more electric appliances, which will ease their daily activities. During last decades, the residential electricity consumption is grown with a steep and steady. Each household needs at least the same electric apparatus such as refrigerators, stoves, lighting, heating systems and small electric equipments.

The electricity consumption of individual varies with their user behaviors as well as time of the day. Typical the household demand has risen in the morning and evening period when people leaving home and come back to home. As well as the electricity demand of the middle of the day has not a very high value depending on user profile types.

The total household can be divided into two categories: critical loads and controllable loads or non-critical loads. Critical loads are loads that can not be disconnected, such as lighting, cooking and refrigerators. Controllable or non-critical loads can be interfered without noticeable effect to the consumer’s lifestyle. Since these non-critical loads account for a significant percentage of the total household demand, controlling these loads during peak hours will help to reduce the peak demand in the house.

The air conditioning (AC) unit, water heater, washing machine, clothes dryer, small electric equipments and electric vehicle are identified non-critical power intensive residential loads in this project. Further, the non-critical power consumption of each residence is assumed to be 40 percentage of total consumption without EV loads by analyzing this actual data consumption of residences.

3.4.2 The load behaviors of residences with and without BIPV system

There are five BIPV system residences and others are without BIPV installed residences. These five houses are developed as roof mounted building integrated PV system and it is considered that these BIPV system residences are considered as without any battery storage capability. These houses have been occupied and started collecting energy consumption and production with power quality data. When PVs produce electricity, it satisfies the user consumption and delivers the excess energy to the distribution network. This PV generation electricity varies with day time and month of the year.

By analyzing all BIPV residences in this distribution network, the day time period in summer period generates electricity and delivers excess electricity as shown in figures in section 3.2.1. It minimizes the housing energy demand through the building energy efficiency and utilize the local PV generation.

3.4.3 Demand limit profile

The utility have been provided the demand limit profile to end-users, when the distribution system is implemented DSM mechanism. According to the equation 3.9, the utility always try to manage their electricity user consumption within this demand limit. The fictional demand limit profile is used in this project as tabulated in Table 3.5. This gives the residential power consumers' ability to select which loads will use within the limited power capacity provided by a distribution network operator. The demand limit creates the changes in the load shape while changing household loads. The upper limit of 6.75 kW per consumer equals the low voltage distribution transformer maximum power capacity with 150 kVA and power factor of 0.9.

Table 3.5: Hour based demand limit profile

Period (Hour)	**Demand limit [kW]**
00.00 – 07.00	6.75
07.00 – 10.00	5.50
10.00 – 15.00	5.75
15.00 – 20.00	5.00
02.00 – 00.00	6.50

The demand limit profile has five main demand limit levels that are used for the analysis purpose of this objective. Since the peak demand in the distribution sector increases during morning and evening sessions such as time period between 07:00 to 10:00 and 15:00 to 20:00, where a low value of demand limit has been used during that period. Moreover, the off-peak time period is taken between 00:00 to 07:00 and the intermediate time period is taken as between 10:00 to 15:00 and 20:00 to 00:00.

Chapter 4

4 Load Management Programmes

This chapter mainly focused on the intelligent scheduling for charging EVs using the smart load management simulation model. The optimal scheduling method provides to shift charging loads to minimum power consumption time-period without overloading in equipments. Further, a residence with BIPV and a residence without BIPV are selected to shift loads to off-peak hours using DSM techniques to identify the periods of best suitable EV charging and non-critical user consumption. In addition, the economic aspects to calculate electricity demand charging will be outlined in this chapter.

4.1 Base load analysis

Before introducing any EV charging strategies, it is important to analyze the system in its household load current state. All the base load household power variation is related to the Sparknes project as given in section 3.2.1. Load consumption as well as the PV production will vary and may depend on the climate conditions as well as change in user behavior, load pattern and time of the day. The real time hourly net energy consumption in BIPV houses are analyzed on monthly average energy taken from the grid and supplied to the grid. Also the on-site monthly measured energy consumption between Sep-15 to Aug-16 for five BIPV residences: C04, C06, C10, C17 and C19 are given in section 3.2.1. It is observed during Sep-15 to Oct-15 and Feb-16 to Aug-16, the monthly PV production is the highest and exported to the grid. In the winter period of during Nov-15 to Jan-16, the PV production is the lowest compared to others months, hence the demand is the highest.

The hourly energy consumption for other fifteen houses without BIPV is given in Appendix C. In this project, it is assumed that all user profiles without BIPV system have the same base load consumption as given in Sparknes project real time data between last year monthly average power usage between Sep-15 to Aug-16.

According to the monthly average user consumption, the highest user consumption is on January month. This can be considered as the worst-case scenario. This base load analysis will be used as reference scenario to compare against the results from EV charging strategies.

4.2 Charging strategies

The total household load consumptions are important to identify the impact of power system stability and power quality. The household loads depend on the total of base loads and the additional loads from the EV charging. The impact on distribution system will depend on its total power consumption in all houses. Consequently, increasing the amount of EVs in a power system will contribute to exacerbating the peak power demand significantly. In this section, the impact of energy consumption of EVs are considered. The charging strategies of EVs in residences mainly depend on the number of EVs connected to the charging scheme, charging power conditions, its charging period and number of charging hours related to SOC battery status of EV.

According to the Statistics Norway [32], the average driving distance of a passenger car is 37 km, which results 66 percentage of SOC, assuming the battery was fully charged before use. For simplicity of large scale EV adoption, the same car model has been applied with similar charging sequence characteristics and all home energy charging stations installed same capacity. Using these conditions, most important charging assumptions made in this project are presented below.

- The constant charging power of 3.3 kW is chosen for all houses, because of the slow charging standard electronic outlets in houses for single phase 230V outlet.
- All EVs are Nissan Leafs with the initial SOC value of 66 percent.
- All EVs are plugged when user arrived to house (according to user profile).
- EVs are assumed to charge one time each day.
- EVs will be charged to full capacity before leave home (End time).
- Battery is linearly charged with full battery capacity of 24 kWh. The charging hours can be calculated using this linear charging capability as equation 3.1.

The three different charging strategies: “charging pattern as it is”, “smart coordinated” charging and “DSM coordinated” charging are analyzed and presented below to illuminate the benefits of load shifting in 24-hour simulation.

4.2.1 Objective 1: Uncoordinated charging (charging pattern as it is)

The most conventional charging scheme is to plug in EVs and start to charge at full power, (e.g.3.3kW) as soon as plugged in and continue until batteries are full like any other regular loads. This is referred as “uncoordinated charging” or “charging pattern as it is”. In this charging strategy, there is no control of active power charging and it is only consider the completeness of fully charging. This will cause local grid problems in terms of extra power losses, which can be regarded as voltage deviations and economic concerns. This charging scenario serves as a reference case when identify the effectiveness of the algorithms in the smart charging scenario and DSM charging algorithms.

To develop the algorithm of uncoordinated charging, the household base load data given in section 3.2 with their user behavior and EV plug in time are simulated without a load management system and without considering power system constrains in section 3.3. In this scenario, all the EVs begin to charge immediately when they return their last journey of the day as given in user profile.

The process of uncoordinated charging is shown as the flow chart in figure 4.1. The simulation model in this process is implemented using Matlab algorithms. The month of the year can be manually or automatically selected as an input to the simulation model to identify the different charging patterns in whole year. According to SOC value, number of charging hours are calculated and EVs are implemented to charge this calculated hours from when they arrives. This objective is useful to estimate how much EV penetration impact to the distribution power system before shifting the loads to minimum power consumption hours.

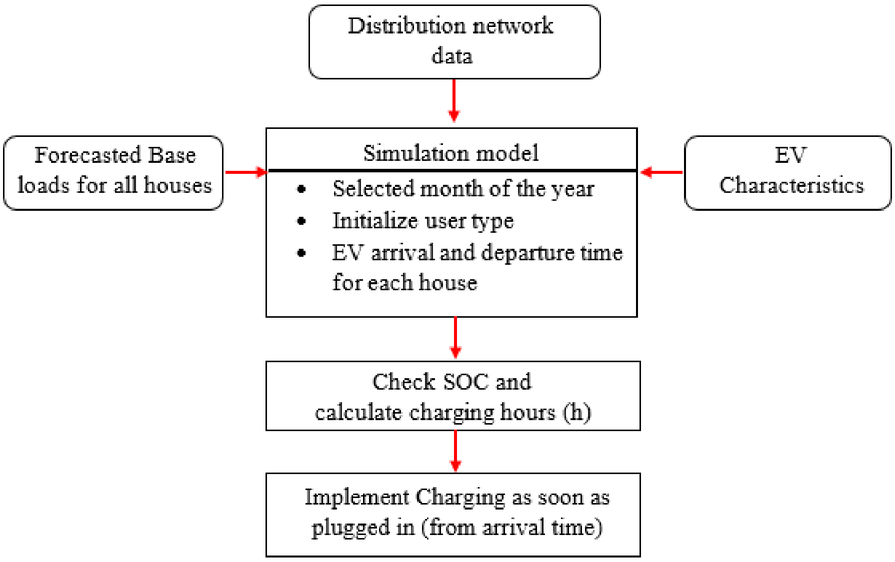


Figure 4.1: The flow chart of uncoordinated charging scenario: objective 1

4.2.2 Objective 2: Coordinated charging (Smart charging schedule)

The uncoordinated charging of EVs in distribution network can lead to local grid problems due to the overloading conditions of distribution system. The coordinated charging is investigated to reduce the impact of uncoordinated charging behaviors in this section. The objective 2: coordinated charging is achieved through the smart charging schedule that rescheduling the charging plan by shifting charge hours of EVs to minimum power consumption hours by considering low voltage distribution network constrains.

The algorithm of the smart load management(SLM) is based on the input to the system as given in forecasted hour-based load data, distribution network data and stipulated EV data. This objective algorithm is a continuation of the algorithm in objective 1, where initializing month of year, user profile type, charging hours for the state of fully charged and available EV charging time periods. In this coordinated charging objective, it is optimized the best optimal charging hours that EV can be charged within the available time slots for each users. To find the optimum and minimum power consumption time-periods, the Matlab algorithm is implemented. It generates all possible time slots using arrive time, departure time and number of charging hours for all 20 users. It returns the all combinations using a binomial coefficient method as described in figure 4.2.

As an example for three hours in charging period, there are lot of possible charging slots within arrive and departure time period as shown below.

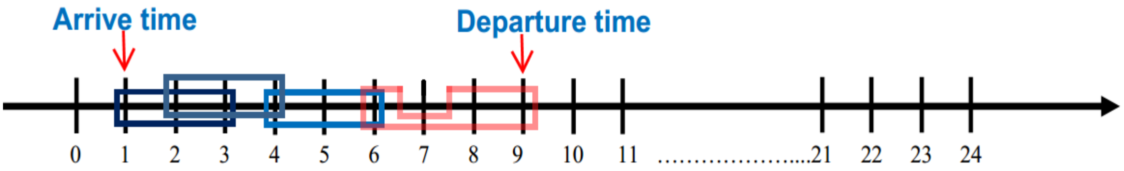


Figure 4.2: The possible charging slots for 3 hours in charging period (ex: 4 time slots:1 2 3; 2 3 4; 4 5 6; 6 8 9)

The Matlab simulation model has been derived to select the minimum power consumption time slot by checking the generated all possible time slots which satisfies the distribution system constrains such as voltage limits, current limits and power of transformer limitations. The voltage control in distribution network is implemented as one of the constrain in this optimization problem to reduce the voltage deviation of the system. The other two constrains of current control and transformer power control in distribution network are considered to increase the system reliability.

The SLM process for coordinated charging scenario is developed through the flow chart as shown in figure 4.3 and the Matlab simulation model has been developed as flow chart steps.

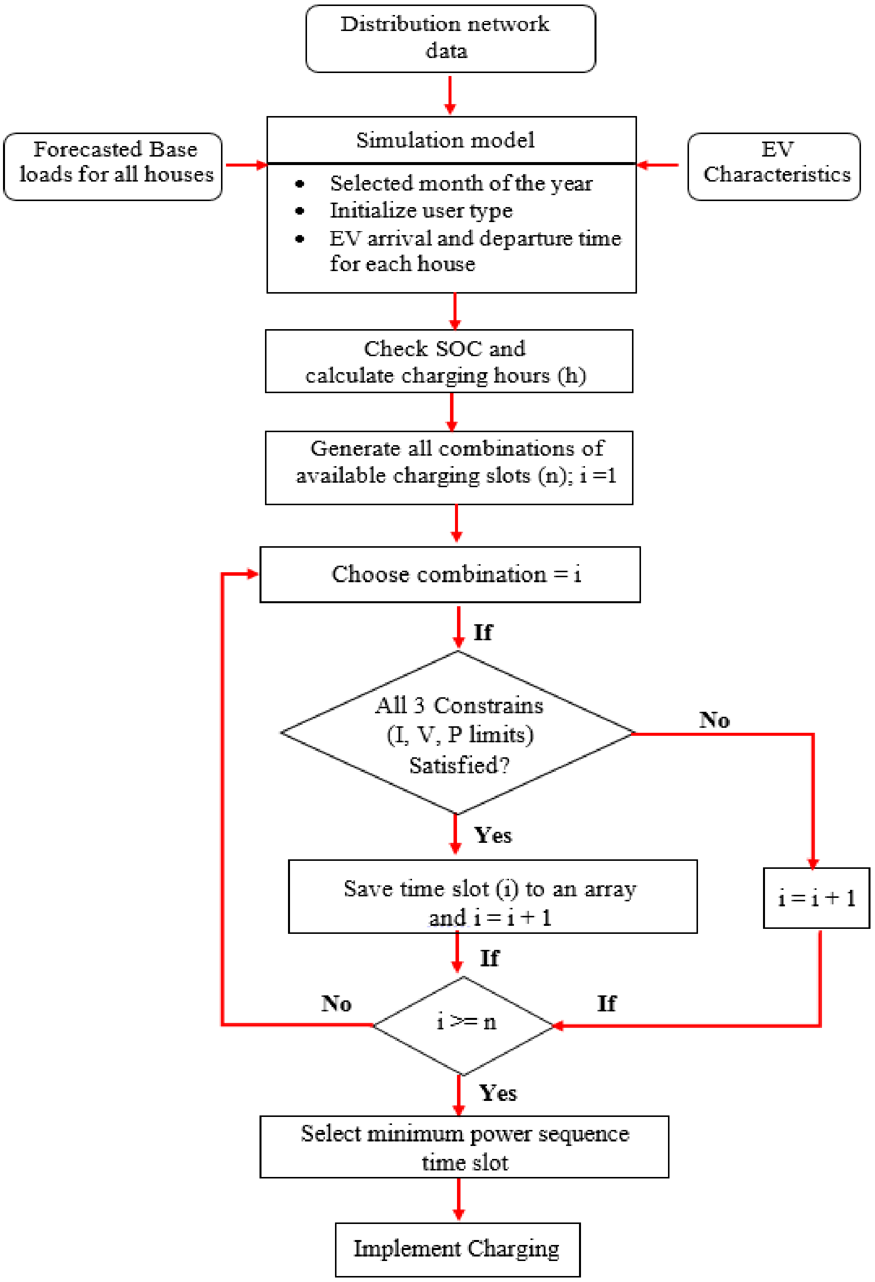


Figure 4.2: The flow chart of coordinated charging scenario: objective 2

4.2.3 Objective 3: DSM load scheduling

This objective is achieved using DSM techniques to load shape modification of the existing electricity user consumption. This can be enables by controlling the energy consumption of customer side as described in section 2.4. In this project, the load shifting technique method is used as the load management forms, which shifts peak to off-peak periods without changing overall consumptions. The changes in electricity usage from their normal usage pattern will be help to changes in the price of electricity over time when system reliability increases. This DSM load scheduling is mainly considered the fictional demand limit profile, user energy consumption analysis and BIPV load generation capabilities as described in section 3.4.

This objective is developed using the assumptions and limitations used in objective 2 as well as below assumptions are under considerations.

- The forecasted base loads in sep-15 to aug-16 is anlysized to identify the new user consumption scheduling.
- Non-critical load is assumed to be 40 percentage of total consumption except EV loads.
- The load scheduling for residences without BIPV is only considered that shift the peak time user consumption to the off-peak time period in whole the year.
- The load scheduling for residences with BIPV is only considered to shift the peak time user consumption to the PV generation time period in summer period.

The DSM scheduling has been developed through the flow chart as shown in figure 4.4 using Matlab simulation. According to the flow chart, the minimum power consumption time period for charging EVs are identified using the voltage, current and power limitation constrains (output of objective 2). In this process, first only EVs are shifted to minimum power consumption periods and then identify the peak time periods' non-critical loads which can be exceeds demand limit in peak times after connecting the EVs. The total non-critical loads in peak time are calculated and shifted to off-peak hours for the residences without PV system. As well as the total non-critical loads in peak time are shifted to electricity generation by residential PV systems in summer period of residences in PV system. When non-critical loads are shifted to off-peak or PV generation time, it always check there have been not charged EVs in that time. After scheduling EV charging and shifting non-critical loads, the total energy consumption with EV connections are compared with demand limit as given in table 3.5. If the fourth constrain (eq: 3.9) is not satisfied this process is again checked by changing its new base load that is equal to new non-critical shifted loads. If the scheduled EV charging and shifted non-critical loads are not exceed, the new schedule is implemented as described in figure 3.3. This objective is useful to identify the DSM load shifting techniques and the benefits to user and distribution network.

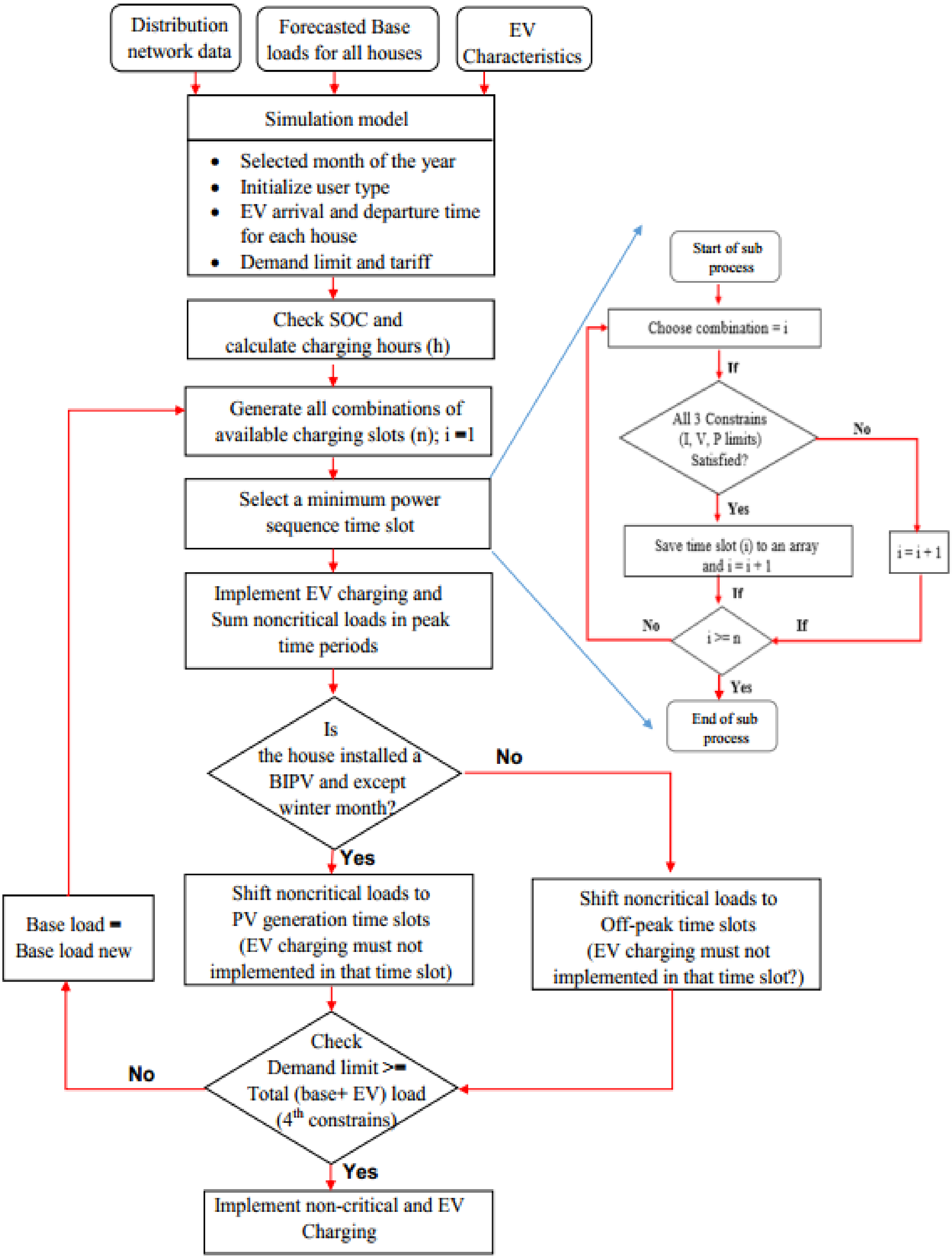


Figure 4.3: The flow chart of DSM scheduling: objective 3

4.3 Economic Aspects

The economical analysis is identified in this project to compare the cost saving analysis to the users on developed energy management system. The electricity pricing mechanism in Norway is considered in the typical energy pricing.

4.3.1 The electricity pricing in Norway

The Nordic countries deregulated their power markets in the early 1990s, and their individual markets were brought into a common Nordic market. The hourly electricity prices for the different Nordic and Baltic countries can be found at Nord Spot's webpages [33]. The market place, which is called Nord Pool, is owned by Nordic transmission system operators and the Baltic transmission system operators is Europe's leading power market and it gives the transparent and reliable power price produced within markets in every hour, every day.

The hourly based electricity pricing for Kristiansand area in Norway for a year period is attached in Appendix A: Table A3. It is clear that there is a smaller variation in the electricity prices in every hours. This is due to the fact that most of the Norwegian power produces from hydroelectric power plants, which has excellent power regulation ability to most other types of power plants. Currently, most Norwegian consumers do not face any incentives to respond to price changes as the accumulated energy consumption and the hourly prices remain invisible due to lack of advanced metering system technology. The Norwegian government has decided that the implementation of smart metering systems to give a more accurate billing system [34].

4.3.2 Electricity pricing mechanisms

The production of electricity prices vary significantly from hour to hour and power plant types. During high peak hours, the fossil fuel based power plants which has a high production cost have to be used to balance the peak demand and supply. Therefore the production of electricity prices in peak hours gives spikes during peak demand periods. As the production cost of electricity varies hour to hour, the cost of consuming electricity should vary accordingly. The domestic user consumes much more energy during late afternoon and morning session periods. This could be impact on the cost of production electricity as well as it may be effect to the reliability of the power grid. Therefore, researchers have introduced different electricity pricing mechanisms which reflect the actual electricity market prices, such as Real Time Pricing (RTP) and Time of Use(TOU). This pricing mechanisms will encourage user to shift in their consumptions to off-peak hours.

Typically electricity pricing is changed with hourly basis and it is called as RTP. The average RTP values for this distribution network area are attached in Appendix C as taken from Elspot prices in Nord Pool [33]. It is indicated that a higher prices for peak demand periods and a lower prices for off-peak demand periods. Further, this prices changes with a month of year. The TOU tariff gives the electricity prices for a certain demand time period. By using this TOU tariff, consumer can shift their loads to minimum electricity pricing time periods which reduces the peak demand and increases the system reliability. In this project, TOU tariff charges are used to develop the scheduling of user consumptions and it will help the customer to reduce their bill. In addition, it will increase the system reliability.

According to the RTP actual tariff charges in Appendix A: Table A3, average TOU tariff charges are developed for January month as shown in figure 4.4.

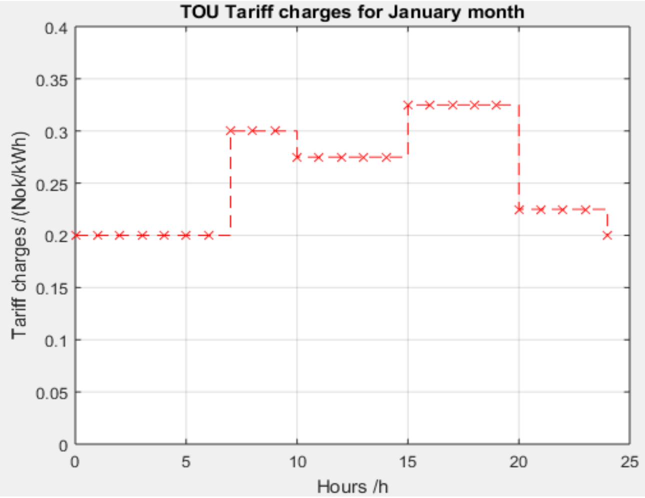


Figure 4.4: Variation of electricity prices with TOU tariff charges for January month

In the considered TOU pricing mechanism, 24 hours of the day is divided into five time periods and five different energy prices are used for these time periods. The two peak time periods, two off-peak time periods and one intermediate time period are defined as illustrated in below Table 4.1.

Table 4.1: The TOU energy prices using Elspot prices in Nordic Pool

Period	**Time interval**	**Energy prices (Nok /kWh)**
On-peak period 1	15.00 – 20.00	0.325
On-peak period 2	07.00 – 10.00	0.300
Intermediate peak period	10.00 – 15.00	0.275
Off- peak period 1	20.00 – 00.00	0.225
Off- peak period 2	00.00 – 07.00	0.200

4.3.3 Electricity Bill calculation

In TOU energy pricing mechanism, the energy used during each time slot is multiplied by the per unit price of the electricity at that time period. The values obtained from these time periods are added together to find the energy cost for the considered day. The average TOU value and energy consumption per each hours for one month are used to calculate the electricity bill for that month as following calculation.

$$Electricity\ bill\ per\ day\ (Nok) = \sum_{i=1hours}^{24hours}(Energy\ usage_i\ \times Enegy\ price_i) \qquad (4.1)$$

The monthly electricity bill can be calculated by multiplying the value of electricity bill per day with number of days per month. These calculations used to comparison of economic aspects of three objectives. The electricity bill calculation have developed in the Matlab simulation model.

4.4 Matlab simulation model

The Matlab simulation model has developed to reschedule the load patterns of three objectives. The algorithms have been derived using Matlab to scheduling the optimal placing of the EV loads and non-critical loads by referencing system as it is. The algorithms of Matlab simulation model is developed by using the flow charts discussed in section 4.2. Matlab native and user-defined functions are used to achieve the project objectives. The Matlab simulation model results will be discussed in Chapter 5.

Chapter 5

5 Results and Discussion

In this chapter, the results from the Matlab simulation model will be discussed in comparison of SLM and DSM scheduling with the reference model system as it is. The worst case scenario of 100% EV adaptation is anlysized with the maximum energy consumed month: January-2016. The voltage and power quality improvements in the distribution network are presented. Further, the economic considerations are analyzed and discussed the energy cost savings that can be achieved through the developed EV and load scheduling in this chapter.

5.1 Initializing the simulation model

The Matlab simulation model is included the distribution network characteristics, forecasted user consumption data during the period of September-2015 to August-2016 and EV characteristics of Nissan leaf to develop the charging strategies. According to the monthly average user consumption, it is observed that January month has the highest user consumption. The results of this chapter is based on the actual power demand and electricity prices in that distribution network area on January month as the worst-case analysis. The SLM and DSM charging strategies will be discussed with the reference case of base load user consumption on January-2016. Further, 100% EV adaptation will be discussed to analysis the impact of EV charging to the distribution network.

The initialization of EV user type, their arrival and departure time using EV user profile (section 3.2.2) for 20 residences are considered as below Table 5.1. All the results on this section will be established using this user characteristics of each residence.

Table 5.1: The initialization of user type, arrival and departure time for each houses based on the user profiles

(where user profile: 1-Normal family,2-Sigle EV user, 3- Unemployed user, 4-Night worker)

House number [C01- C10]		**User profile**	**Arri-val time**	**Depar-ture time**
C01	144500622	2	1600	0700
C02	144500711	1	1600	1900
C03	144500791	1	2200	0600
C04	144500617	1	2200	0600
C05	144500721	3	0000	1100
C06	144500741	4	0700	2000
C07	144500615	1	2200	0600
C08	144500771	2	1600	0700
C09	144500751	3	0000	1100
C10	144500731	3	0000	1100

House number [C11 – C20]		**User profile**	**Arri-val time**	**Depar-ture time**
C11	144502932	1	2200	0600
C12	144500625	2	1600	0700
C13	144500761	2	1600	0700
C14	144500611	1	1600	1900
C15	144500781	4	0700	2000
C16	144590621	3	1400	1800
C17	144500621	2	1600	0700
C18	144503070	2	1600	0700
C19	144503089	1	2200	0600
C20	144500619	1	2200	0600

5.2 Uncoordinated charging Results: Objective 1

The EV uncoordinated charging scenario is the method of charging all connected EVs when users plug in, immediately when they return from their last journey of the day. This scenario serves as the reference case for scheduling new charging strategies: SLM scheduling and DSM scheduling. The uncoordinated charging results for the worst scenario of most-power demanding month: January and all user connected EVs (100% EV adoption) will be presented in section 5.3 and section 5.4 as reference case.

5.3 Coordinated charging Results: Objective 2 (SLM scheduling)

In this section, the results of the suggested coordinated load profile (SLM algorithms in Matlab) will be presented and discussed with the reference case: system as it is before and after plug-in EVs for all 20 residences.

5.3.1 Demand pattern in coordinated charging scenario for 20 residences

The rescheduling process of EV charging mainly depends on the user profile and their possible EV charging time periods (refer table 5.1). The output of Matlab results in this objective demonstrate the new EV charging schedule pattern by shifting charge hours of EVs to minimum power consumption hours by considering low voltage distribution constrains as described in section 4.2.2.

The optimized EV charging schedule for all houses has been plotted with reference cases of base load profile and uncoordinated charging for January-2016 as shown below figures. They consist three comparison curves in a figure under these considerations:

- Black colour curve
    - Base load profile (Only user consumption load without plug in EVs)
- Blue colour curve
    - Uncoordinated load profile (User consumption load with EV charging as soon as plug in to fully charged battery within 3 hours)
- Red colour curve
    - Coordinated load profile (User consumption load with smart scheduling EV charging patterns)

All twenty residences’ hour based power consumption are shown in figures from 5.1 to 5.20. All twenty residences’ new EV charging patterns can be observed in red color curve in below figures and it will be help to increase the power quality, system reliability and distribution network stability as well as cost savings in customer point of view. The figure 5.1 to figure 5.20 can be referred to identify the modifications of smart load management algorithm.

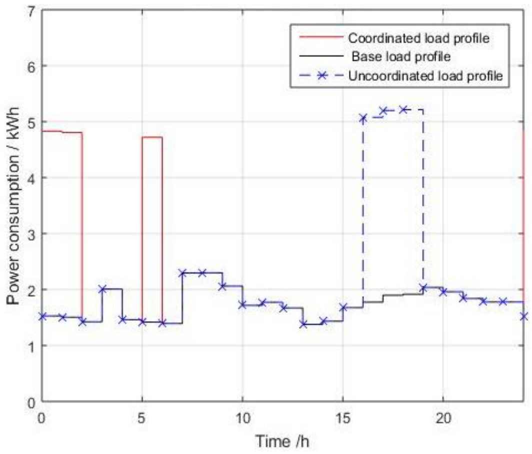


Figure 5.1: Load schedule for house C01

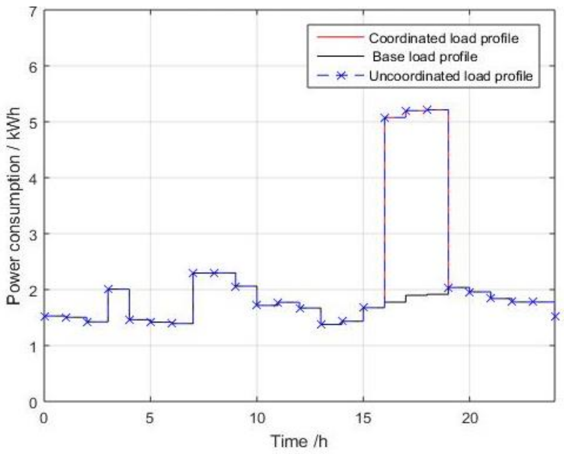


Figure 5.2: Load schedule for house C02

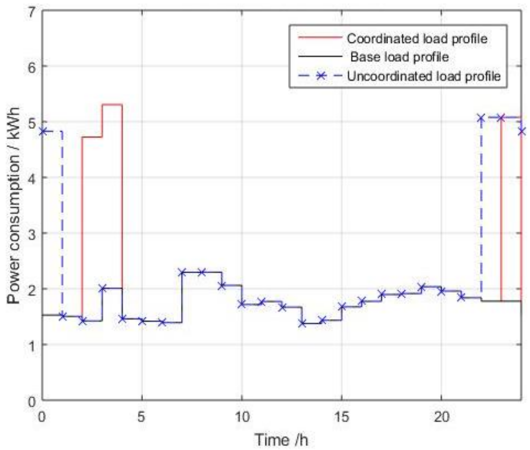


Figure 5.3: Load schedule for house C03

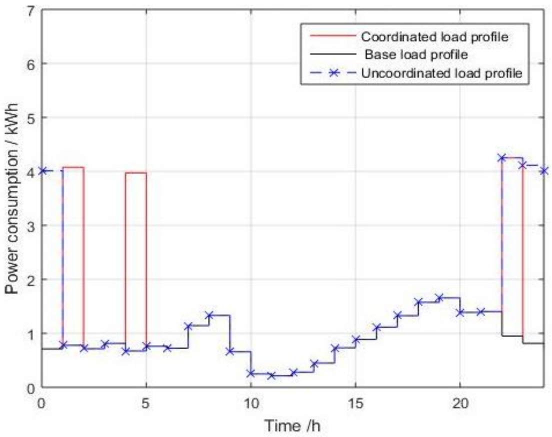


Figure 5.4: Load schedule for house C04

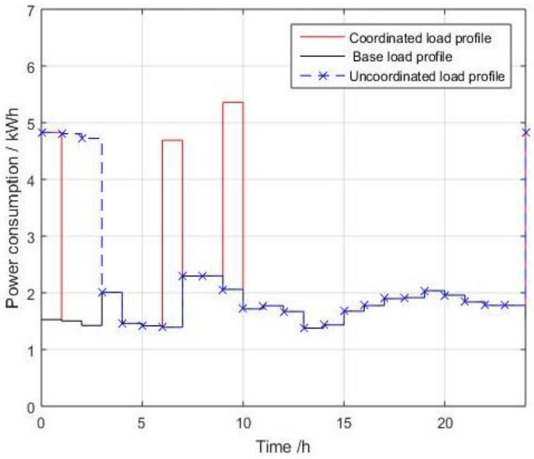


Figure 5.5: Load schedule for house C05

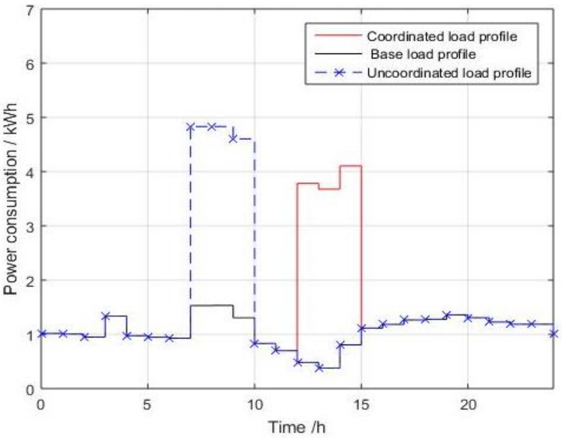


Figure 5.6: Load schedule for house C06

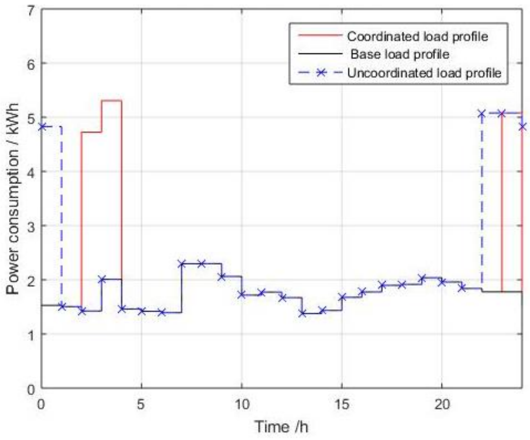


Figure 5.7: Load schedule for house C07

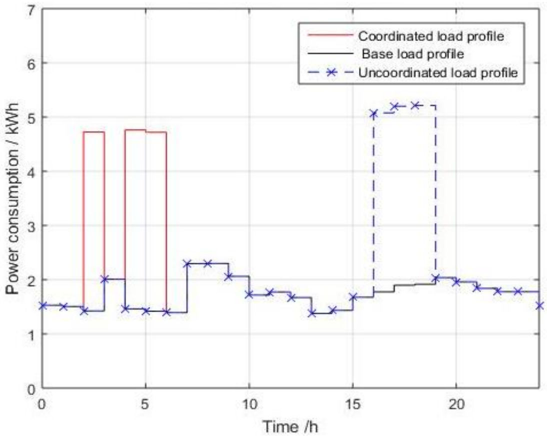


Figure 5.8: Load schedule for house C08

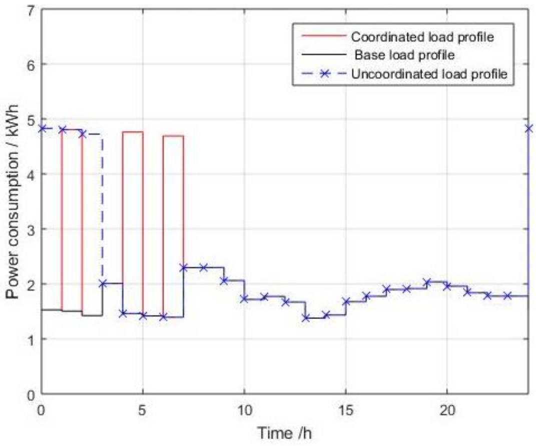


Figure 5.9: Load schedule for house C09

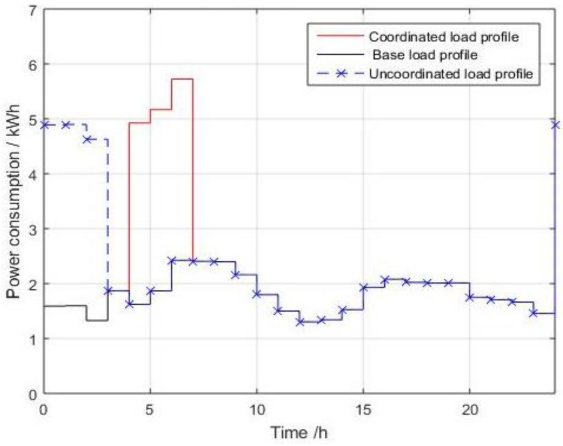


Figure 5.10: Load schedule for house C10

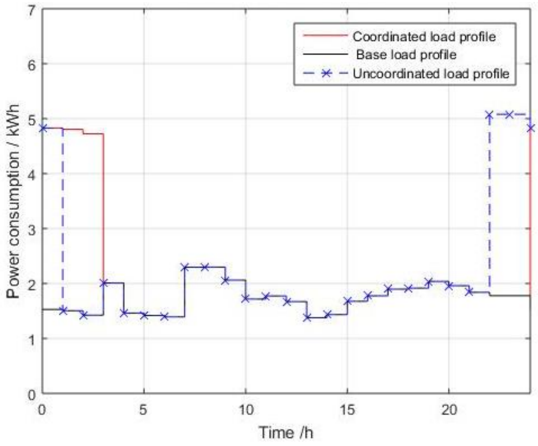


Figure 5.11: Load schedule for house C11

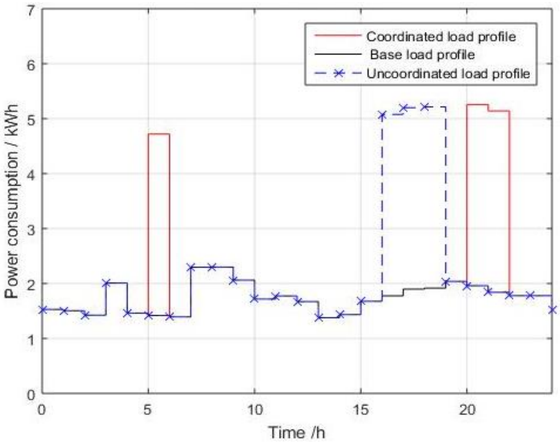


Figure 5.12: Load schedule for house C12

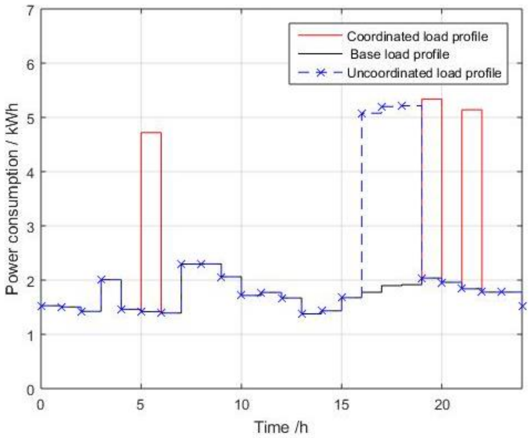


Figure 5.13: Load schedule for house C13

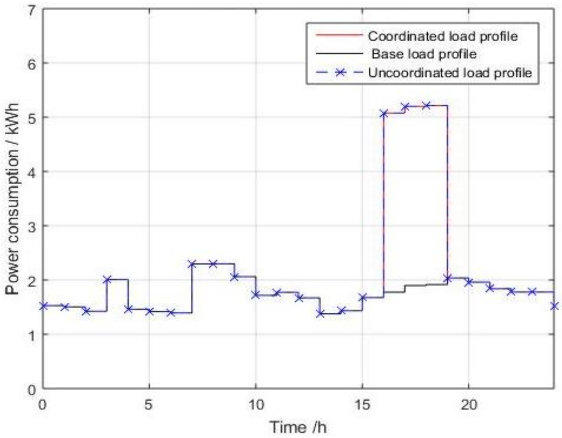


Figure 5.14: Load schedule for house C14

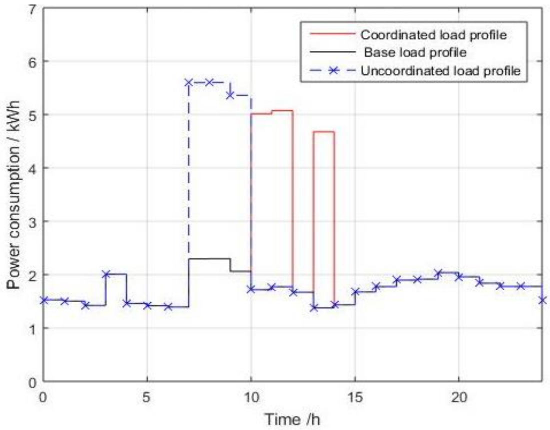


Figure 5.15: Load schedule for house C15

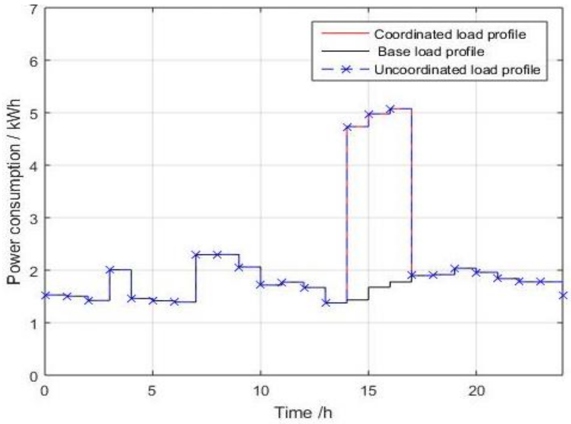


Figure 5.16: Load schedule for house C16

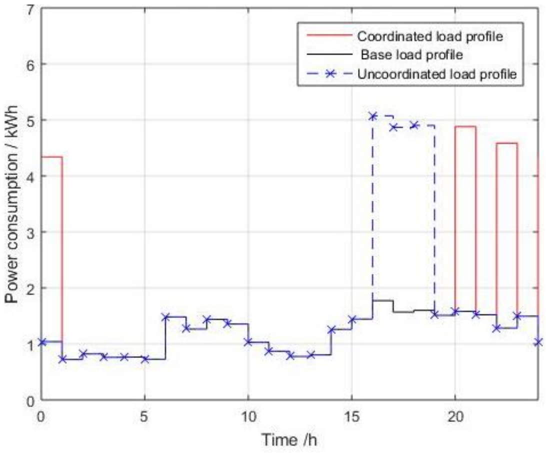


Figure 5.17: Load schedule for house C17

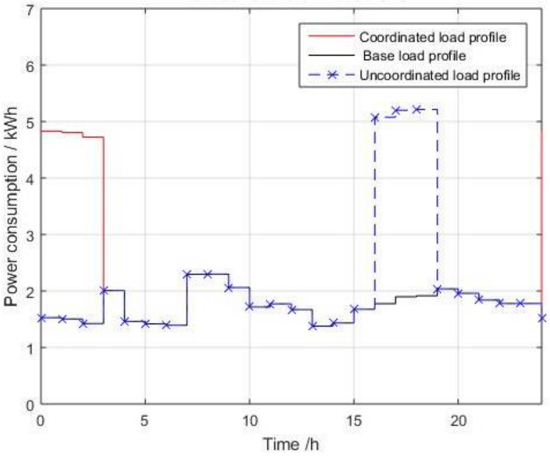


Figure 5.18: Load schedule for house C18

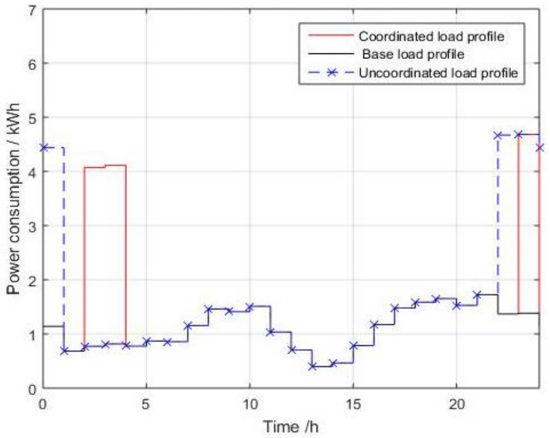


Figure 5.19: Load schedule for house C19

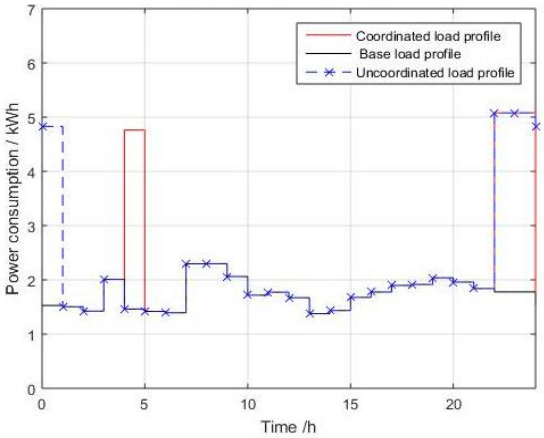


Figure 5.20: Load schedule for house C20

By analyzing these figures, the coordinated charging pattern has rescheduled with uncoordinated charging except figure 5.2, 5.14 and 5.16. These different coordinated charging patterns are developed by considering the current, voltage and power limitations as well as minimum power consumption time slots among the charging period of each users. The developed Matlab simulation model has optimized EV charging slots for each user with their available charging periods.

In addition, coordinated load schedule for house C02 and C14 (see figure 5.2 and 5.14) has coincided with system as it is, due to these users can only charge between that a 3 hour time slot between 16:00 to 19:00.

Further, house C16 has not rescheduled using coordinated charging algorithms as shown in figure 5.16. This user plugs in between 14:00 and 18:00 and charge between 14:00 to 17:00, which is the minimum power consumption and a 3 hour time slot that can be generated and satisfied all three constrains.

5.3.2 Total transformer loading in coordinated charging scenario

According to the results described in section 5.3.1, the coordinated charging algorithm is very useful to shift the loads to optimal charging hours with minimum power consumption requirements by considering constrains of overvoltage, overcurrent and transformer loading. When considering all residences are plugged in EVs to the distribution network, the system transformer can not be overloaded (equation 3.8). Total transformer power demand in 24 hour period in January month can be plotted as below figure 5.21 (assume that cable power losses are very small). It indicates three main curves for base load, uncoordinated EV charging and coordinated EV charging to identify how transformer loading on different charging strategies. It shows that smart charging schedule algorithms have been minimized the load at high power consumption time and shift the load to low power consumption time.

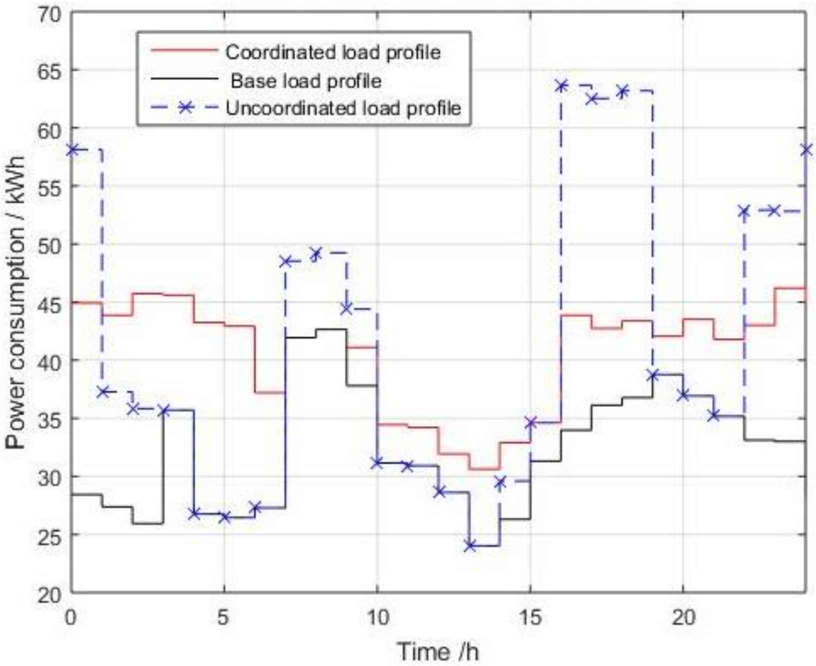


Figure 5.21: Total load distribution of all connected residences for coordinated, uncoordinated and base load profile (Transformer loading)

According to the figure 5.21, the maximum power consumption is between 16:00 to 17:00. It shows that the uncoordinated charging maximum power demand is 63.67 kW and coordinated charging maximum power demand is 43.87 kW. In this project, the distribution transformer can supply the maximum power of 135kW. Then transformer overloading constrain is not affected any of charging strategies if there is only 20 EVs connected. Moreover, the transformer demand loading at uncoordinated condition is 47% and at coordinated charging is 32%. The 15% percentage of peak power reduction can be achieved using this developed coordinated charging scenario.

5.3.3 Voltage pattern in coordinated charging scenario

The voltage at the residence can be changed with the increment of user consumption and it may be effected to the distribution network quality. The minimum and maximum voltage variations at twenty residences are attached in Appendix A: Table A4. According to that table, the minimum voltage is at C15 house. The impact of the EV demand on a 24 hour period on the voltages at residence 15, in the case of coordinated and uncoordinated charging is shown in figure 5.22.

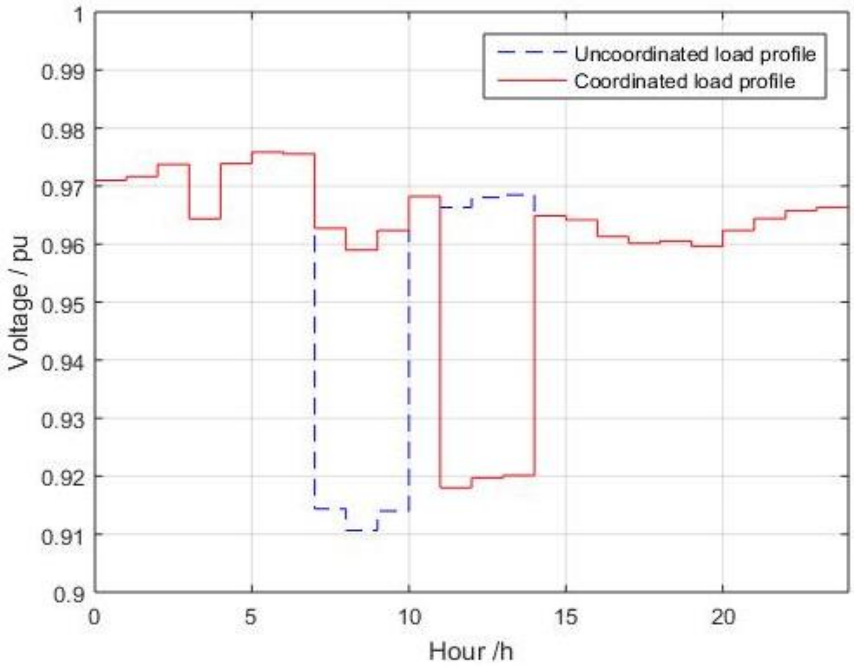


Figure 5.22: The effect of uncoordinated and coordinated charging scenario on the voltage at residence C15

According to the figure 5.22, it is clear that the EV causes a big drop in the voltages. The lowest voltage in the uncoordinated charging is 0.9106 pu, and the lowest voltage in the coordinated charging is 0.918 pu. The voltage constrain is between 0.9 pu to 1.1 pu and it is not effected in both cases. In coordinated charging, it will help to minimize the reduction of voltage drop as well as shift to lower demand time period.

5.4 DSM Results: Objective 3

In this section, the DSM results are presented and discussed with the reference case of uncoordinated EV charging load for all 20 residences. It has developed the new EV charging pattern as well as shifted noncritical loads from peak hours by checking system constrains and fixed demand limit. The hour based fixed demand limit has applied to all residences (with and without BIPVs) connected to the low voltage distribution network.

5.4.1 Demand pattern in DSM scenario for 20 residences

The output results of this objective is based on one of the DSM load shaping techniques: load shifting as described in section 2.4.1 theory part. The rescheduling process of EV charging mainly depends on the user profile and their possible EV charging time periods (refer table 5.1) and EVs can be shifted to minimum power consumption hours. The rescheduling process of noncritical loads can be shifted from peak hours to minimize the peak demands. Further, the developed demand pattern is checked with demand limit to reduce overloading of the utility and enhance the system stability.

The DSM schedule for all houses are plotted with reference cases of demand limit, base load profile and uncoordinated charging for January-2016 as shown below figures. They consist four comparison curves in a figure under these considerations:

- Black colour curve
    - Base load profile (Only user consumption load without plug in EVs)
- Blue colour curve
    - Uncoordinated load profile (User consumption load with EV charging as soon as plug in to fully charged battery within 3 hours)
- Red colour curve
    - DSM load profile (User consumption load with rescheduling EV charging patterns and noncritical load connection patterns)
- Green colour curve
    - Demand limit to reduce impact on distribution network

All twenty residences' hour based power consumption are shown in figures from 5.23 to 5.42. In this project, it is used two different noncritical load shifting method for the residences without BIPV and for the residences with BIPV. These two different methods are described below in DSM scheduling method.

- **DSM Load scheduling for without BIPV residences**

There are 15 residences without BIPV in this distribution network. The EVs has shifted to minimum power consumption hours in available charging period that satisfy all constrains. The process of shifting noncritical load is calculated noncritical load summation in peak demand periods (07:00-10:00 and 15:00-20:00) and shifted to off-peak time periods (00:00-07:00 and 20:00-24:00). Moreover, the demand limit has been checked to identify the best load scheduling method for houses without BIPV. According to below figures, there are new DSM load schedule pattern for all the residences.

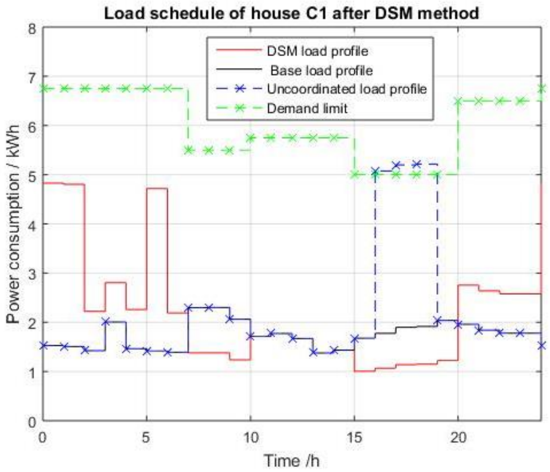


Figure 5.23: New load profile of house C01

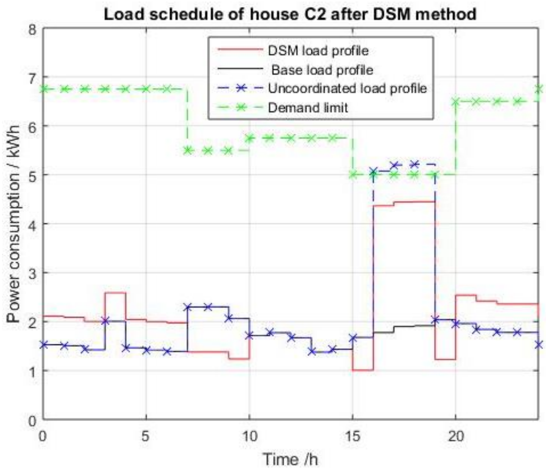


Figure 5.24: New load profile of house C02

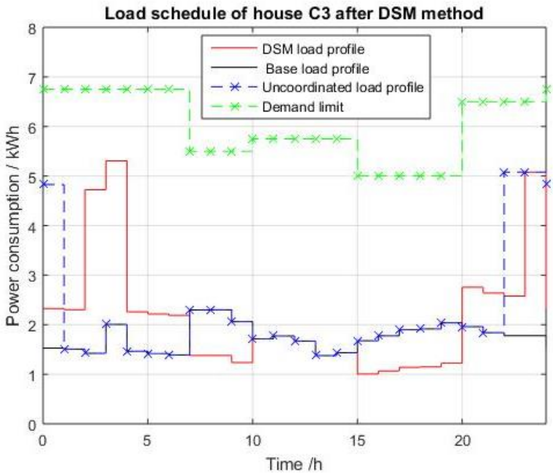


Figure 5.25: New load profile of house C03

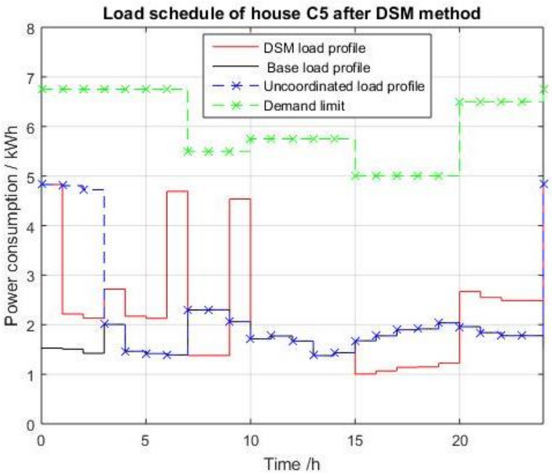


Figure 5.26: New load profile of house C05

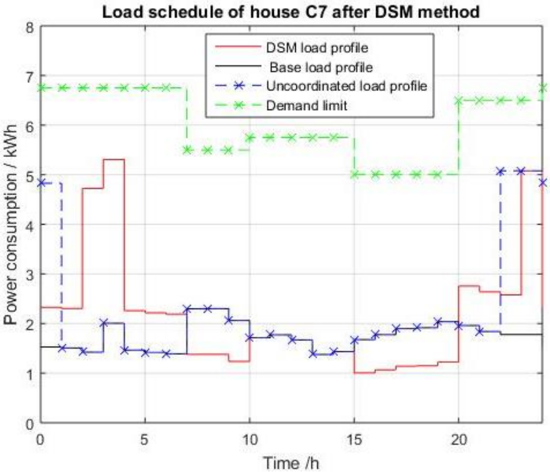


Figure 5.27: New load profile of house C07

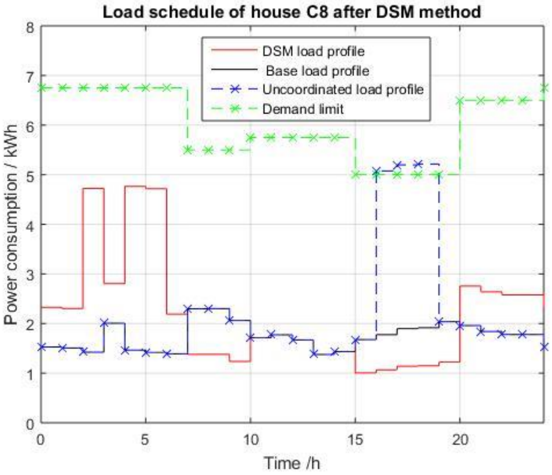


Figure 5.28: New load profile of house C08

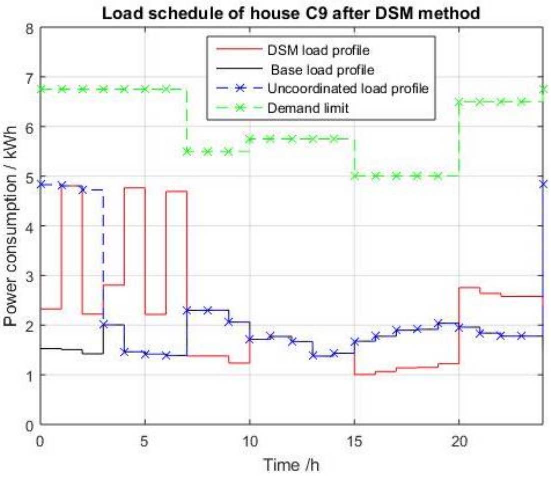


Figure 5.29: New load profile of house C09

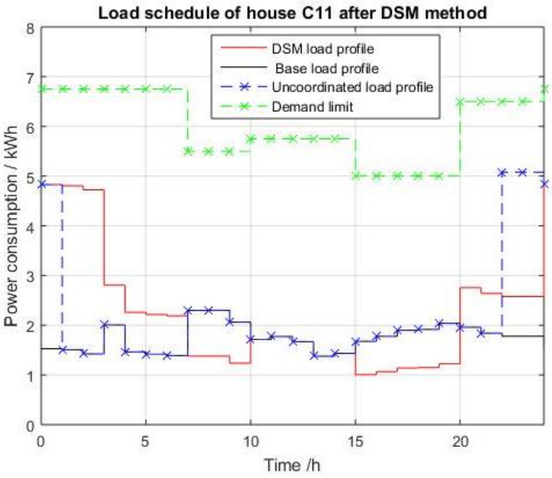


Figure 5.30: New load profile of house C11

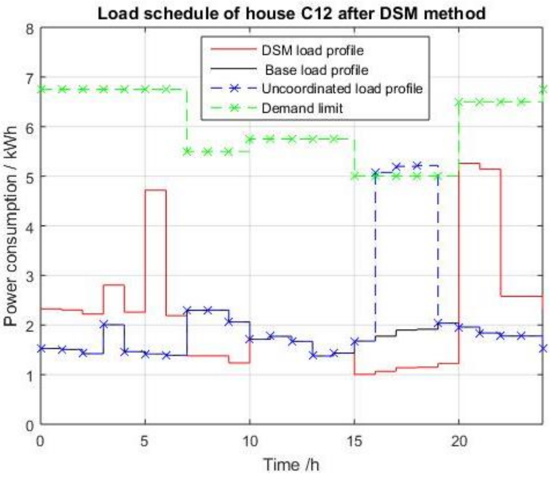


Figure 5.31: New load profile of house C12

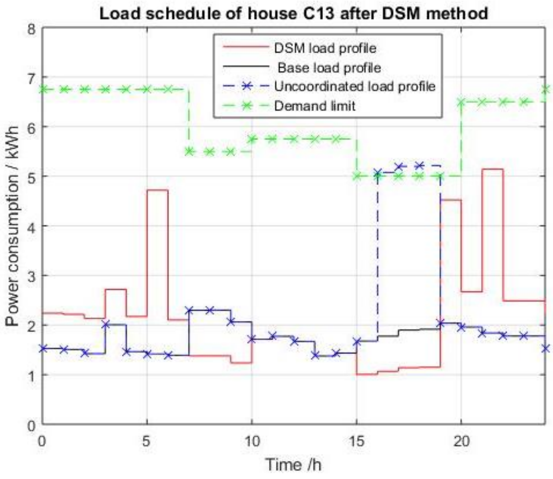


Figure 5.32: New load profile of house C13

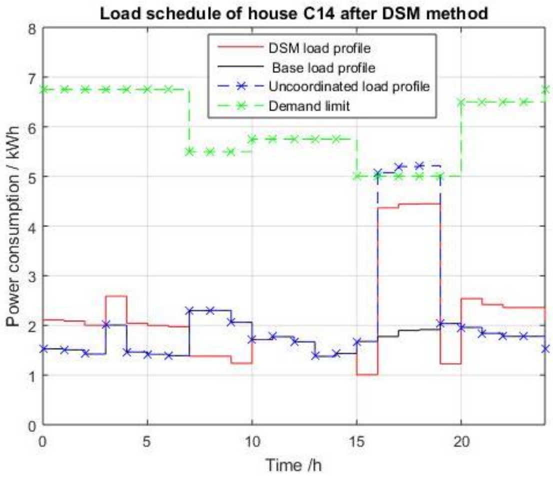


Figure 5.33: New load profile of house C14

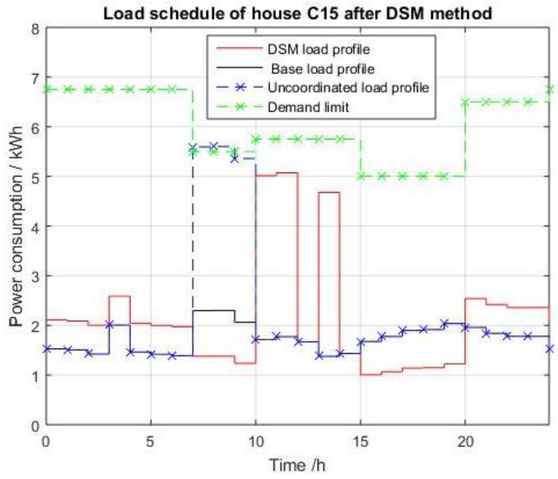


Figure 5.34: New load profile of house C15

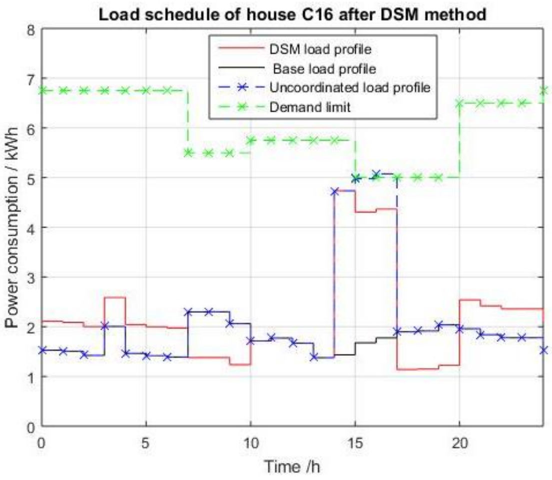


Figure 5.35: New load profile of house C16

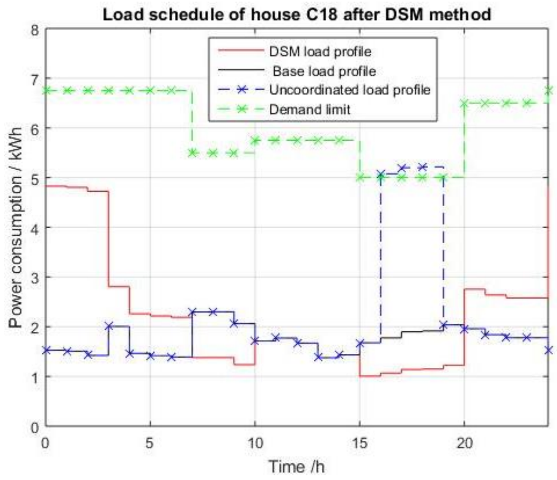


Figure 5.36: New load profile of house C18

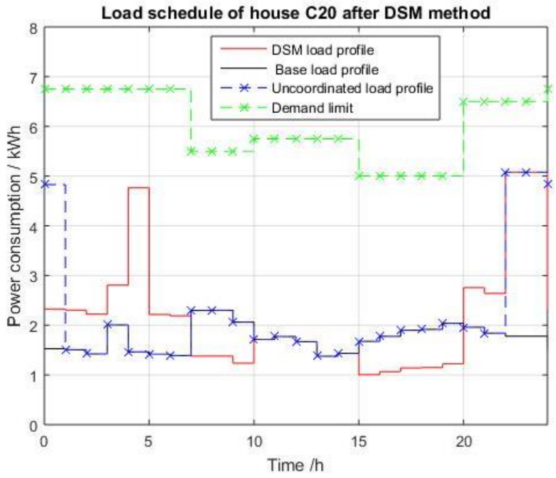


Figure 5.37: New load profile of house C20

According to the uncoordinated load profile in above figures, the residences of C01, C02, C08, C12, C13, C14 and C15 had been exceeded the demand limit at the peak time period. By using DSM load scheduling, the new load profiles of these houses had not been exceedes the demand limit. Because EVs are shifted to minimum power consumption period as well as noncritical loads are shifted to off-peak time periods except the residences of C02, C14 and C15. The residence C02 and C14 have not shifted EVs due to the user can only charge between that 16:00 to 19:00, 3 hour time slot. Hence, the noncritical loads in peak hours are shifted to off-peak hours in these two residences. Hence, the demand limit has not been exceeded after using DSM scheduling. Further, the figure 5.35 is shown that EV had not rescheduled and noncritical loads had shifted from peak time period to off-time period in residence C16.

Moreover, it has been shown that the residences C03, C05, C07, C09, C11 and C20 had not been exceeded demand limit at the uncoordinated charging method. However, in this DSM load scheduling method, it had been developed new load scheduling pattern for these houses to shift EVs to minimum power consumption time slots and to shift noncritical loads in peak hours to off-peak time periods.

The overall DSM scheduling will be help to increase the power quality, distribution network stability as well as cost savings due to minimizing peak demands in all residences.

- **DSM Load scheduling for with BIPV residences**

There are five residences with BIPV in this distribution network. In this DSM scheduling, EVs are shifted to minimum power consumption hours in available charging period that satisfy all constrains. The process of shifting noncritical load is calculated noncritical load summation in peak demand periods (07:00-10:00 and 15:00-20:00) and shifted to PV power generation time periods (10:00-15:00) in summer period as well as shifted to off-peak time periods (00:00-07:00 and 20:00-24:00) in winter period of the year. Moreover, the demand limit has been checked to identify the best load scheduling method for houses with BIPV. The new DSM load scheduling is shown in below.

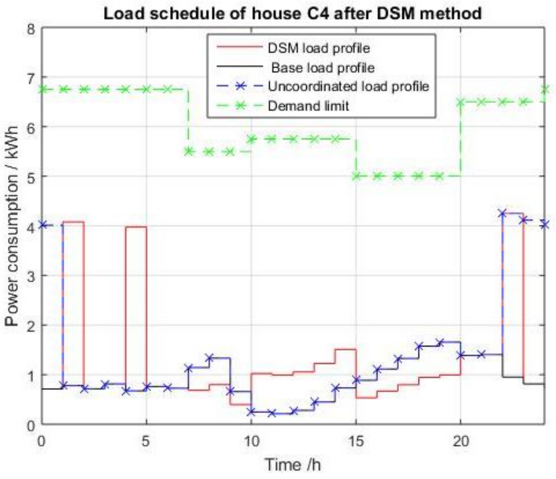


Figure 5.38: New load profile of house C04

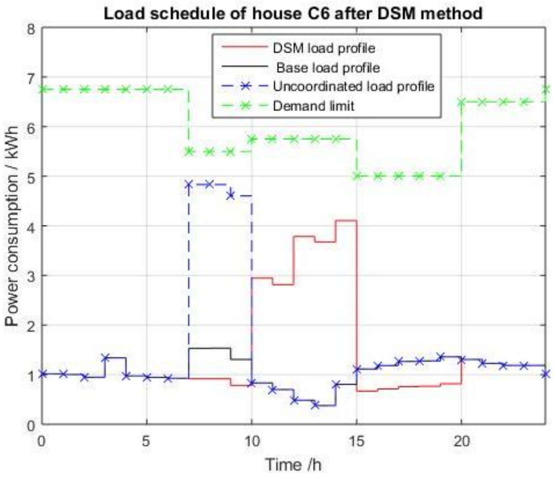


Figure 5.39: New load profile of house C06

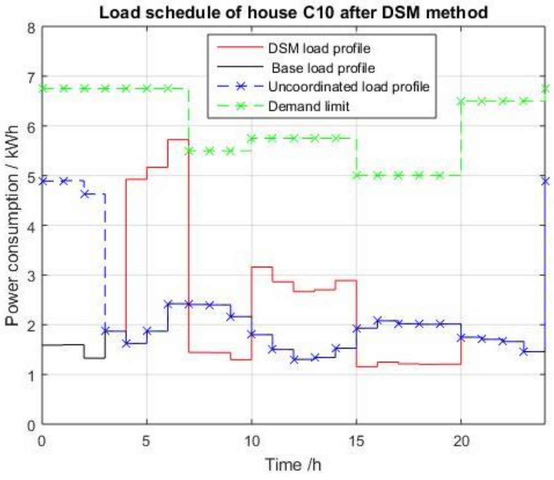


Figure 5.40: New load profile of house C10

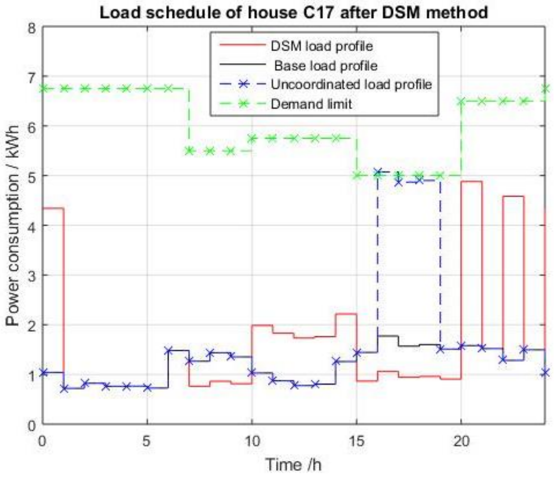


Figure 5.41: New load profile of house C17

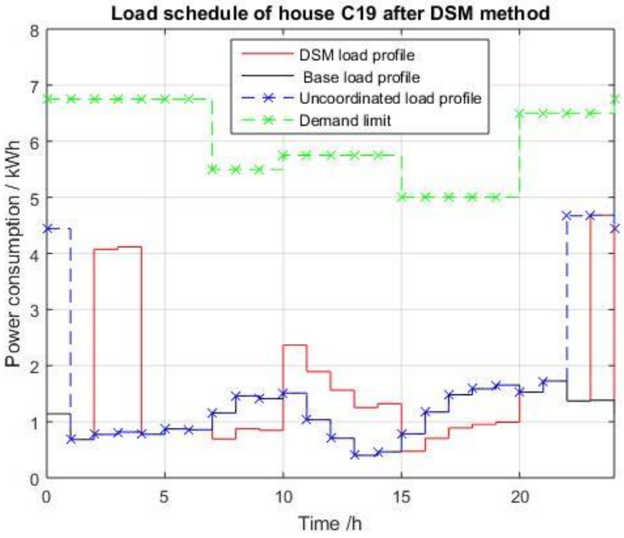


Figure 5.42: New load profile of house C19

According to the new load profile of BIPV residences, there are new DSM load schedule pattern for all BIPV residences. The residence C17 had been exceeded the demand limit in uncoordinated charging and it has been shown that after DSM load scheduling, the demand limit has not been exceeded. The other four houses had not been exceeded demand limit under uncoordinated charging. However, the DSM load scheduling have generated new load profile pattern that has been shifted EV to minimum power consumption hours as well as noncritical loads in peak period has been shifted to PV generation time periods. By shifting loads as DSM load shifting method, it will help the system stability by reducing large peak demands.

5.4.2 Total transformer loading in DSM scenario

According to the results described in section 5.4.1, the DSM load scheduling is useful to shift EVs and noncritical loads to minimize the peak period demand limits, transformer overloading, overvoltage and overcurrent. The analysis of transformer load demand in 24 hour period in January month can be plotted as shown in figure 5.43. It is indicated that three main curves for base load, uncoordinated EV charging and DSM load profile to identify how transformer loading on different charging strategies.

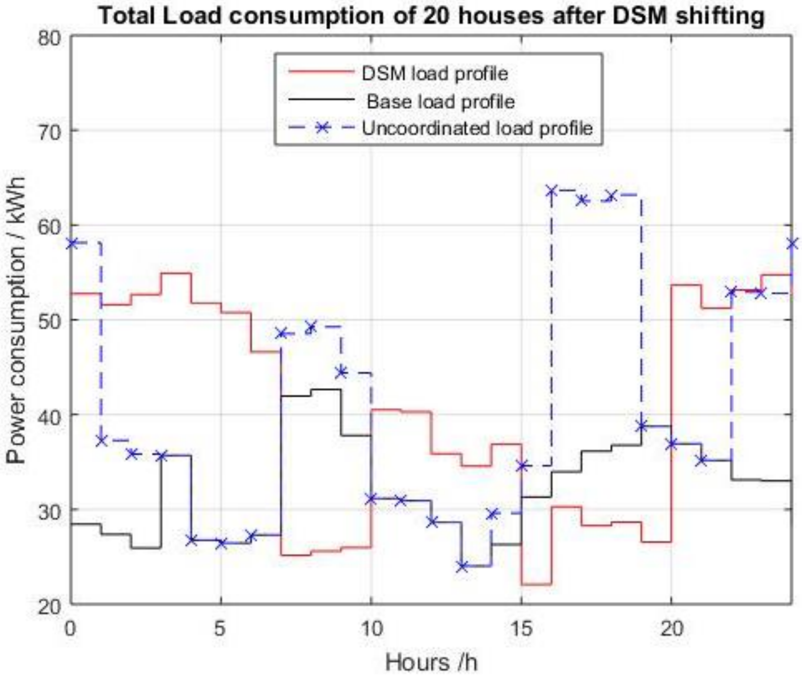


Figure 5.43: Total load distribution of all connected residences for DSM, uncoordinated and base load profile (Transformer loading)

In this project, the distribution transformer can supply the maximum power of 135kW. As shown in above figure, the transformer maximum power has not been exceeded and the transformer overloading constrain has not affected any of charging strategies if there is only 20 EVs. According to the figure 5.43, the maximum power consumption is between 16:00 to 17:00. It shows that the uncoordinated charging maximum power demand has been 63.67 kW and maximum power demand of DSM load scheduling has been 30 kW in that time period.

Moreover, it has shown that the transformer demand loading at uncoordinated condition was 47% and at DSM condition was 22% at the maximum peak time period. The 25% percentage of peak power reduction can be achieved using this developed DSM load shifting pattern. It shows that DSM scheduling algorithms had minimized the load at high power consumption time and shift the load to low power consumption time.

5.4.3 Voltage pattern in DSM scenario

The voltage at the residence determines on the load flow calculations in the distribution network. The minimum and maximum voltage variations at all residences are attached in Appendix A: Table A5. According to that table, the minimum voltage is at C15 house. The impact on the voltages at residence 15, in the case of DSM scenario and uncoordinated charging is shown in figure 5.44. When comparing Apendix A: Table A4 and Table A5, it seems to be same voltage maximum and minimum values. Nevertheless, its voltage variation is different as shown in figure 5.22 and figure 5.44.

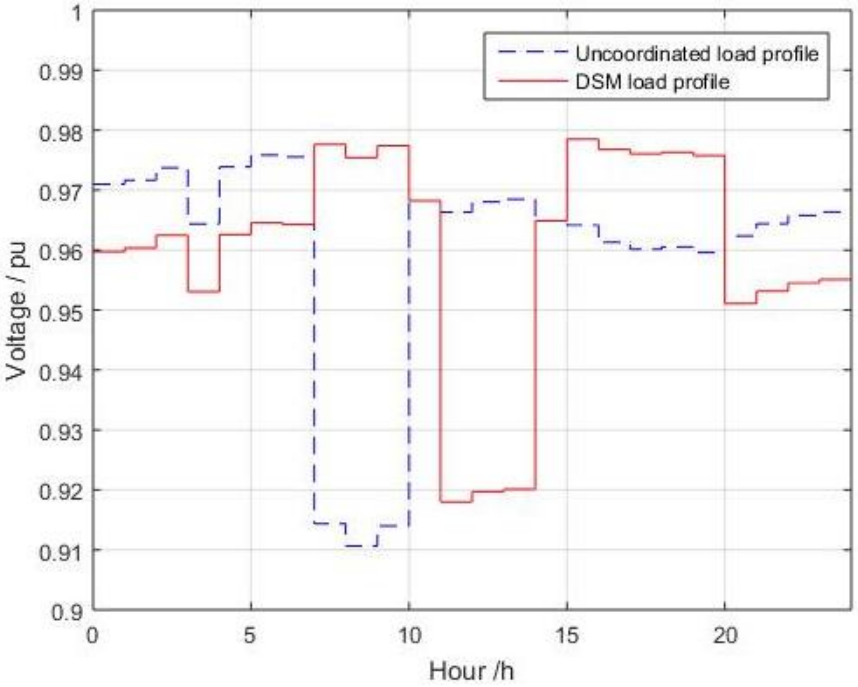


Figure 5.44: The effect of uncoordinated and DSM load shifting scenario on the voltage at residence C15

According to the figure 5.44, it is clear that the EV causes a big drop in the voltages. The voltage limitation is between 0.9 pu to 1.1 pu and it is not effected in both cases. The lowest voltage in the uncoordinated charging is 0.9106 pu, and the lowest voltage in the DSM scenario is 0.918 pu. In DSM method, it will help to minimize the reduction of voltage drop as well as shift to lower demand time period.

5.5 Economic Analysis

It has been observed that not only the system power quality and stability has been improved, but also energy cost saving can be obtained by using electricity bill calculation (equation 4.1) under TOU values in table 4.1. The annual electricity bill for the three main objectives and profit for SLM and DSM load scheduling are calculated and tabulated for all 20 residences as table 5.2.

Table 5.2 : Annual electricity bill for all residences and cost savings for the uncoordinated, SLM and DSM scenario

House No:	**Cost of Uncoordinated charging scenario (Nok)**	**Cost of SLM charging scenario (Nok)**	**Cost of DSM load scheduling (Nok)**	**Profit from SLM (Nok)**	**Profit from DSM (Nok)**
C01	5157.60	4880.40	4653.32	277.20	504.28
C02	5157.60	5157.60	4927.56	0	230.04
C03	4771.50	4731.90	4504.78	39.60	266.72
C04	944.62	905.02	890.24	39.60	54.38
C05	4712.10	4670.50	4644.27	41.60	67.83
C06	1670.07	1632.94	1631.87	37.13	38.20
C07	4771.50	4746.75	4516.32	24.75	255.18
C08	5157.60	4959.60	4733.04	198.00	424.56
C09	4712.10	4700.20	4673.20	11.90	38.90
C10	1607.93	1547.53	1540.05	60.40	67.88
C11	4771.50	4712.10	4489.51	59.40	281.99
C12	5157.60	4952.17	4721.73	205.43	435.87
C13	5157.60	4944.75	4713.34	212.85	444.26
C14	5157.60	5147.60	4927.56	10.00	230.04
C15	5068.50	4999.20	4769.16	69.3	299.34
C16	5098.20	5098.20	4868.16	0.00	230.04
C17	1645.48	1415.30	1397.70	230.18	247.78
C18	5157.60	4801.20	4576.90	356.40	580.70
C19	865.20	833.02	841.77	32.18	23.43
C20	4771.50	4731.90	4504.79	39.60	266.71
Total	81513.40	79567.88	76525.27	1945.52	4988.13

According to the above table, the DSM method can be obtained minimum expenses and the uncoordinated charging scenario can be observed the maximum electricity cost. Further, the annual profit for all residences from SLM and DSM is shown in the table 5.2. It has been analyzed that evaluation of load patterns with DSM for all the residences can be achieved the profit compared to the system as it is.

Chapter 6

6 Conclusion and Future improvements

This chapter concludes the summarization of the objectives with the results. Further, it will presented new research directions as the future improvements.

6.1 Conclusion

The main objective of this thesis is the evaluation of the EV charging pattern with DSM method in the distribution network residences with and without BIPV system. A study of the vehicle owners' willingness to participate in grid services would strengthen the analysis of both smart charging and DSM charging presented in this thesis.

The DSM load pattern was developed using two main reference objectives: system as it is (uncoordinated charging) and SLM (coordinated) charging scenario. In the system as it scenario, the EV charging remains completely uncontrollable and the profile of the charging demand is highly dependent on the user arrival time. According to the observed data in between Sep-2015 to Aug-2017, the smart controlling of EV charging pattern has been developed. Further, DSM load shifting technique has used to implement new EV charging patterns and noncritical load scheduling patterns for residences with and without BIPV. The developed SLM charging scenario and DSM load scheduling are studied with system as it to identify the load consumption for 24 hour period on maximum consumption month, January. As well as the developed load management techniques are analyzed with the transformer overloading, voltage variations to identify the system power quality and reliability with EV charging scenarios. Moreover, the cost saving through these DSM load scheduling is examined for all type of residences.

In this thesis, all twenty residences are connected their EVs as soon as they arrive to house. January month is concluded as worst case scenario and developed the all charging patterns using SLM and DSM scheduling with their actual user consumption data. The minimum power consumption time slots are used to implement the SLM scheduling. It is important to manage the noncritical domestic loads in order to reduce the peak demand of the household as well as shift EVs on peak demand periods. This load shifting technique is used to implement DSM load scheduling by considering effect of PV generations.

The evaluation of these two objectives taken "system as it is" objective as the reference case and identify transformer overloading, voltage fluctuations, demand limit exceeding as well as cost savings. According to the user profile in this distribution network, majority of the vehicles return from the last journey between 16:00 to 17:00. With uncoordinated EV charging, this leads to a high peak in demand. The coordinated EV charging pattern is reduced peak power reduction of that period in 15% and DSM load scheduling gives 25% of transformer peak power reduction. The power quality improvement through the EV charging patterns with DSM can be identified. It is observed that BIPV residences can be shifted noncritical loads to PV generation time periods and it reduces the total power taken from utility and it will reduce the transformer loading. It could be noted that using proposed smart charging algorithm and

DSM load scheduling resulted in a reduction in the peak demand of distribution system and it is benefited to reduce the voltage variation to the each residence.

In this distribution network, C15 residence has the minimum voltage value due to the far away from the transformer and the calculated value of residence voltage. According to that C15 house, it has been identified that the reduction of voltage variation at the peak periods. The EV charging patterns with DSM load shifting techniques is enhanced the system power quality as well as system stability compared to uncoordinated charging.

The economic analysis showed that the total demand in the distribution network is flatten and the moving EV charging and noncritical loads to times of the low electricity price periods .It showed that there was annual cost savings for each residences in DSM method and total profit for all twenty houses was calculated as 4988 NOK. Same as the annual total profit for all residences in the SLM method was 1945 NOK. The BIPV residence are useful to shift in peak loads to PV generation time and the evaluation of EV and noncritical load pattern in DSM method improve the profit maximization.

6.2 Future improvements

The project can be continued to find out more reasonable load models to use in the DSM algorithms. By using collected data over years can be used to find out more sophisticated models to forecast future loads. Then a real time load scheduling can be implemented. This project is developed through one EV type of Nissan leaf and the SOC value of 0.66. A further study with different EVs with different battery SOC can be implemented. The number of EV consumption can be increased for residences to identify the impact of increasing EV charging to distribution network.

The simulations of the scenarios used in this study are for a 24-hour period and monthly average load. As a future improvements, it can compare the effect of these charging scenarios for different days during the year, as there are some changes in daily. And the minute based analysis as 15-minute periods can be done to develop for more accuracy EV charging and noncritical load shifting. The DSM scheduling was used noncritical loads with 40% from the total load demand and this can be specify to shift by relevant power equipment to the significant time period of the day.

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▪ Appendix A : Data Tables

Table A1: Ground cable specifications from transformer to residential in distribution network

Ground Cable (0.23kV)							
Node 1	Node 2	Cable type	Length (km)	Resistance(ohm)	Reactance (ohm)	Capacity to ground (uF)	Max. current(A)
80955-A1	144503089	TFXP 4X95 AL	0.135	0.0432	0.0101	0.0770	220
80955-A1	144503070	PFSP 3X450 AL	0.103	0.0661	0.0103	0.0690	150
80955T1	80955-0	TFXP 4X240 AL	0.009	0.0011	0.0006	0.0058	435
80955T1	80955-0A	TFXP 4X240 AL	0.008	0.0010	0.0006	0.0051	435
80955-29	144502932	TFXP 4X50 AL	0.041	0.0263	0.0032	0.0217	150
80955-4	80955-5	PFSP 3X50 AL	0.031	0.0199	0.0024	0.0164	150

Table A2: Overhead line cable specifications from transformer to residential in distribution network

Overload line cable (0.23kV)						
Node 1	Node 2	Type	Length(km)	Resistance (ohm)	Reactance (ohm)	Max. operating current (A)
80955-1	80955-16	EX 3X95 AL	0.0980	0.0314	0.0074	280
80955-16	80955-17	EX 3X25 AL	0.0500	0.0600	0.0041	115
80955-17	144500615	EX 3X25 AL	0.0130	0.0156	0.0011	115
80955-16	80955-19	EX 3X50 AL	0.0380	0.0244	0.0029	180
80955-19	80955-22	EX 3X50 AL	0.1330	0.0853	0.0102	180
80955-22	80955-23	EX 3X25 AL	0.0370	0.0444	0.0030	115
80955-23	80955-A1	EX 3X25 AL	0.0030	0.0036	0.0002	115
80955-23	80955-24	EX 3X25 AL	0.0460	0.0552	0.0038	115
80955-24	144500619	EX 3X25 AL	0.0060	0.0072	0.0005	115
80955-22	80955-26	EX 3X25 AL	0.0860	0.1032	0.0071	115
80955-26	144500621	EX 3X25 AL	0.0420	0.0504	0.0034	115
80955-26	144590621	EX 3X25 AL	0.0250	0.0300	0.0021	115
80955-19	144500611	EX 3X25 AL	0.0100	0.0120	0.0008	115
80955-1	80955-18	EX 2X25 AL	0.1770	0.2124	0.0145	115
80955-0	80955-1	EX 3X95 AL	0.0300	0.0096	0.0023	280
80955-0A	80955-1A	EX 3X95 AL	0.0300	0.0096	0.0023	280
80955-1A	80955-9	EX 3X95 AL	0.1540	0.0493	0.0117	280
80955-9	80955-10	EX 3X95 AL	0.0380	0.0122	0.0029	280
80955-10	80955-14	EX 3X50 AL	0.2040	0.1308	0.0157	180
80955-14	144500625	EX 3X25 AL	0.0110	0.0132	0.0009	115
80955-14	80955-29	EX 3X50 AL	0.0350	0.0224	0.0027	180
80955-9	144500617	EX 3X25 AL	0.0180	0.0216	0.0015	115
80955-1A	80955-4	EX 3X50 AL	0.1200	0.0769	0.0092	180
80955-5	144500622	EX 3X25 AL	0.1570	0.1884	0.0129	115
80955-29	144500731	EX 3X25 AL	0.0420	0.0266	0.0033	115
80955-1	144500771	EX 3X25 AL	0.0018	0.0216	0.0024	115
80955-18	144500751	EX 3X25 AL	0.0016	0.0192	0.0013	115
80955-17	144500741	EX 3X25 AL	0.0012	0.0144	0.0010	115
80955-26	144500781	EX 3X25 AL	0.0044	0.0528	0.0036	115
80955-19	144500761	EX 3X25 AL	0.0021	0.0300	0.0021	115
80955-9	144500721	EX 3X25 AL	0.0017	0.0227	0.0017	115
80955-4	144500791	EX 3X25 AL	0.0268	0.3216	0.0220	115
80955-5	144500711	EX 3X25 AL	0.0129	0.1884	0.0129	115

Table A3 The actual hourly based electricity price values from Sep-2015 to August-2016 (all values are in Nok/MWh) from Elstop prices in Nord Pool

Hour	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	June-16	July-16	Aug-16
00.00	210	268	316	272	197	164	190	194	200	225	223	201
01.00	205	264	313	269	191	159	186	188	189	217	218	194
02.00	201	261	308	265	188	157	180	186	181	209	212	189
03.00	197	261	305	264	186	157	184	184	176	204	207	185
04.00	198	263	304	264	186	161	187	187	179	204	203	184
05.00	208	270	308	266	194	167	194	195	192	212	207	188
06.00	213	276	315	271	211	176	200	202	205	220	212	196
07.00	217	281	326	277	255	212	215	215	224	226	217	202
08.00	219	284	342	281	299	234	230	230	233	231	221	206
09.00	220	285	350	285	298	220	223	226	232	232	225	208
10.00	220	284	348	285	294	207	214	218	228	232	226	210
11.00	220	283	346	284	289	196	209	212	223	231	225	208
12.00	219	282	343	284	278	188	205	208	219	231	225	207
13.00	218	281	342	283	274	185	202	205	216	230	223	205
14.00	216	279	341	283	266	180	200	203	214	229	220	202
15.00	216	279	341	283	267	180	199	201	212	227	218	201
16.00	217	280	341	284	282	182	199	201	211	228	218	203
17.00	219	283	354	286	326	193	205	204	214	230	222	205
18.00	220	284	364	287	324	199	212	207	216	230	224	206
19.00	221	285	357	286	281	189	210	209	219	231	225	206
20.00	221	284	345	284	245	182	207	211	218	231	226	207
21.00	221	282	337	282	223	175	202	211	219	230	225	207
22.00	219	279	331	281	209	170	197	206	218	230	224	206
23.00	213	272	326	277	198	164	191	200	209	228	221	202

Table A4: Minimum and Maximum Voltage at all the residences before and after shifting EVs(SLM)

House no:	**Uncoordinated Charging (Obj 2)**		**Coordinated charging (Obj 3)**	
	Minimum Voltage	**Maximum Voltage**	**Minimum Voltage**	**Maximum Voltage**
C01	229.9068	235.7825	230.4806	235.757
C02	230.4583	235.9336	230.4583	235.9336
C03	227.5712	234.9463	227.3914	234.9463
C04	236.0849	237.6693	236.0849	237.6693
C05	235.9229	237.3507	235.9229	237.3507
C06	235.124	237.3874	235.409	237.3874
C07	234.9321	237.1017	234.8792	237.1017
C08	237.087	237.7498	237.2279	237.747
C09	232.2308	236.1965	231.5852	236.1965
C10	232.8053	236.4399	232.2415	236.5445
C11	231.952	236.229	232.3804	236.229
C12	231.9088	236.331	232.2055	236.3118
C13	235.2791	237.2545	235.3485	237.2459
C14	235.7669	237.3881	235.7669	237.3881
C15	216.732	232.2464	218.4814	232.2464
C16	230.2297	235.8419	230.2297	235.8419
C17	229.9193	235.829	230.3978	235.8175
C18	230.5693	235.964	231.5394	235.9406
C19	232.2661	237.0591	232.2661	237.0591
C20	231.2992	236.0379	231.7233	236.0379

Table A5: Minimum and Maximum Voltage at all the residences uncoordinated scenario and DSM load shifting

House no:	**Uncoordinated Charging (Obj 2)**		**Coordinated charging (Obj 3)**	
	Minimum Voltage	**Maximum Voltage**	**Minimum Voltage**	**Maximum Voltage**
C01	229.9068	235.7825	230.4806	235.757
C02	230.4583	235.9336	230.4583	235.9336
C03	227.5712	234.9463	227.3914	234.9463
C04	236.0849	237.6693	236.0849	237.6693
C05	235.9229	237.3507	235.9229	237.3507
C06	235.124	237.3874	235.409	237.3874
C07	234.9321	237.1017	234.8792	237.1017
C08	237.087	237.7498	237.2279	237.747
C09	232.2308	236.1965	231.5852	236.1965
C10	232.8053	236.4399	232.2415	236.5445
C11	231.952	236.229	232.3804	236.229
C12	231.9088	236.331	232.2055	236.3118
C13	235.2791	237.2545	235.3485	237.2459
C14	235.7669	237.3881	235.7669	237.3881
C15	216.732	232.2464	218.4814	232.2464
C16	230.2297	235.8419	230.2297	235.8419
C17	229.9193	235.829	230.3978	235.8175
C18	230.5693	235.964	231.5394	235.9406
C19	232.2661	237.0591	232.2661	237.0591
C20	231.2992	236.0379	231.7233	236.0379