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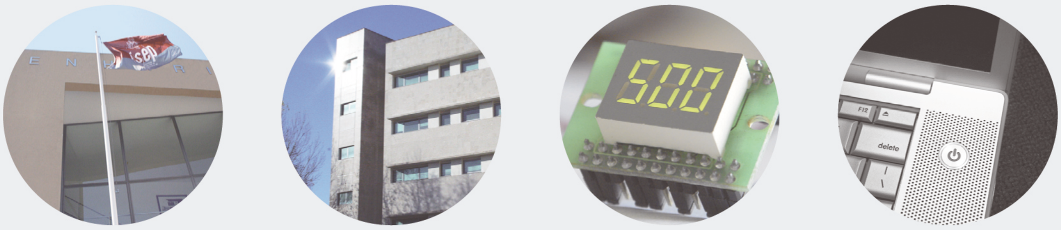

APPLICATION OF DEMAND RESPONSE PROGRAMS FOR PEAK REDUCTION USING LOAD AGGREGATOR

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Resumo

O aumento do consumo de energia requer atenção. Os especialistas propuseram muitas soluções para otimizar o uso de energia e propõem um sistema de gestão de energia eficiente. No entanto, desenvolver um sistema de energia que contempla agregadores de carga é óbvio para aprimorar o processo de gestão de energia. Este trabalho discute um sistema de gestão de energia para implementar programas de Demand Response (DR) usando abordagens de agregação de carga.

Neste trabalho, dois estudos de caso comparam as diferentes respostas do sistema. O objetivo principal é discutir o papel de diferentes modelos de agregador de carga no sistema de energia, implementando um programa de DR. Esses agregadores de carga controlam diferentes tipos de cargas. Neste contexto, vários tipos de cargas domésticas são consideradas cargas controláveis. No processo de agregação, o objetivo é agregar as cargas que possuem as mesmas características usando a análise de agrupamento das cargas.

A contribuição científica desta dissertação está relacionada com a redução da ponta e a agregação de cargas, considerando as cargas controláveis e os recursos de geração no sistema. Para atingir o objetivo anterior, foram realizados dois estudos de caso. Cada estudo de caso consiste em três cenários baseados no modelo de agregação de carga.

Os resultados dos estudos indicam as respostas do sistema aos diferentes cenários e ilustram os méritos do modelo de agregador de carga. Além disso, os resultados demonstram como o agrupamento dos dispositivos de carga no sistema pode efetivamente fornecer redução de pico com recurso a programas de DR.

Palavras-chave

Agregador de Carga, Demand Response, Gestão de Energia, Redução da Ponta.

Abstract

The increment of energy consumption takes a high level of attention. The experts have proposed many solutions to optimize energy use and propose an efficient energy management system. However, verifying the load aggregators' role energy system is obvious to enhance the energy management process. This work discusses an energy management system to implement DR programs using load aggregation approaches.

In this work, two case studies compare the different responses of the system. The main goal is to discuss the role of different load aggregator models in the power system by implementing a DR program. Those load aggregators control different types of loads. In this context, various types of domestic loads are considered controllable loads. In the aggregation process, the goal is to aggregate the loads that have the same features using the clustering analysis of the loads.

The scientific contribution of this thesis is related to the integration of providing the peak reduction and the clustered aggregation of loads, considering the controllable loads and generation resources in the system. To achieve the previous goal, two case studies have been done. Each case study consists of three scenarios based on the load aggregation model.

The results of the case studies indicate the system responses to the different scenarios and illustrate the merits of the load aggregator model. Furthermore, the results demonstrate how clustering the load appliances in the system can effectively provide peak reduction due to the DR programs.

Keywords

Energy Management, Demand Response, Peak Reduction, Load Aggregator, Clustering.

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Acronyms

AC – Air Conditioner

AGC – Automatic Generation Control

AS – Ancillary Services

BRP – Balance Responsible Party

CA – Cluster Analysis

CAP – Capacity Market

CHP – Combined Heat and Power

CM – Capacity Market

CPP – Critical Peak Pricing

CSP – Curtailment Service Provider

DB – Demand Bidding

DG – Distributed Generation

DLC – Direct Load Control

DR – DR

DRER – Distributed Renewable Energy Resources

DSM – Demand Side Management

DSO – Distribution System Operator

DW – Dishwasher

EDR – Emergency DR

EE – Energy Efficiency

FH – Fan heater

GHGs – Greenhouse Gas.

IBR – Inclining Block Rate

ICS – Interruptible/Curtailable Service

ISO – Independent System Operator

LA – Load Aggregator

PV – Photovoltaic

RERs – Renewable Energy Resources

RTP – Real-time pricing

SO – System Operator

SR – Spinning Reserve

TOF – Time-of-Use

TSO – Transmission System Operator

VPP – Virtual Power Plant

WH – Water Heater

WM – Washing Machine

1. INTRODUCTION

This chapter presents an introductory discussion about the motivation of this thesis in subsection 1.1. Then, the objectives are outlined in subsection 1.2, which are related to the aspects identified in subsection 1.1. Finally, the outline and organisation of the thesis are exposed in subsection 1.3.

1.1. MOTIVATION

Nowadays, electrical power systems are growing rapidly. As a result, the controlling process is taking a high level of attention, along the systems from generation to consumers side, and this growth is expected to increase by 30% between 2008 and 2035 [1].

One of the consequences of the change in energy consumption is global warming and air pollution; thus, environmental issues are getting greater attention due to the primary fuel used in generation. Therefore, a series of actions started to be implemented by many countries to reduce pollution emissions. However, those actions aimed to mitigate the harmful effects, such as increasing the usage of Combined Heat and Power (CHP) units, using filtering technologies for the fossil fuel power plant, and integrating renewable energy resources [2]. Nevertheless, each of those actions followed by various consequences that still make the energy consumption topics challenging. For instance, even though the penetration of Renewable Energy Resources (RERs) presents clean energy and replace the harmful effects of the traditional fossil fuel, but at the same time, the uncertainty and stochasticity cause new issue requires advanced planning strategies [3].

In this context, electrical power grids are moving towards the smart grid paradigm. Smart grids bring a high level of flexibility for energy management, which leads to different parties controlling the power consumption and generation [4]. Also, Demand Response (DR) is an essential resource in the management process of the power systems by taking advantage of the active role of the consumers, hence, enabling a more efficient system operation [5]. DR programs are known as the modification of electricity consumption profiles, in which the grid operator pays the customer due to several economic or technical reasons [6]. DR programs can be categorised into two main groups, Price-based methods and Incentive-based methods [7].

Previously, the electrical utilities were vertically integrated. A single utility was responsible for the whole electricity industry from generation to distribution. And the power delivered to the consumers as one product, after the deregulation and liberalisation process, the electric utilities could not manage all the needed services by themselves, thus, as a result of the separation of competitive activities and monopoly activities during the liberalisation process in the electricity industry, the Ancillary services (AS) are created as tradable products [8]. The AS providers moved toward DR programs to unlock the full potential of those programs and to avoid building new generation plants; therefore, new entities appeared to take the responsibility of engaging the DR participants in the AS provision process, later known as Curtailment Service Provider (CSP) or Load Aggregator (LA). The LA mission is to combine the capacities of distributed energy resources and the DR participants into one single energy source, which can be utilised to provide Ancillary Services (AS) [9].

Previous research demonstrated the potential DR and smart buildings for various system ancillary services such as frequency regulation [10], voltage regulation [11], load following [12], and system reserves [13]. However, the majority of DR programs are focusing on the large-scale consumers (industrial- commercial) while the potentials of the smaller scall consumers (residential) still have not exploded significantly [14].

However, the value of the domestic DR participants' capacity may consider small compared to the whole system, not to mention the complicated controlling process due to the high number of participants required to achieve a notable contribution. Here, the LA coordinates the small capacities and aggregates them in one large capacity, facilitating and decreasing the system operators' burden.

Furthermore, several studies have examined the potential of the flexible loads to provide AS products, taking advantage of DR programs and the data mining techniques to optimise the system response, hence, to achieve sustainability to the system [15], and load management [16], and to define the remuneration to the DR participants [17]. However, most studies concentrate on typical DR for emergency or price-driven demand. Therefore, reducing the demand in the system using DR programs from different types of consumers is essential to provide a practical energy management approach and overcome the energy consumption issues. Therefore, this work aims to study the energy management process through DR programs led by the different aggregators by employing the clustering method and eventually reducing the consumption when it is necessary.

1.2. OBJECTIVES

DR programs are considered a practical energy management approach since they encourage consumers to conserve energy during peak hours and high-demand periods. These programs provide financial benefits to consumers and increase the reliability of the grid. Different types of DR participants bring different levels of power reserves to the system. It means that consumers can engage in DR events based on their characteristics and infrastructure. These programs change users' consumption patterns by reducing or shifting their consumption; however, these modifications reduce their energy consumption thus, increasing the levels of reserves in the system.

Many studies and research work in energy management and DR implementation provide consumption reduction in the system. However, most of them focused either on the type of participants (commercial or industrial) or the economic aspects, but to a lesser extent, the issue of load aggregation approaches. Therefore, it deserves to study the impact of aggregation techniques in the process of consumption reduction through numerical case studies.

Therefore, the objectives of this thesis are:

- How does consumer participation in a DR program related to providing Peak hours?

- Does the load aggregation always enhance the load profile during DR events?
- Does the clustering method of the DR participants during the DR event optimise the shape of the load curves?

To achieve the mentioned objectives above, this thesis contributes to:

- Design two different virtual networks with different types of consumers using MATLAB-SIMULINK
- Test three different load aggregation models on each network.
- Implement grouping using the clustering method (k-mans) on the DR event's participants as a key work of LAs.

1.3. ORGANIZATION OF THE THESIS

This thesis consists of six primary chapters. After this introductory chapter, chapter 2 discusses a review of the state-of-the-art with a specific focus on DR programs in the energy systems. After that, chapter 3 provides the proposed methodology followed in this thesis. Then, in chapter 4, the implemented case studies are presented. Next, the results of these case studies are presented in chapter 5 to show the proposed methods' main achievements. Finally, chapter 6 exposes the main conclusion and findings gained through this thesis and provides several paths for future works to explore.

2. BACKGROUND AND CONCEPTS

The increment usage of electricity in the last decades creates an increase in greenhouse gas emissions (GHGs). The deployment of distributed energy resources (e.g., gas-fired distributed generation, solar PV, small wind farms, electric vehicles, energy storage, and DR) contributes to overcoming this issue [18]. However, the massive penetration of these resources makes the power system unstable as they have uncertainty and stochastic characteristics in generation over time. Therefore, DR programs are suitable in this context to mitigate grid instabilities [19]. The main idea of this section is to present a review on the current state-of-the-art in the scope of Demand Side Management section 2.1, DR programs section 2.2, Ancillary Services section 2.3, Load Aggregator in power systems section 2.4, and Data clustering section 2.5. finally, the conclusion of this chapter is presented in section 2.6.

2.1. DEMAND SIDE MANAGEMENT

The DSM presents the actions carried out by the utility on the customer’s side that helps to manage the customer’s electrical usage by modifying energy usage patterns, including electricity demand timing or amount of demand to meet specific goals. The power demand varies during short periods of time; therefore, the DSM concept emerged to mitigate the economic and environmental consequences of engaging new generation units [20]. DSM aims to achieve the desired utility load shape through different methods such as peak clipping, valley filling, load shifting, strategic load growth, strategic conservation, and flexible load shapes figure (1).

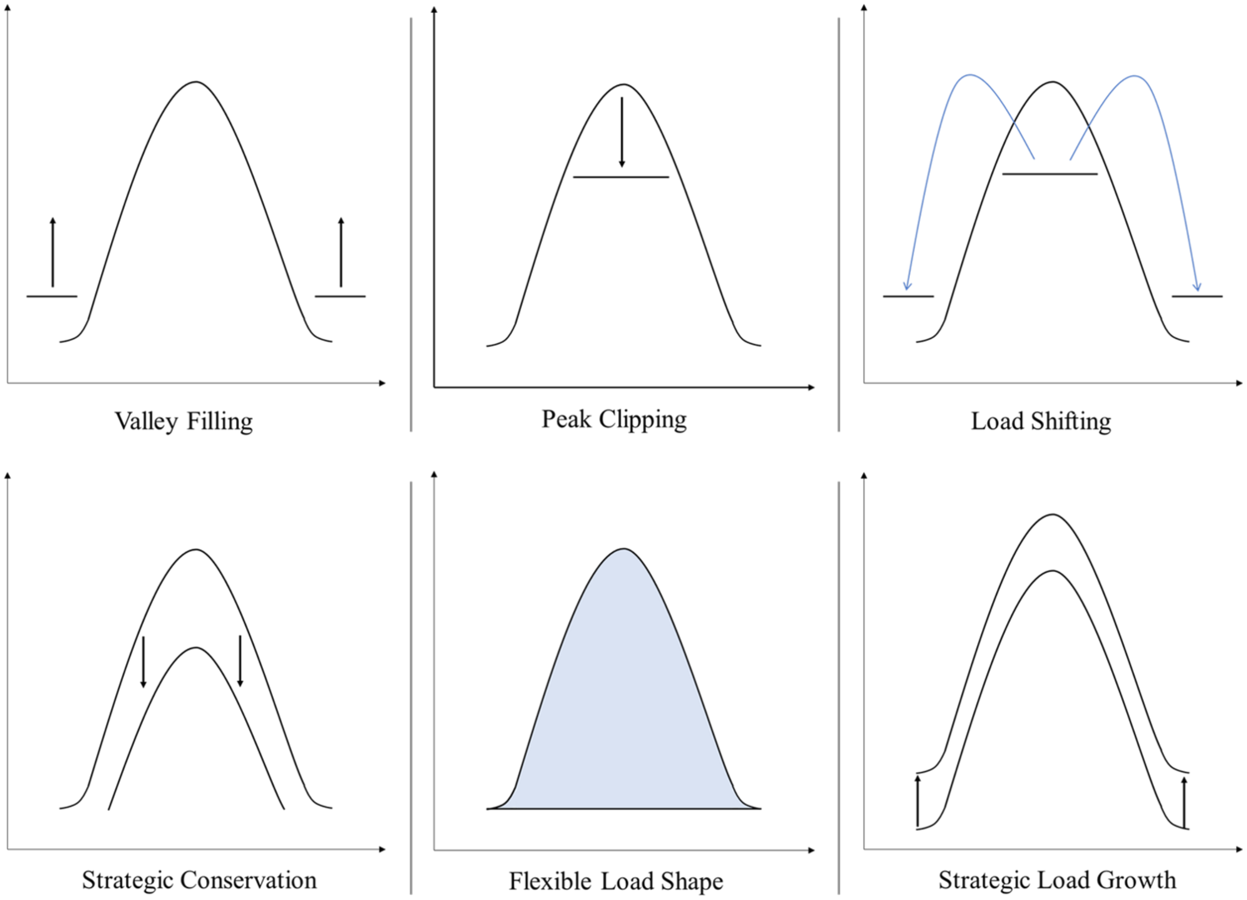

Figure 1:DSM techniques [4].

DSM methods are organised in four different aspects, as follows [21]:

1. Energy Efficiency (EE): improve the efficiency of the electrical appliances or the whole building to reduce energy losses. This strategy is associated with technical features of the electrical appliances and not with the changes in the consumer's comfort and behaviour [22].

2. Time-of-Use (TOF) is related to opportunities to consume at a lower cost since there are periods in electricity markets where energy tariffs are lower. Thus, consumption is less costly during these periods[23].

3. Demand Response (DR): consists of events arranged by a high-level entity -e.g., independent system operator (ISO), regarding changing of the consumption by increasing or decreasing, of which the consumers have the freedom to choose to participate in them or not [24].

4. Spinning Reserve (SR): namely a resource of power from the consumers' side which is always available to correct system parameters deviations, such as frequency, voltage level, or any other grid issue that requires an immediate consumption correction[25].

2.2. DEMAND RESPONSE PROGRAMS

The increasing penetration of Renewable Energy Sources (RES) in power systems raises the need to enhance the system's flexibility to fill the gap caused by the uncertain power output of the leading RES, e.g., wind and solar generation. Thus, the interest in developing Demand Response (DR) programs became a priority to the system operators.

The definition of DR programs is the programs that lead to change the electric usage of the final customers from their standard consumption patterns as a response to the variation of the electricity prices or to the incentive payments from the system operators or when the stability of the power system is in a critical situation [26]. In other words, the DR programs are the modification of electricity consumption profiles, in which the grid operator pays the customer for several economic or technical reasons[6]. The main objective of DR is to manipulate the controllable loads by the consumers to meet the generated energy and maintain the stabilisation requirements for the electrical power system.

This process got significant attention from the regulators; therefore, they made efforts to make DR a resource compared to conventional resources. Whereas the Federal Energy Regulatory Commission (FERC) in the United States order (NO.719) said, ‘‘*Accept bids from DR resources in their markets for certain ancillary services on a basis comparable to other resources*’’ [27]. Moreover, the regulators in the European Union set essential changes in this sector. [28] Describes DR programs as following “… *DR is to be understood as voluntary changes by end-customers of their usual electricity use patterns – in response to market signals (such as time-variable electricity prices or incentive payments) or following the acceptance of customers’ bids (on their own or through aggregation) to sell in organised* *energy electricity markets their will to change their demand for electricity at a given point in time. Accordingly, DR should be neither involuntary nor unremunerated*.” [29].

In this context, the DR supports the other power generation sources; therefore, they should be appropriately managed to get the expected benefits. Those benefits can be summarised as maximising PV consumption, optimising battery storage, exploiting the electric vehicle flexibility, managing reliability issues, manage emissions [7]. And should be considered as an energy source that can be used to ensure the system’s stability and optimise the power system operation [5]. The market defined two types of demand: baseload that happens regularly and the peak demand at certain times. And on the duration of the second type, the DR programs can provide resource adequacy, especially with the objective of load curve smoothing (peak shaving) [19].

DR programs can be classified into two categories. In the first category of DR programs, referred to as “incentive-based DR programs,” the consumers are awarded incentives for changing their consumption patterns as per the desire of the supply side. In the second category of DR programs, referred to as “price-based DR programs,” the consumers are charged with different rates at different consumption times; therefore, retail electricity tariff is affected by the cost of electricity supply. DR programs can be categorised into two main groups, Price-based methods and Incentive-based methods [7]. as shown in figure (2).

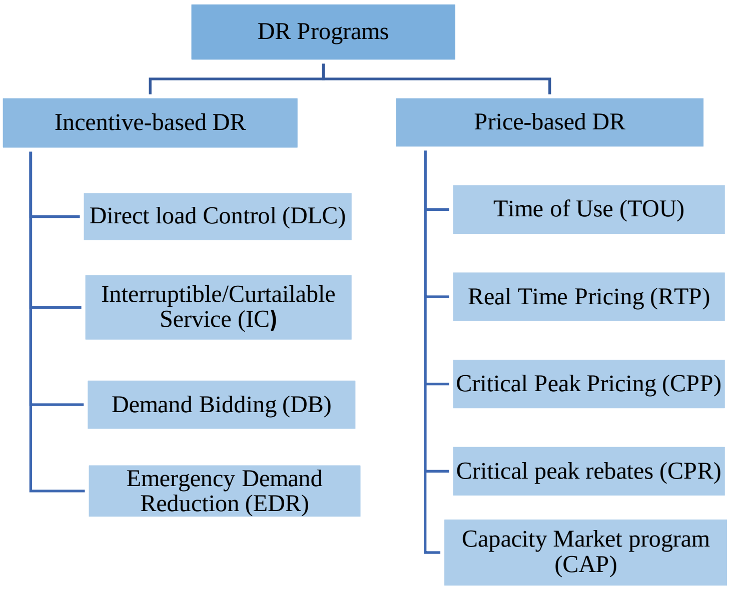

Figure 2: DR programs[30].

1. **Incentive-based methods:** it refers to the programs that give the consumers incentives for changing their consumption models. Some of these programs penalise consumers that fail during the events. Under this title there are six programs can be included:

    a. Direct Load Control (DLC): in this program, the operators install controlling devices in the customer's place and remotely shut down the customer’s electrical equipment. This program is mainly offered to small consumers such as residential or small commercial customers [31].

    b. Interruptible/Curtailable Service (ICS): This program is based on reduction options integrated into market rates that provide a discount or bill credit by agreeing to reduce load during system contingencies and includes penalties for contractual response failures [32].

    c. Demand Bidding (DB): in these programs, the customers offer curtailment capacity bids at a particular bid price; this program typically the large-scale consumers [33].

    d. Emergency Demand Reduction (EDR): A combination of DLC and ICSs applied in periods when the contingency reserve becomes insufficient [34].

    e. In Capacity Market (CM): the customers offer load curtailment as system capacity to replace traditional generation or delivery resources [19].

2. Price-based methods: It refers to the variation of the consumptions to respond to the price variations, such as:

    a. Time-of-Use (TOU): the pricing method here is as follows; the electricity price rates for consumers depend on the period of consumption. Typically, a day is divided into three categories: Peak, mid-peak, off-peak, and maximum rates on the peak periods. That leads to charge the consumers different rates. In this way, they are encouraged to reduce their consumption at peak hours and shift their shiftable loads to off-peak hours[35].

    b. Real-time Pricing (RTP): In this pricing method, the electricity rates typically change by the hour, indicating variations in the wholesale electricity market price. Typically, the consumers will be informed on a day-ahead or hour-ahead basis [36].

c. Critical-Peak Pricing (CPP) rates: This method here is similar to TOU, but this is applied only when the reliability of the power system is endangered. Then the normal peak price is replaced by a significantly higher one. Again, this program only applies for very short periods per year and improves power system reliability [37].

d. Inclining Block Rate (IBR): This method has two pricing levels according to the consumers' energy consumption. When consumers reach a determined threshold of consumption, electricity rates will be higher [38].

e. Capacity Market Program (CAP): the customers offer load curtailment as system capacity to replace traditional generation or delivery resources.

After the DR program's summary, the participating consumers will get financial benefits by reducing the electrical bills by modifying the consumption profile toward off-peak periods. Moreover, the DR programs as a Distributed Renewable Energy Resources (DRERs) application in the DMS performs significantly in the smart grid.

Besides that, building consumption in all types is 40% of the world's energy consumption and in the United States of America (USA) is almost 35% is consumed by commercial buildings [39] [40]. Therefore, the DR programs will present a confident source for sustainability through the flexible and controllable loads. In this context, Air Conditioners (ACs), Water Heaters (WH), and Washing Machines (WM) can serve this purpose due to their contribution to electricity consumption and because of their characteristics that make them suitable for DR programs, for instance, Direct Load Control (DLC) [39].

2.3. ANCILLARY SERVICES

Previously, the electrical utilities were vertically integrated, and a single utility was responsible for the whole electricity industry from generation, transmission, distribution, and supply. Moreover, the power delivered to the consumers as one product, after the deregulation and liberalisation process, the electric utilities could not manage all the needed services by themselves; thus, as a result of the separation of competitive activities and monopoly activities during the liberalisation process in the electricity industry the Ancillary services (AS) was created as tradable products [8].

Ancillary services objectives are keeping the system in a reliable situation, fixing any imbalance between the generation and the demand, maintaining the proper power flow of electricity, and helping the system recover after any disturbance happens to the system. To achieve those constraints, the ancillary services can be categorised into four main types [41] [42] [43]:

1. Regulation service: the use of generation equipped with governors and automatic-generation control to maintain minute-to-minute generation/load following within the control area to meet ISO control performance standards; these services resources are typically some types of electricity generator, DR, or energy storage [44].
2. Spinning reserve: the provision of generating capacity, usually with governors and automatic generation control, that is synchronised to the grid and is unloaded that can respond immediately to correct for generation/load imbalances caused by generation and transmission outages, and that is fully available within 10 minutes. These services correct short-term changes in electrical imbalances that affect the stability of the system. Generators and transmission lines are subject to failure at any time. Therefore, Contingency reserves restore the generation/load balance after the sudden loss of a major generator or high-capacity transmission line. As a result, power system frequency falls quickly when generation trips [45].
3. Non-spinning reserve: similar to spinning reserve, except that the generating capacity is not required to be synchronised to the grid. These services also correct short-term changes in electrical imbalances [46].
4. Replacement reserve: the use of generation to compensate for the transmission-system losses from generators to loads. Which can be either:
   a. Flexibility reserve responds to large and unexpected wind and solar ramp events [47].
   b. Voltage Control which the service that provides basic compensation for a generator to provide incremental voltage or to absorb voltage on the transmission system [48].
5. Black start provides the generation resources necessary to restart the power system in a major blackout. In addition, the power output from these resources is utilised to

start other power stations and provide critical-needs services. Therefore, black start generators must be capable of starting themselves quickly without an external electricity source [49].

However, each AS product has features that differentiate it from the other, table (1) shows the main features for regulation and load following products, and table (2) summarises AS products' features regarding time response and duration to be available to use.

Table 1: Comparison of regulation and load following characteristics [41].

	Regulation	**Load Following**
Patterns	Random and uncorrelated	Highly correlated
Control	Requires AGC	Can be manual
Max Swing	Small	10-20 times regulation
Ramp Rate (MW/min)	5-10 times load following	Slow
Signs change per unit time	20-50 times load following	Few

Table 2: General Ancillary Services products [18].

AS Type	**Description**	**Respond Time**	**Duration of Response**	**Time to Full Respond**	**Repetition**
Regulation	Response to random unscheduled netload.	30 Sec	in 15 min	5 min	Continues within the specific bid period
Contingency	Rapid and immediate response to supply loss.	1 min	≤ 30 min	≤ 10 min	≤ Once per day
Flexibility	Additional load following reserve for large un-forecasted ramps.	5 min	1 hour	20 min	Continues within the specific bid period

AS Type	Description	Respond Time	Duration of Response	Time to Full Respond	Repetition
Energy	shed or shift consumption over time	5 min	≥ 1 hour	10 min	1-2 times per day with 4-8 hours ahead notification
Capacity	Ability to act as an alternative generation.	Top 20 hours coincident with balancing authority area system peak			

The previous subsection explained the various types of AS, and its provision has evolved through the years. However, there is much research that investigated different methods to provide the AS products to the systems. Table (3) presents some studies which used the DR programs to provide AS products.

Table 3: Studies about AS provision.

Ref.	AS Product	Summary	Consumer Type
[50]	Peak reduction	The authors present a case study to provide AS during the peak period by prioritising different thermal loads according to their flexibility.	Residential
[51]	Regulation & Load Following	This work proposed providing ancillary services by the combination of industrial loads and an on-site energy storage device.	Industrial
[52]	Frequency control	This work examines the provision of demand-side ancillary services using building HVAC loads.	Residential
[53]	Frequency control	This work proposes a case study to provide the frequency reserve as an ancillary service from flexible loads (refrigerators) by minimising the charging/discharging rates.	Residential

Ref.	**AS Product**	**Summary**	**Consumer Type**
[54]	Load following	This work proposes direct load control and load shedding on 100 consumers to minimise power outages in sudden grid load changes and reduce the Peak.	Residential
[55]	Load following	This work proposed an algorithm that aims to achieve the balance (generation/consumption) in an office and to reduce the energy consumption from the network by prioritisation of the used appliances	Commercial
[56]	Full AS services	This paper proposes a DC community grid consisting of 100 consumers (with two renewable energy resources) and providing ancillary services to the distribution grid.	Residential
[45]	Spinning Reserve	This work discusses providing the Spinning reserve to the system by controlling the Air Conditioner (ACs).	Residential
[57]	Load following	In this work, scheduling, and load-following in an Industrial plant, with the integration of solar energy.	Industrial

2.4. LOAD AGGREGATION

At this time, most of the implemented DR programs are namely procured for large-scale resources. However, small-scale resources do not apply to these programs; it means small-scale consumers, such as residential or commercial offices, cannot participate in the DR programs individually. To solve this issue, new concepts have appeared.

Virtual Power Player (VPP) and Curtailment Service Provider (CSP) are two concepts that can aggregate the small-scale consumers who want to participate in DR programs into one large group [58].

Aggregation is defined as the act of grouping different DR participants (agents) in a power system (i.e., Consumers, producers, prosumers) to act as one independent entity when engaging in power system markets or selling services to the system operators (SO) [59]. The European commission distinct the demand side aggregators from the small generation aggregators, where the European Commission defines the DR Aggregator as a third-party company specialising in electricity demand-side participation. DR Aggregator contracts with the participants (industrial, commercial, or residential consumers) and aggregates their reduction capacities together and provide this capacity to either Transmission System Operator (TSO), Balance Responsible Party (BRP) or to Distribution System Operator (DSO) [60]. The participants can adopt a mixture of increasing on-site generation or reduction or shift loads to deliver the active power demand reduction service required by the System Operator (SO) through aggregators. In exchange, the DR Aggregators receive a percentage of the value created by the avoided consumption to reduce peak demands, balance intermittent generation, provide a balancing service, or increase the security of supply, reflecting the participant consumers [61]. Figure (3) shows the VPP relationships with a different player in the power system.

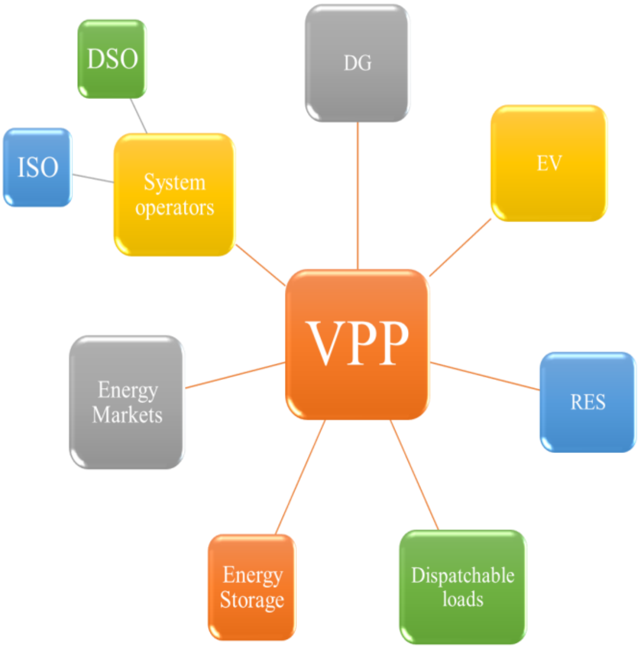

Figure 3: VPP connections with the power system [62].

However, various algorithms and techniques of aggregating capacities are discussed in many studies; table (4) gives a brief on some aggregation work related to the provision of the AS.

Table 4: Studies about LA for AS provision.

Article	AS Product	Summary	Aggregator model	Consumer Type
[63]	Spinning reserve	The authors investigated the impacts of different electricity markets on the behaviour of a DR aggregator.	Yes	N/D
[64]	Regulation	The authors estimate the value of load aggregation in the AS market through a case study.	Yes	Commercial
[65]	N/D	The authors pointed out the participation of the aggregators in the ancillary services provision could optimise their profits and performance.	Yes	N/D
[66]	Reserves.	This work improved the role of the aggregators providing ancillary service from controllable loads by using information and communication technology (ICT).	Yes	N/D
[67]	Frequency control	In this work, the authors proposed a frequency detection method to control an aggregated flexible load.	Yes	Mix
[68]	Reserves/ peak reduction	This work uses the load aggregators of the residential appliances to reduce the peak demand by dividing the appliances into different groups depending on the features.	Yes	Residential
[69]	Full AS services	The authors proposed a multi- aggregators model to control different types of HVAC and provide the system operator with the AS.	Yes	Mix

However, the previous studies seldom consider how to coordinate energy loads based on their consumption profile. Moreover, few articles present an advanced reward distribution system, which is essential because it may directly affect the residents' participation levels.

2.5. CLUSTERING APPROACHES

The amount of data the Smart Grid produces every minute is enormous; analysing this data is essential to improve the whole power system hence life quality for the human race. One of the methods used is (Cluster Analysis).

The cluster analysis is known as one of the unsupervised learning techniques to analyse no labelled data. It aims to separate the data set into discrete sets or groups according to mutual features within the same group. There are several clustering algorithms, and it is hard to categorise clustering methods into clear separated groups due to the features of each method may overlap into another one, so that a method may have features from different categories. However, in general, the main clustering methods can be classified into the following categories [70]:

1. Partitioning methods (PM).
    a. k-Means: A Centroid-Based Technique.
    b. k-Medoids: A Representative Object-Based Technique.
2. Hierarchical methods (HM).
    a. Agglomerative versus Divisive Hierarchical Clustering.
    b. Distance Measures in Algorithmic Methods.
    c. BIRCH: Multiphase Hierarchical Clustering Using Clustering Feature Trees.
    d. Chameleon: Multiphase Hierarchical Clustering Using Dynamic Modeling.
    e. Probabilistic Hierarchical Clustering.
3. Density-based methods (DBM)
    a. DBSCAN: Density-Based Clustering Based on Connected Regions with High Density.
    b. OPTICS: Ordering Points To Identify the Clustering Structure.
    c. DENCLUE: Clustering Based on Density Distribution Functions
4. Grid-based methods (GBM)
    a. STING: STatistical Information Grid.
    b. CLIQUE: An Apriori-like Subspace Clustering Method.

Table (5) summarises the four clustering methods, in addition to a brief of each method's characteristics.

Table 5: Characteristics of clustering methods [70].

METHODS	GENERAL CHARACTERISTICS
Partitioning Methods	➢ Find mutually exclusive clusters of spherical shape. ➢ Distance-based ➢ May use mean or medoid to represent cluster centre. ➢ Effective for small- to medium-size data sets
Hierarchical Methods	➢ Clustering is a hierarchical decomposition. ➢ Cannot correct erroneous merges or splits. ➢ May incorporate other techniques like micro clustering or consider object “linkages.”
Density-Based Methods	➢ Can find arbitrarily shaped clusters. ➢ Clusters are dense areas of objects in space that are separated by low-density areas. ➢ Cluster density: Each point must have a minimum number of points within its “neighbourhood.” ➢ May filter out outliers
Grid-Based Methods	➢ Use a multiresolution grid data structure. ➢ Fast processing time.

Several clustering methods can be used for cluster analysis, but the most applied one regarding the load aggregation is the k-means method; many studies use clustering in the process of optimising the aggregation process and DR program events. For instance, in [15], the authors use the k-mean clustering method to achieve a self-sustainable community; the common consumption patterns among the consumers drove clustering, regardless of the consumption volumes. Also, in [17], the k-means method is used to aggregate both DG units and DR participants, while in [71], a comparison among six clustering methods is performed through a case study. moreover, the authors in [72] used two data mining techniques in the work to determine effective and efficient DR programs that can be put into practice, where they use k-means as a clustering algorithm. Also, in [73] a comparative process is done between k-means and self-organizing maps (Kohonen) based on measured daily load curves.

2.6. CONCLUSION

The goal of this chapter was to review the concepts that related to this work. Also, the literature review has been conducted to consumption reduction through AS providing to the power systems, including those that use the DR programs, LA, and data mining techniques. It was clear that the AS provision topic was considered essential to investigate, especially after the energy market liberalisation. However, most studies showed the influence of implementing DR programs and LA models on an industrial or commercial scale and certain residential loads (e,g, HVAC), but not considering mutual feature of loads on large scale residential scope. Thus, starting from this point, we can study the impact of aggregating different types of residential loads in the provision of consumption reduction during critical situations.

3. METHODOLOGY

This chapter presents the proposed methodology applied in this work in 3.1, an explanation about the clustering method in subsection 3.2. Subsection 3.3 presents the k-means method used in this work, and subsection 3.4 the method of choosing the number of clusters, subsection 3.5 presents some applications of the methodology to provide the Ancillary services, finally, the conclusion of this chapter in subsection 3.6.

3.1. PROPOSED METHODOLOGY

This work aims to provide the peak reduction to the power system during peak hours by implementing DR events using LA models. Figure (4) illustrates the proposed methodology of the work, describing the phases that the work goes through and representing the various stages.

The first step is the networks model; the MATLAB Simulink environment is used to build the case study models. In general, the models consist of external power sources, DG units and domestic consumers. The general model of the consumer is shown in figure (5), which has two types of loads (Rigid load and Controllable loads) along with measurements and data import function.

The second step is Data acquisition; the initial consumption for the network's consumers and PV generation is collected for the desired duration considering the sampling intervals, at which the end of the day, there are a fixed number of periods. Moreover, after collecting the data, a cleaning process from any values that do not fit each period. That is, in periods where there are very high values of consumption and PV production compared to other periods, those values are replaced by a value determined by the average daily consumption or production.

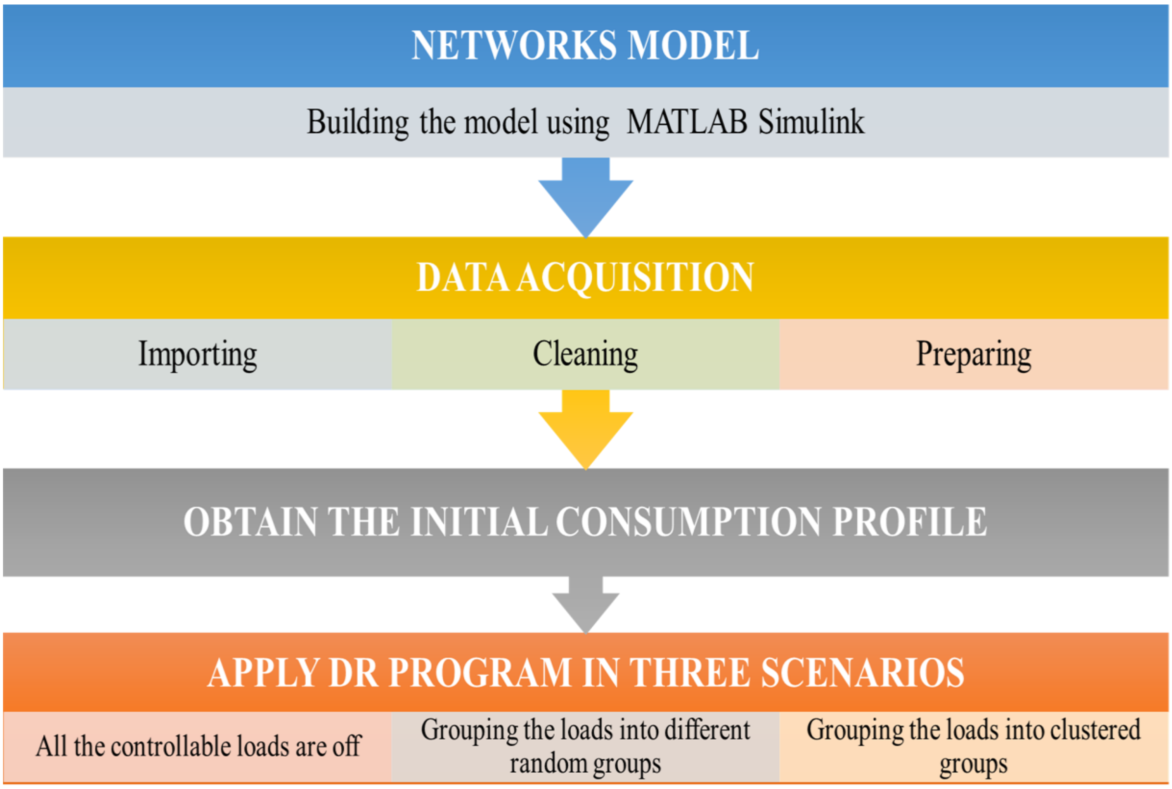

Figure 4:The proposed methodology.

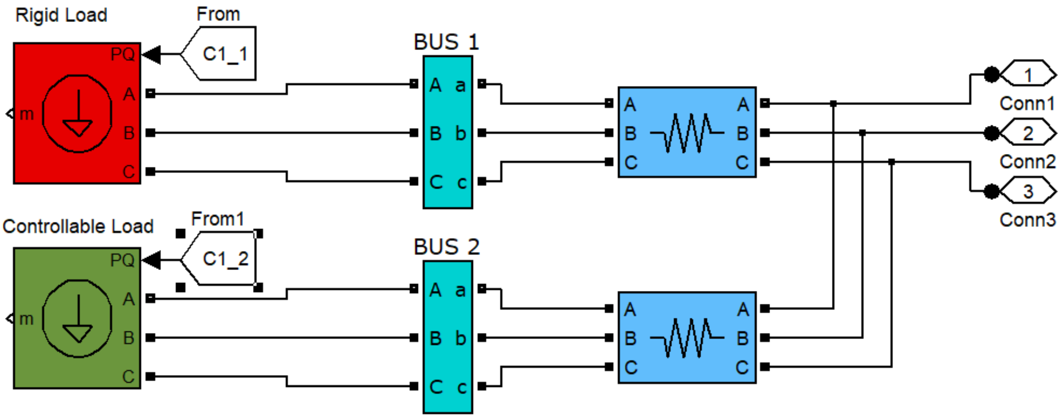

Figure 5: General model for a consumer.

Thus, the third step is to obtain the initial load consumption, by this step, the load curve gives a clear view of the peak periods (day and night peaks) in addition to the values and the time of the maximum demand; these marks indicated the time where the DR event takes place. Also, after preparing the data, the number of groups of consumers is defined through the elbow method before performing the clustering algorithm to cluster the consumers based on the mutual features.

After completing the previous stages, the DR event's duration and time are determined. However, due to the third stage, the DR event is applied considering three different scenarios; thus, the loads are aggregated into several groups according to various factors (either to the consumers' consumption patterns or to the consumers' response time to the DR event or any other criteria). Next, each group presents a load aggregator (LA).

3.2. LOADS AGGREGATION

The clustering methods present an excellent approach to categorise the Models' loads into different groups according to mutual features; the k-means algorithm provides a suitable method to perform the clustering in this work due to the unknown common features for the loads. The clustering process is implemented using each consumer's available reduction capacity (consumption profile) and/or the response time that the consumers take to respond to the DR event.

3.3. K-MEANS CLUSTERING

The K-means algorithm is widely used in clustering algorithms [73], therefore, this method is used in this work is the k-Means (Centroid-Based Technique); In this technique, for any given data set (A) contains (x) elements in Euclidean space. The k-means method separates the elements into k clusters, $C_1, \dots, C_k$, thus, $C_i \subset$ A and $C_i \cap C_j = \emptyset$ for $(1 \leq i, j \leq k)$.

the partitioning quality is assessed by an objective function so that objects within a cluster are similar but dissimilar to other clusters. the centroid of a cluster C_i represents the cluster. The mean or medoid of the elements assigned to the cluster defines the cluster's centroid. The difference between an element $p \in C_i$ and c_i, the centroid of the cluster is measured by $\mathrm{dist}(p, c_i)$, The quality of cluster C_i can be measured by the within-cluster variation, which is the sum of squared error between all objects in Ci and the centroid c_i [15] [70], defined as

$$E = \sum_{i=1}^{k} \sum_{p \in c_i} \mathrm{dist}(p, c_i)^2 \qquad (1)$$

Where: E: is the sum of the squared error for all objects in the data set.

p: is the point in space representing a given object.

c_i: is the centroid of cluster Ci (both p and ci are multidimensional).

Figure (6) illustrates the different steps that k-means goes through to obtain the final clusters. And the box diagram in figure (7) shows the algorithm steps.

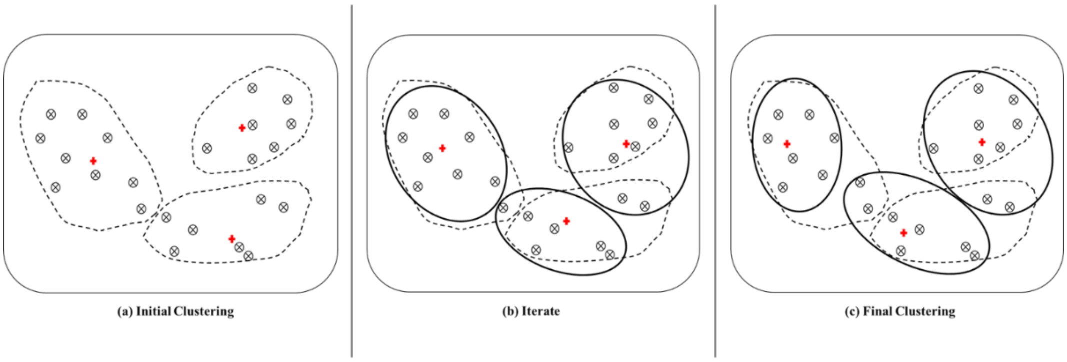

Figure 6: Clustering steps[70].

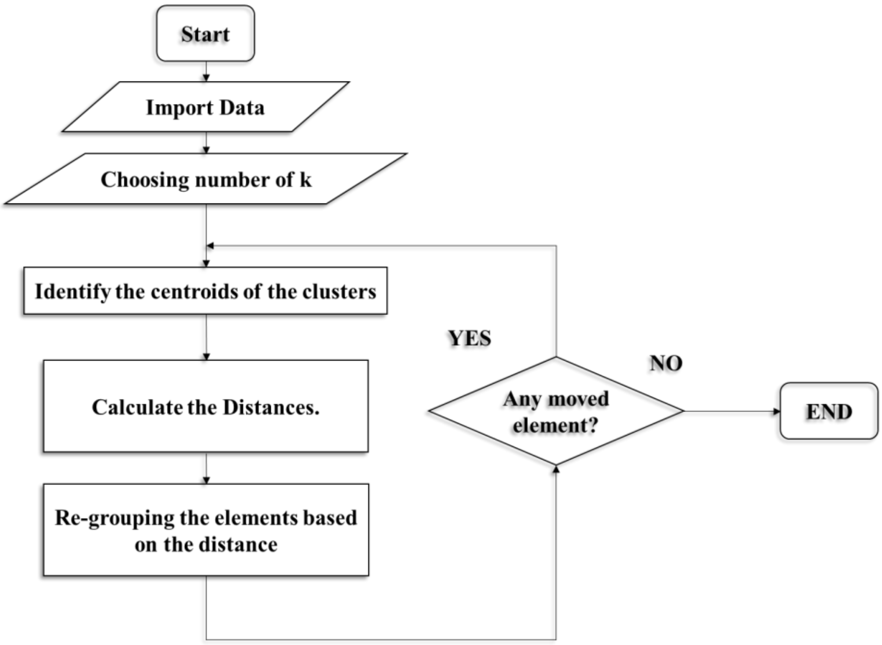

Figure 7: k-means algorithm [74].

3.4. NUMBER OF CLUSTERS DETERMINATION

The elbow method is applied to obtain the optimal number of the consumers' clusters (k). Rstudio software is used to implement this method. The basic idea behind k-means clustering is to define clusters to minimise the total intra-cluster variation:

$$minimize \sum_{k=1}^{k} W(C_k) \tag{2}$$

where $\mathrm{C_k}$ is the k^{th} cluster and $W(C_k)$ is the within-cluster variation. The total within-cluster sum of square (wss) measures the compactness of the clustering, and (wss) should be as small as possible. Thus, according to elbow method: first Computing k-means clustering algorithm for different values of k. Then For each k, calculate the total within-cluster sum of square (wss). After that, wss plot according to the number of clusters k. Finally, the bend in the plot is considered an indicator of the optimal number of clusters k [75][76].

3.5. CONCLUSION

The proposed methodology is based on the need to improve the accuracy and effectiveness of the LA response during DR events. Usually, in previous works, devices were activated to reduce consumption with respect to each type of device, e.g., All the HVAC devices were engaged to the DR event simultaneously. However, it may be that depending on the time of day, in any network, multi appliances may have similar features (consumption profile, response time), so they should be aggregated and activated to lower demand at the same time. The clustering approach provides these groups.

4. CASE STUDY

In this chapter, two case studies are proposed to discuss the roles of the load aggregator in providing peak reduction to the power systems when needed. Three different scenarios have been executed and simulated to study the different network responses under DR programs. Subsection 4.1 presents the features of the cases, then in subsection 4.2 an explanation of the sampling time, next subsection 4.3 and subsection 4.4 present the case studies (I & II), finally, subsection 4.5 shows the scenarios which will be implemented.

4.1. CASE STUDIES FEATURES

This work proposes two different case studies to illustrate the role of the aggregator in the power system and the added value of using data mining techniques. each case presents a small village, therefore, they will be identified as village I and village II, each one has characteristics to differentiate from one another, (e.g. different numbers of consumers and power demand).

The following table illustrates the differences between the two case studies, presenting the key differences between them.

Table 6: The differences between the case studied I & II.

	Village I	**Village II**
DR participants	Consumers' Appliances	Consumers
N. of participants	30 consumers / 67 appliances	96 end-consumers
Reduction Capacity source	Controllable appliances only	Whole consumer's consumption
DG units	NO	2 rooftop solar systems 1 kW
Power provider	External provider	External provider and solar systems
Min demand (kW)	29	181
Max demand (kW)	52	433

4.2. SAMPLING TIME

The data collection is performed during one random day (24 hours) of 3 minutes intervals, that is, the total number of 480 samples/day, and within MATLAB-Simulink, the simulation run step is 0.2 seconds or (200 ms); therefore, the simulation sampling for each period of 3 minutes of consumption data is run during 2 seconds of simulation timing or (2000 ms), which means 10 run steps/period, that is, each period of 3 minutes in real-time consumption is equivalent to 2 seconds of simulation time, eventually the simulation time will be 960 seconds.

4.3. VILLAGE I

The first case study proposed a network that corresponds to a small electrical power network, consisting of a power source and /30/ consumer. The electrical demand of those consumers comes from the rigid loads (such as lightning, TVs) and the controllable electrical appliances, which are (Air Conditioner AC, Water Heater WH, Washing Machine WM, Dishwasher DW, and Fan Heater FH).

4.3.1. THE MODEL ANALYSIS

The network model has been built using MATLAB-Simulink R2011b. The simulations have been executed for 24 hours duration using data from the research centre of intelligent systems GECAD, which is located in the Institute of Engineering– Polytechnic of Porto (ISEP/IPP), Portugal. The network configuration is shown in figure (8). Each consumer model has a single Three-Phase V-I Measurement unit used to measure the instantaneous three-phase voltages and currents, hence measuring the total consumption of the consumer. Moreover, each appliance is connected to the V-I Measurement block to get the consumption of the appliance itself.

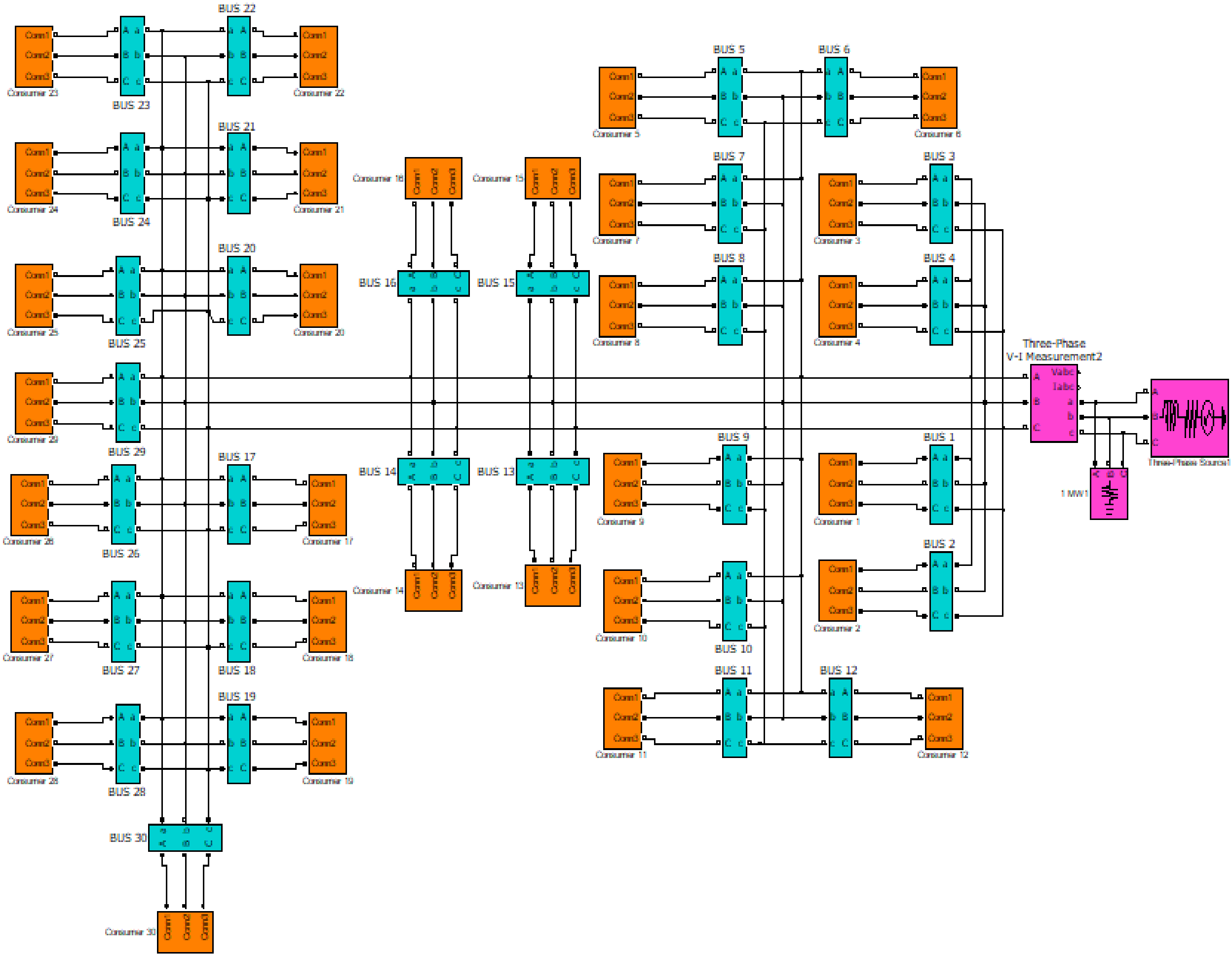

Figure 8: Model configuration / Village I.

4.3.2. THE REDUCTION CAPACITY

To achieve the goals of this study, it is essential to understand the nature of the different loads that exist in the model; also, this helps to execute proposed scenarios. Village I contains /30/ consumers. Each consumer has different types of electrical appliances in addition to rigid consumption. The appliances are Air Conditioner (AC), Water Heater (WH), Washing Machine (WM), Dish Washer (DW), and Fan Heater (FN), and their power consumption presents the reduction capacity which eventually the load aggregators will use in order to respond to the different DR events.

Figure (9) illustrates the share of the total demand for rigid loads and controllable appliances as a percentage of the total model demand. The rigid loads acquire 40% of total network consumption and the controllable appliances 60%; this pie chart illustrates the hidden potential of the flexible loads in managing and controlling the system stability.

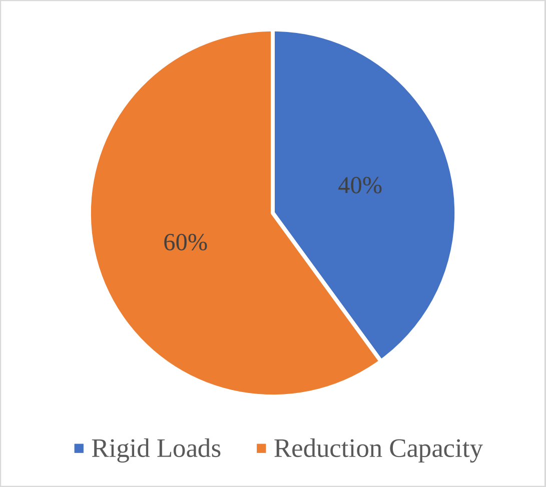

Figure 9: The share of each Load type in the model.

For the distribution of the appliances among the consumers, figure (10) shows that the majority of the consumers have installed ACs with a total number of /26/ units, then DWs with 14 units, after that WHs, those numbers give an initial indication that AC, DW and WH would have the significant impact on the reduction capacity of the model when the aggregators consider them in the DR events.

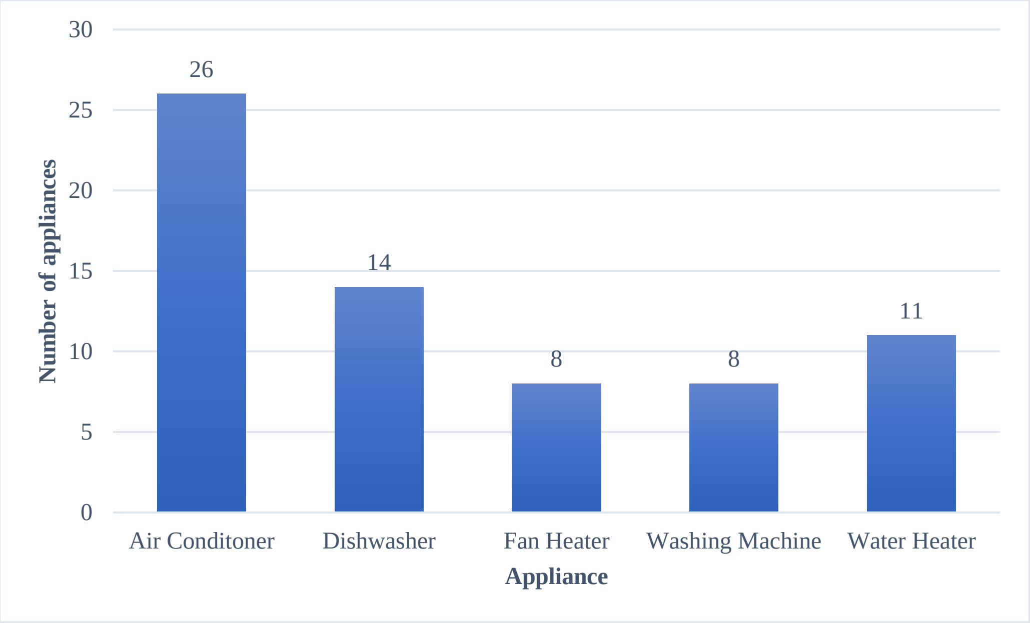

Figure 10: The iteration of each appliance in the network.

However, after analysing the power demand for each type of appliance for one random day, the ACs have a significant part of it with 89% of the total consumption, followed by the FHs with 8%. Thus, even though the number of dishwashers is greater than the fan heater, but the impact of the latter on the reduction capacity is more significant than the former. Figure (11) shows the share of each type in the reduction capacity.

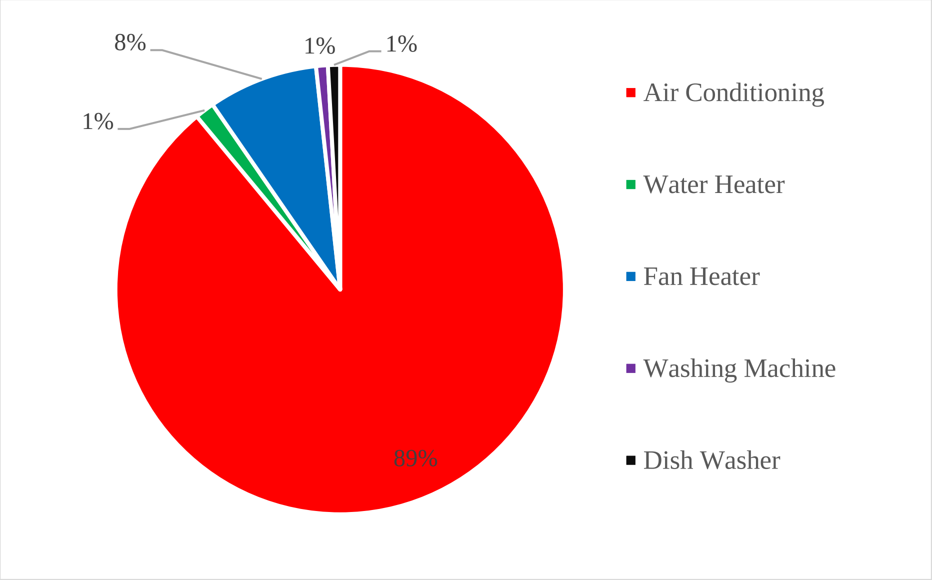

Figure 11: Reduction Capacity Share (%).

After preparing the model and importing the data into the Simulink, the initial state of the network has been executed for the random 24-hours duration to obtain the initial load profile of this network.

Figure (12) illustrates the variation in demand over 24-hours, including the total model consumption, the rigid consumption, and the reduction capacity available from the consumption of the controllable appliance. The peaks demand periods occur between 12:00-14:00 and 18:00 – 20:00. From the load profile of the FCS, there are two peaks in the curve; the first starts at 12:00 and the second starts at 18:00.

During this day, the consumption of the controllable loads is higher than the rigid's consumption, those levels of consumption are mainly caused by the high shares from the ACs and the FHs appliances.

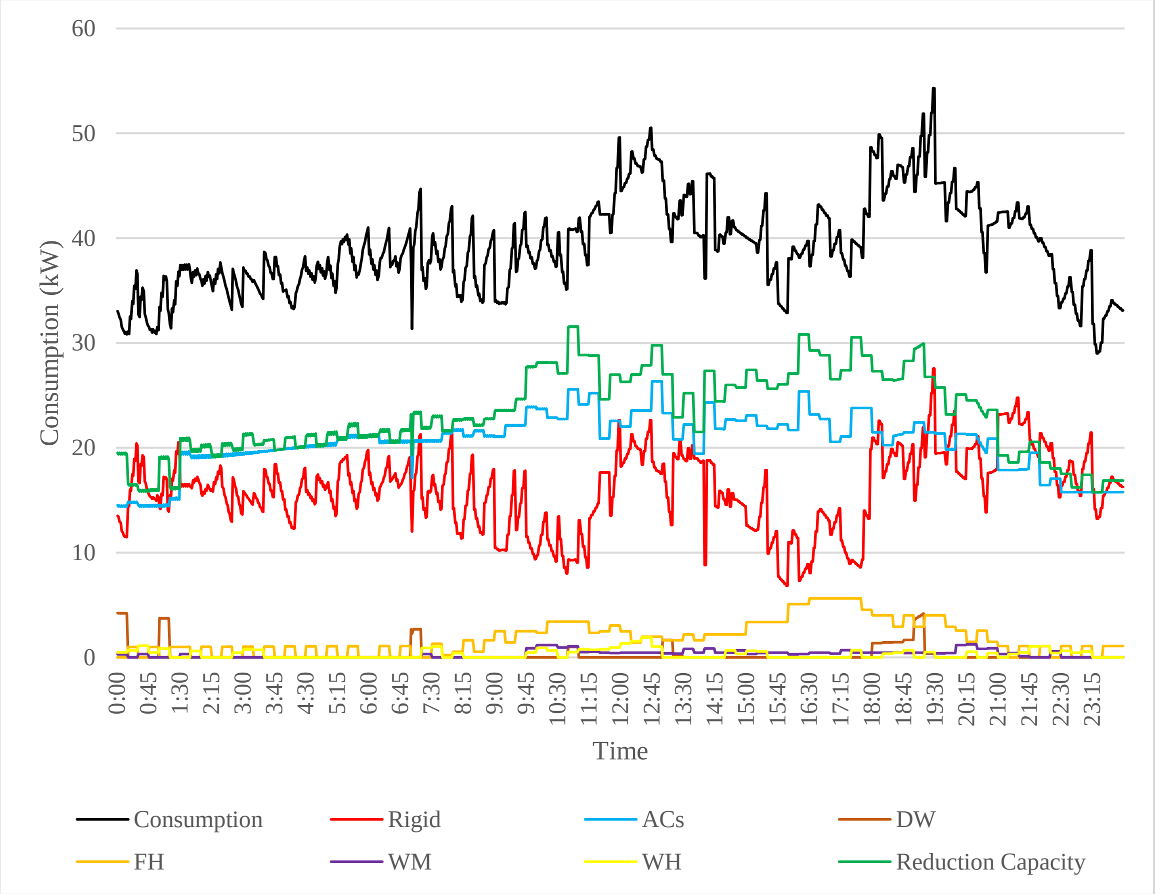

Figure 12: Initial Demand Profiles for Village I.

4.4. VILLAGE II

The second case study's proposed network corresponds to an electrical power network more extensive than the first one, with some significant differences; the second network consists of a power source and /96/ domestic consumer. The electrical demand of those consumers is considered to be fully controllable, with the ability to respond to DR events instantly. Besides the consumers, the network has two small rooftop solar systems (PVs) installed in two different locations with 1kW each, and the external power source 1000 kW.

4.4.1. THE MODEL ANALYSIS

The configuration of village II network is similar to the first one regarding the building environment, tools, and data entry mechanisms. Figure (14) illustrates village II network's diagram, and table (6) shows the components of the network in details.

Table 7: The network's components / Village II.

Component	Number
Buses	236
Lines	235
Transformer 1000KVA	1
End-users	96
PV rooftop 1 kW	2

As mentioned before, the consumers are considered to have fully controllable loads; therefore, the reduction capacity available from each consumer is the total consumption. The initial load consumption of a random day for this network is presented in figure (13).

The samples were obtained within 24 hours over a 3-minute interval, which is equivalent to 480 samples per day. The maximum demand is 433 (kW) at 18:10, and the minimum demand is 181 (kW) at 1:27 a.m. the day peak occurs between 11:45 and 14:00, while the night peak occurs between 17:45 and 20:15.

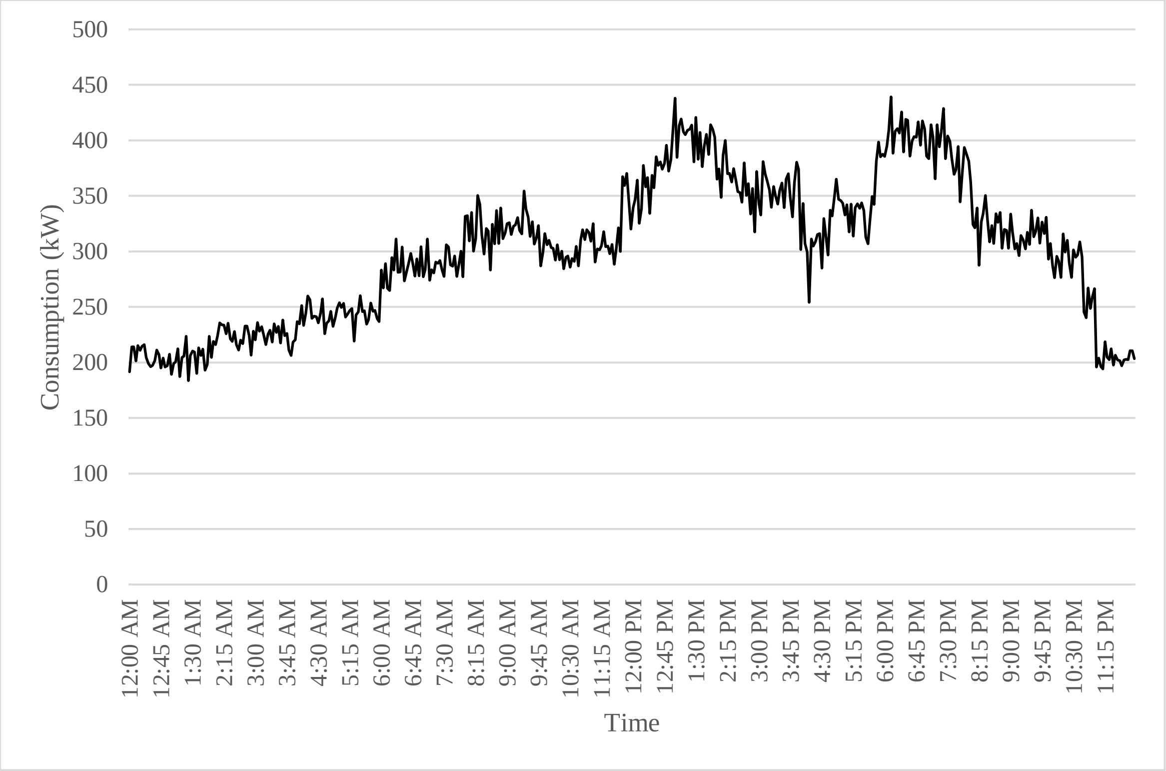

Figure 13: Load profile / Village II.

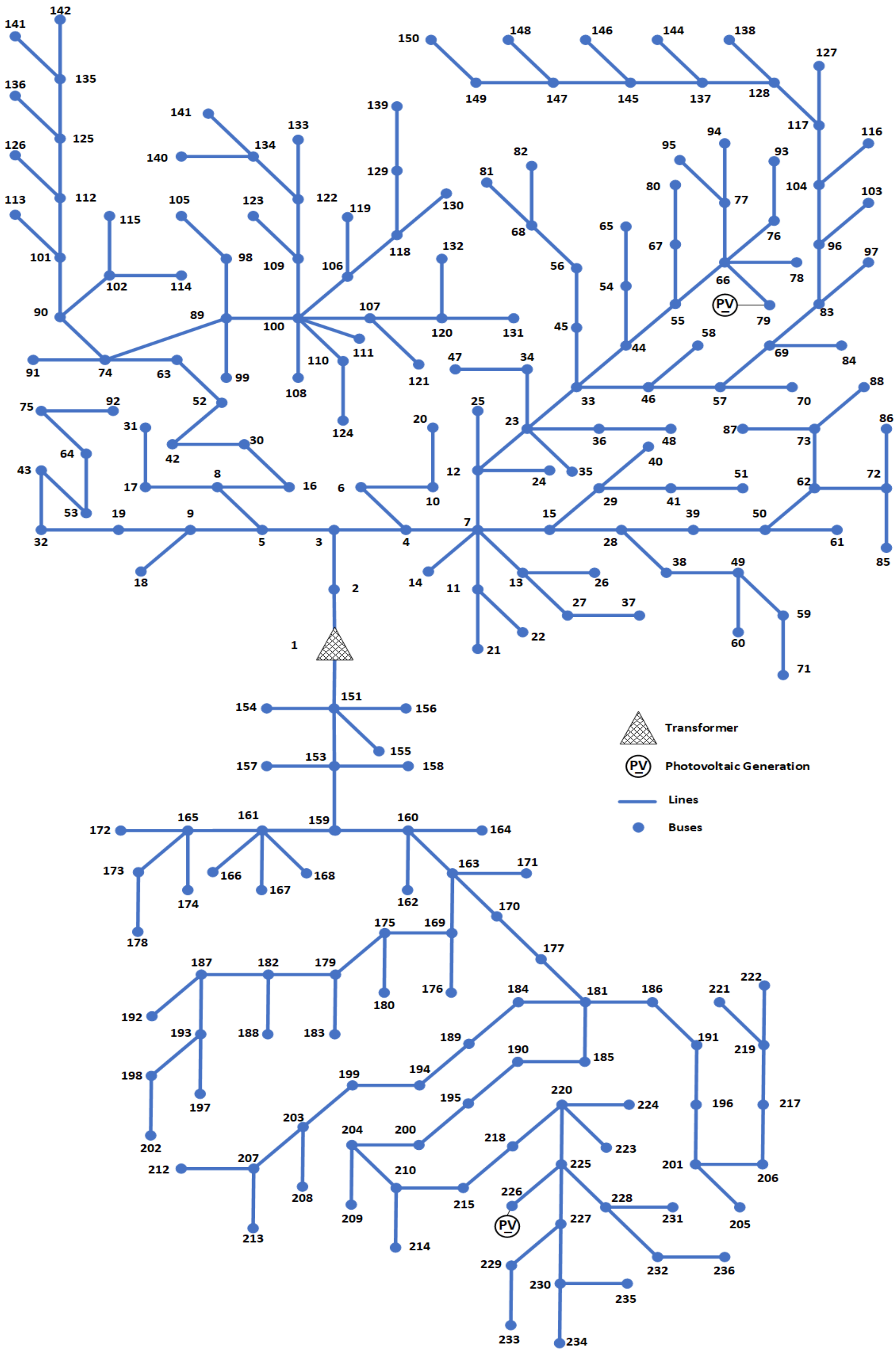

Figure 14: The network configuration / Village II.

Also, the rooftop solar systems generation profile is presented in figure (15) with a maximum power of 136 (W) for the first system and 151 (W) for second one, occurring at the mid-day period. the generated power from the rooftop solar panels is very small compared to the total system demand, and since the installed power for each solar system is 1 kW, the output chart indicates that the weather conditions on the selected day were not optimal to get the maximum possible power from them.

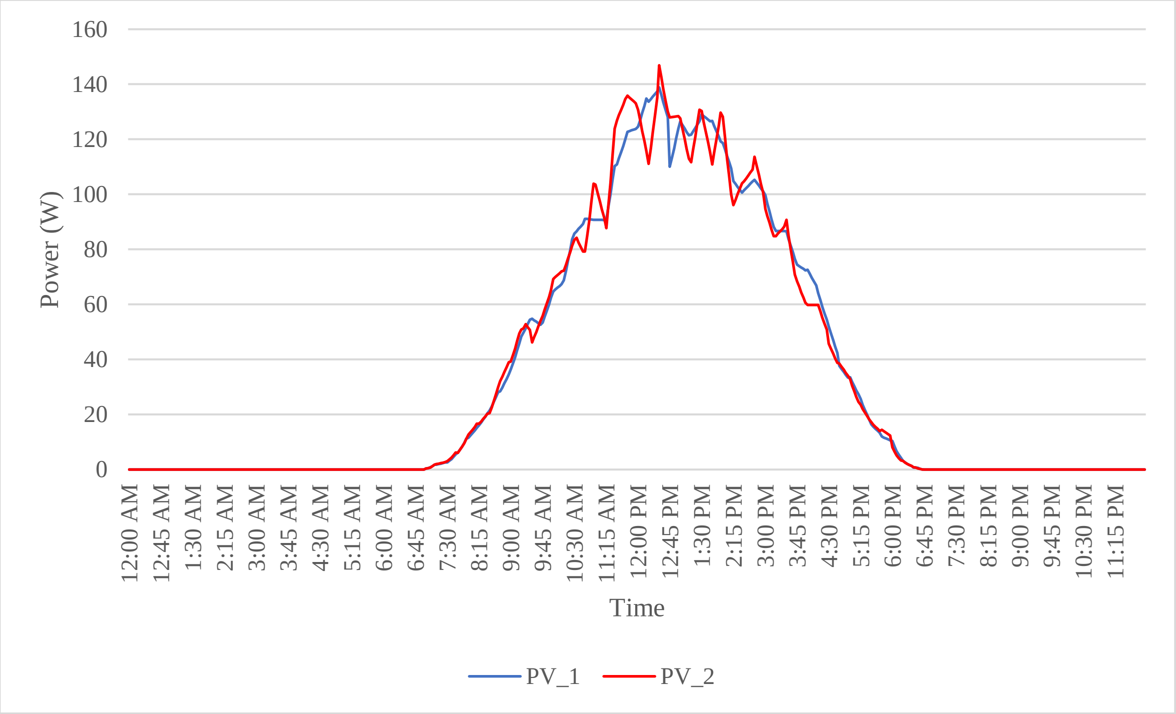

Figure 15: Rooftop Solar Systems Output.

4.5. IMPLEMENTED SCENARIOS

For each village, three scenarios of three different aggregation models are executed during the Peak- periods of demand (Day/Night peak); therefore, the DR event takes place between (12:00 - 14:00) and (18:00 -20:00), the proposed scenarios are presented in table (8).

Table 8: The proposed scenarios for the study.

Scenario ID	Explanation	Time of DR event	Duration	N of LA
A	All the DR participants respond to the DR event simultaneously.	12:00 - 14:00 18:00 -20:00	2 hours	1

Scenario ID	Explanation	Time of DR event	Duration	N of LA
B	The DR participants are divided into three groups randomly, and they respond to the DR event sequentially.	12:00 - 14:00 18:00 -20:00	2 hours	3
C	The DR participants are categorised into groups using the clustering method according to the responding time, then they respond to the DR event sequentially.	12:00 - 14:00 18:00 -20:00	2 hours	3

- Scenario (A)

This scenario corresponds to the simulation of the demand profile of the model's consumers, considering that the DR event takes place at 12:00 (day peak) and 18:00 (night peak). Each event lasts for two hours, and all DR participants respond to it simultaneously. In other words, the ISO request the aggregator to participate in the DR event through the total DR capacity. As a result, all the aggregated capacity of the participants engages in the event.

- Scenario (B)

This scenario corresponds to the simulation of the demand profile of the model's consumers, considering that the DR event takes place at 12:00 (day peak) and 18:00 (night peak). The DR participants are grouped in groups randomly; each group presents one aggregator. The response to each group is monitored and compared to the responses of the other groups.

- Scenario (C)

This scenario corresponds to the simulation of the demand profile of the model's consumers, considering that the DR event takes place at 12:00 (day peak) and 18:00 (night peak). The DR participants are grouped in k groups using a clustering algorithm (k-means); the number of the groups is determined by the elbow method to ensure the optimal number of clusters. Like the previous scenario, each group presents one aggregator. The response to each group is monitored and compared to the responses of the other groups.

5. RESULTS

This section presents the obtained results of the implemented simulations on the case studies. In this case, the outcomes of 14 simulation processes and the simulations in Simulink related to village I &II, the results of the first and second case studies are presented in subsections 5.1, 5.2 respectively, then subsection 5.3. shows the conclusions of the respective section.

5.1. VILLAGE I

As mentioned previously, this case study shows the model of /30/ consumers with the installed appliances. The simulation of the load profile in the initial state is performed then the three different scenarios.

5.1.1. SCENARIO A (ALL THE DOMESTICS RESPONSE TO THE DR EVENT)

For scenario A, all the controllable appliances respond to the DR event, assuming there are two events, the first one between (12:00-14:00), and the second one between (18:00-20:00), figure (16) illustrate the network response to the DR events in scenario A. The consumption has been reduced by 60%.

However, the load curve suffers from a significant instant reduction, which implicates severe consequences to the system, and there is a high probability of leading to a blackout. the response of the system to this scenario shows that associating all DR participants to one load aggregator will lead to harsh outcomes, not to mention the unnecessary effects on the consumers.

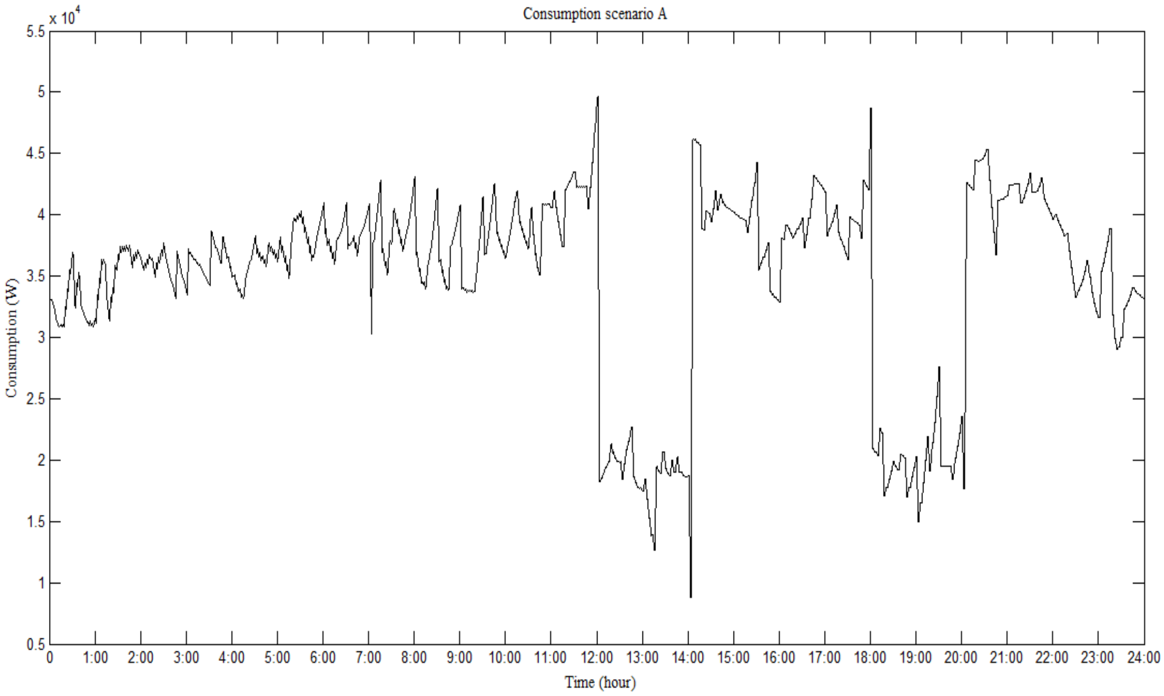

Figure 16:Consumption in Scenario A / Village I.

5.1.2. SCENARIO B (RANDOM DOMESTIC GROUPING)

This section illustrates the network's responses to DR events when the controllable appliances are divided into three random groups as shown in table (9); there is no preference in the division process, the first group includes /23/ appliances, the second group includes /21/ appliances, and the third one includes /23/ appliances. the arrangement of the appliances is done by dividing them ascendingly, where the randomness comes from choosing the number of the appliances in each group, in addition to the ignorance of any feature related to them.

Table 9: The random grouping of the appliances in scenario (B).

GROUP 1	GROUP 2	GROUP 3
WH_1	AC_8	AC_20
AC_1	DW_8	WH_21
DW_1	WH_9	AC_21
WH_2	AC_9	WM_21

GROUP 1	GROUP 2	GROUP 3
AC_2	WM_9	DW_21
DW_2	DW_9	AC_22
WH_3	AC_10	WM_22
AC_3	AC_11	DW_22
WM_3	FH_12	AC_23
DW_3	AC_13	AC_24
WH_4	DW_13	FH_24
AC_4	AC_14	AC_25
WM_4	AC_15	FH_25
DW_4	FH_15	AC_26
AC_5	AC_16	FH_26
WM_5	FH_17	AC_27
DW_5	AC_18	FH_27
AC_6	WM_18	AC_28
DW_6	DW_18	FH_28
WH_7	WH_19	WH_29
AC_7	DW_19	AC_29
DW_7		WH_30
WH_8		WM_30

The responses are presented in figures (17-18-19), respectively. For the first two groups, the consumption reduced by almost 10%, and apparently, there is no difference between the two responses, while for the third random group, the consumption reduction is 50% of the total loads, which (as scenario A), may lead to severe problems to the system.

However, the responses of the random group indicate that the uncalculated reduction has one of two outcomes, either the load reduction is not efficient enough, and there is a need to engage more appliances’ groups in the DR event, or the load reduction is too much which is not the optimal response to the event. it is clear that with randomly aggregating the loads, the responses of the network do not meet the study objectives; therefore, it is not reasonable to use a random aggregating method.

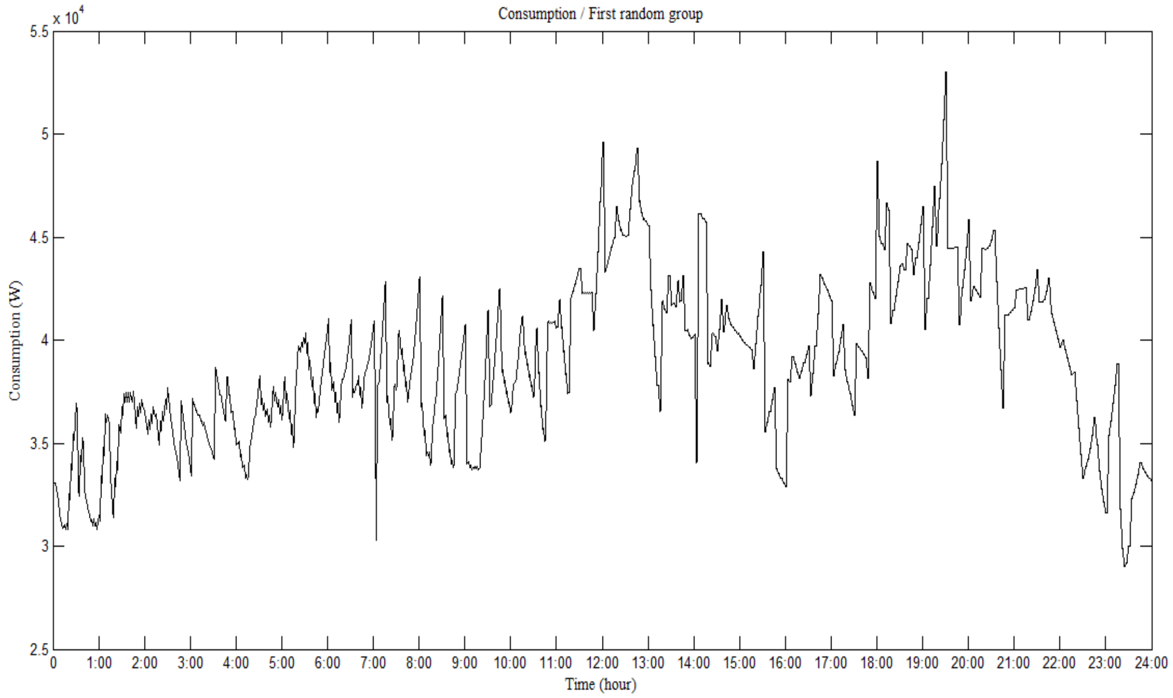

Figure 17:Consumption in first random group / Village I.

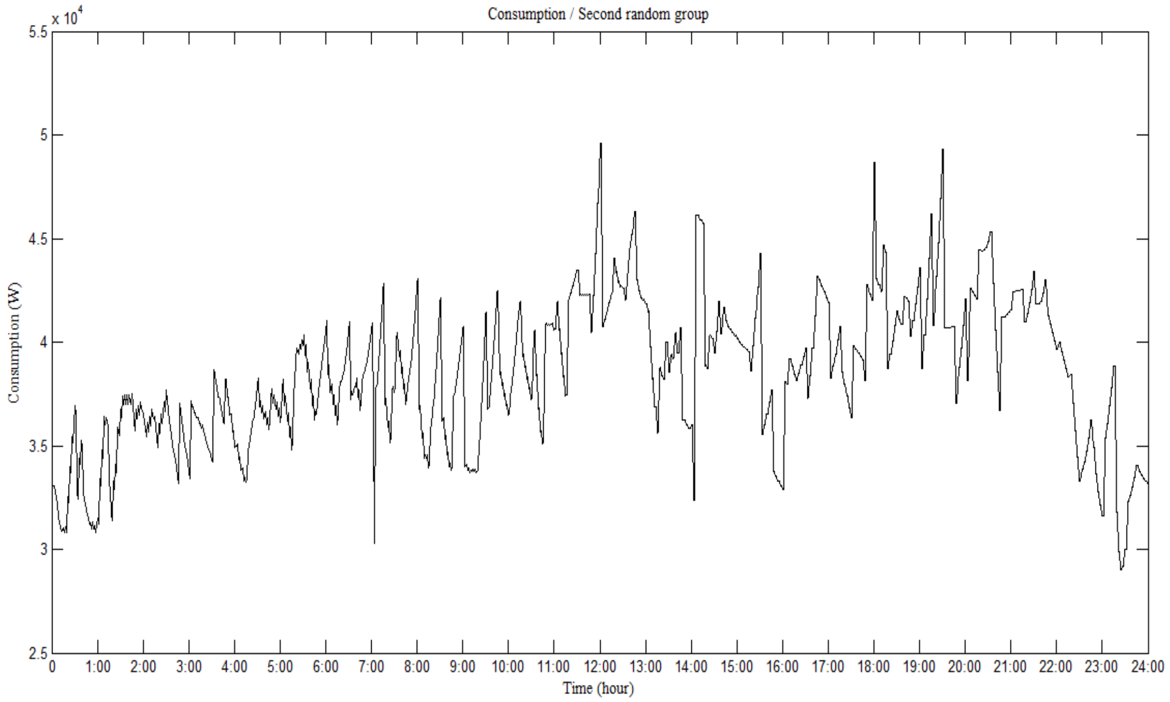

Figure 18: Consumption in second random group / Village I.

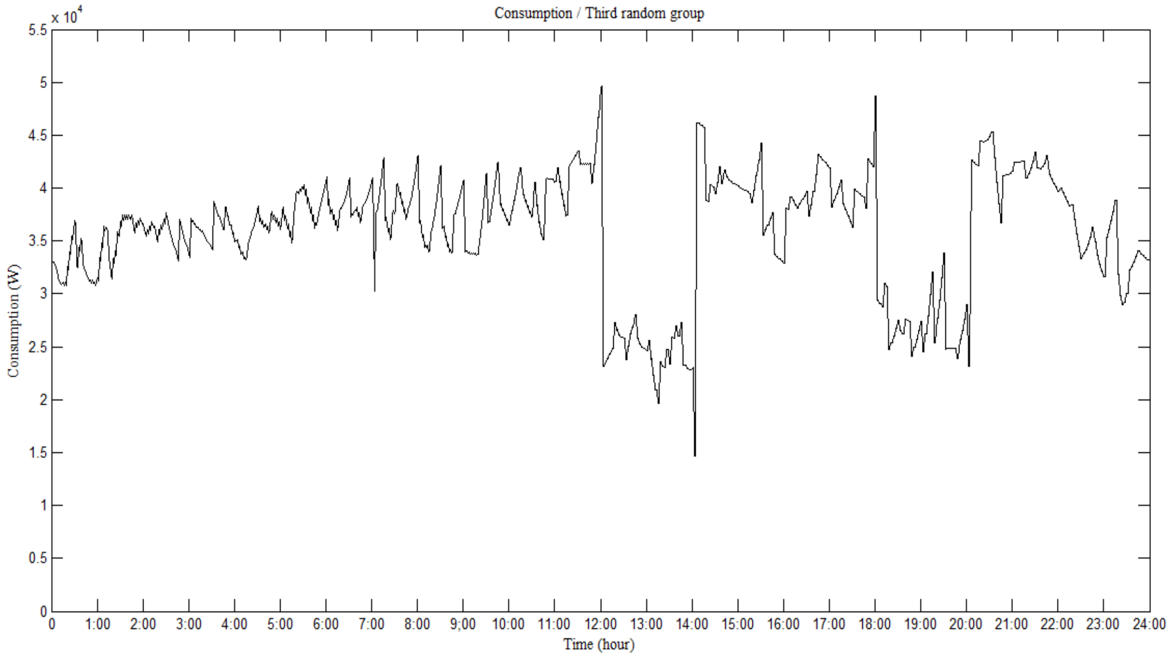

Figure 19:Consumption in third random group / Village I.

Figure (20) gives a clear view of the different responses in this scenario, where the participation of the first group is not enough, and the response of the third group is too much. In contrast, the response of the second group may consider good but not optimal. Due to the lack of information, it is impossible to detect the right group to engage in the DR event; for instance, engaging the third group would make a massive disturbance in the system.

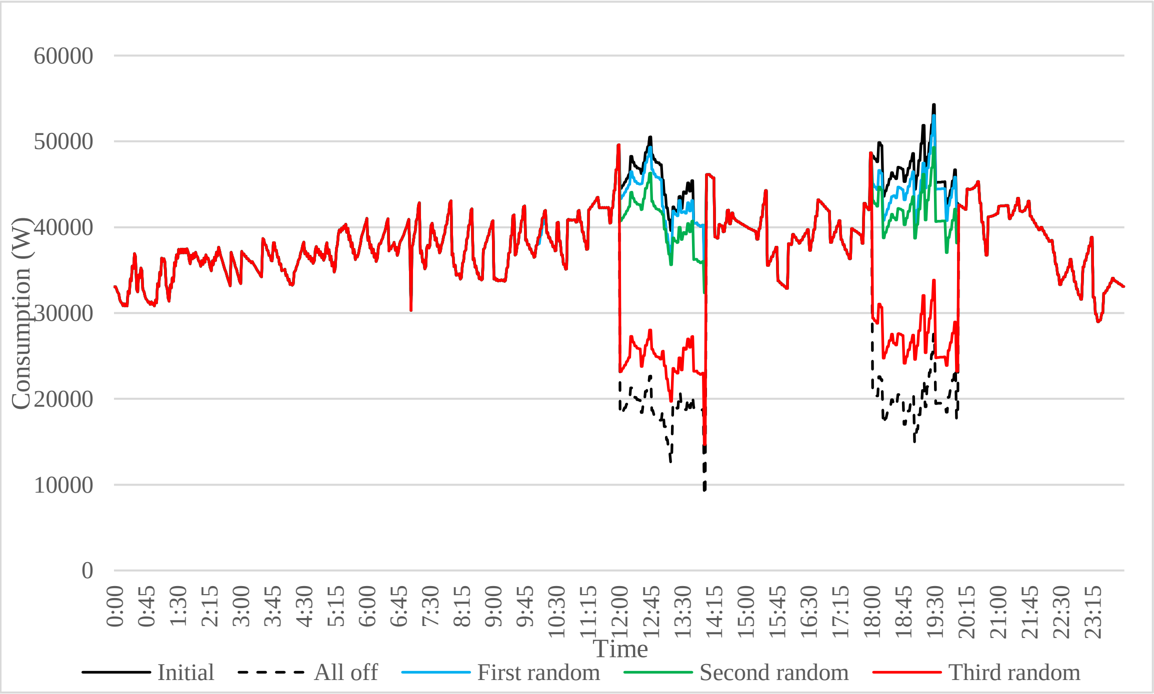

Figure 20: Comparison – Scenario B / Village I.

5.1.3. SCENARIO C (CLUSTERED DOMESTIC GROUPING)

The clustering method presents the optimal approach to categorise the model’s appliances into different groups according to their standard features; for village I, the clustering is done according to the reduction capacity of the appliances and to the response time to the DR event. However, the clustering method is k-means, but it is essential to choose the number of clusters (k) before the clustering process is essential.

To choose the number of clusters for the appliances, the elbow method is applied to obtain the optimal number of k. This method is implemented using Rstudio software. According to this method, the plot's bend is considered an indicator of the appropriate number of clusters. Figure (21) illustrates that the optimal number of clusters for the first case study is three clusters.

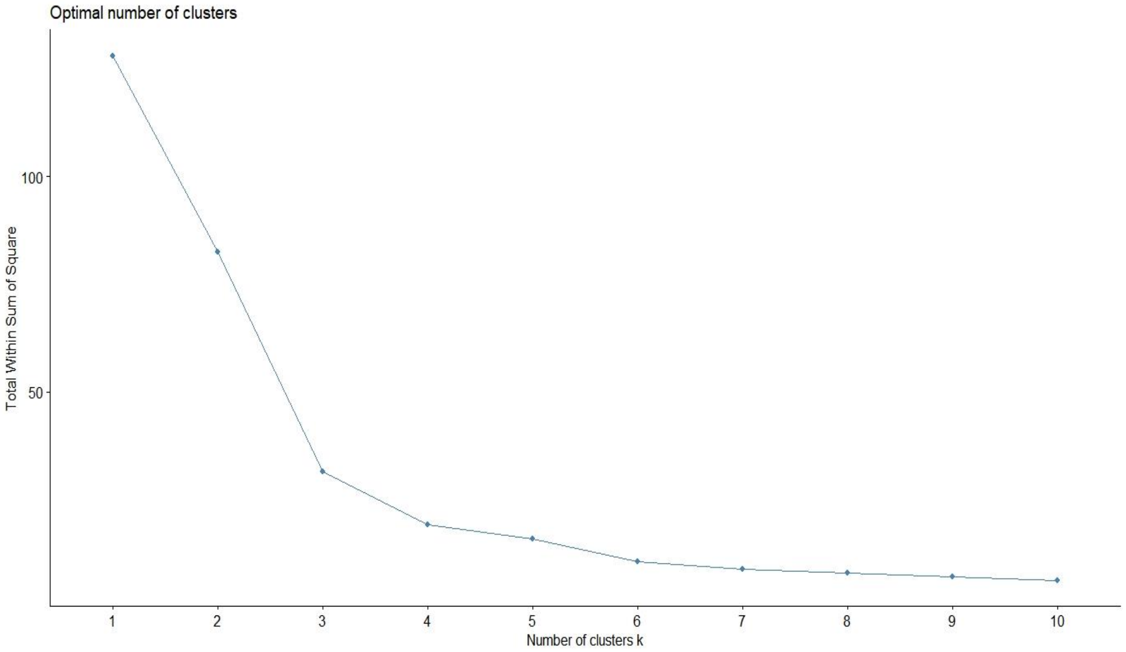

Figure 21: The optimal number of k for the village I (Elbow method plot).

After choosing the clusters numbers (k), the k-means algorithm is performed for data clustering, and the results are shown in figure (22), where the clusters can be assigned to categories according to the appliances' capacity and response time. the suggested terms for the clusters are (Small Capacity/Small Response Time), (Big Capacity/Big Response Time), and (Small Capacity/Big Response Time) for the first, second, and third clusters consecutively.

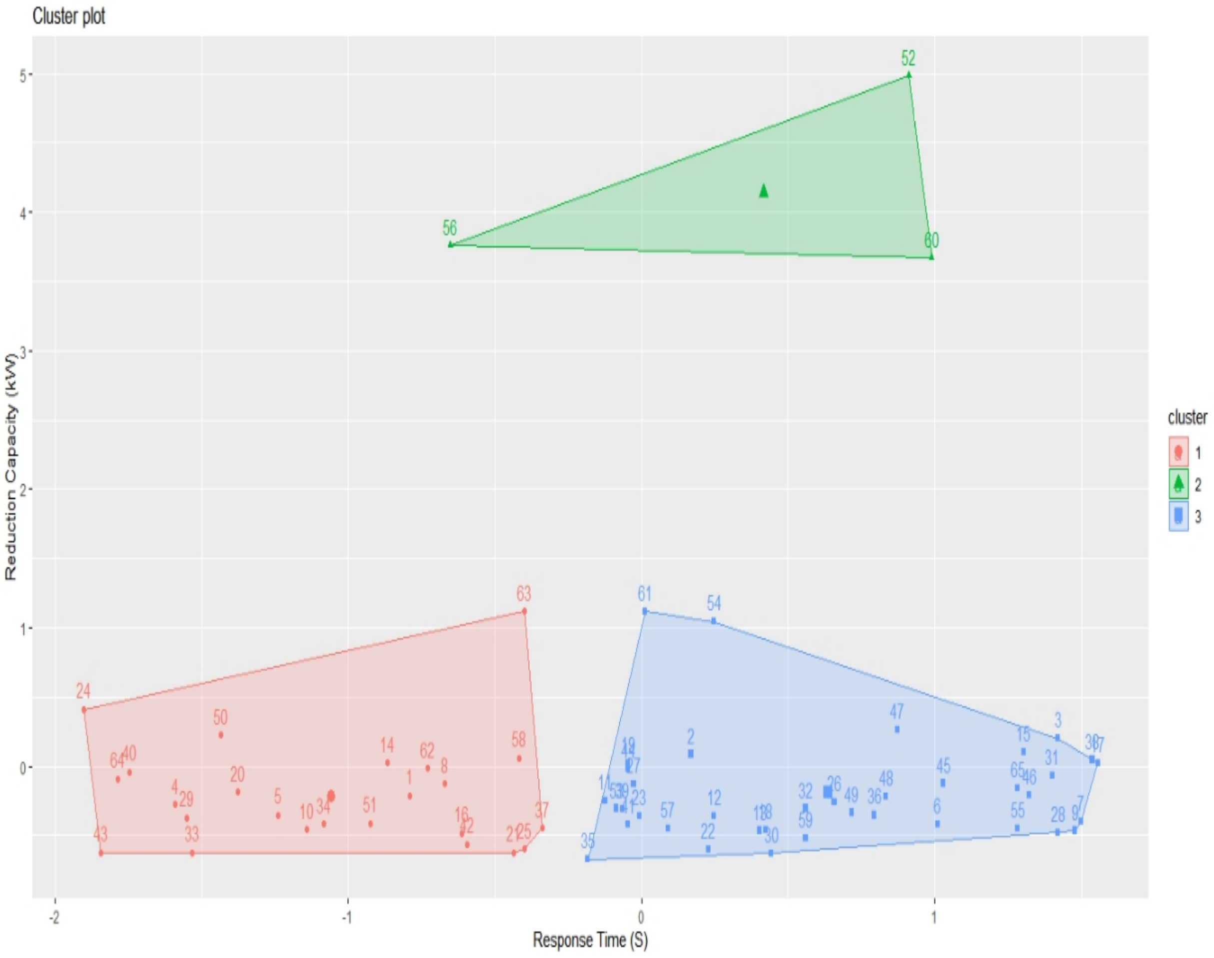

Figure 22: Clustering Groups for village I.

The appliances in the first cluster (Small Capacity/ small Response Time) have /24/ appliances in total; the maximum response duration is /82/ seconds and a total capacity of /16.24/ kW. However, those parameters may consider small compared to the second cluster (Big Capacity/Big Response Time) has only /3/ appliances, and these appliances have a collective capacity of /19.92/ kW and a max response duration of /150/ second. Finally, the third clustered group (Small Capacity/Big Response Time) contains /38/ appliances, and the collective capacity of them is /26.77/ kW with a max response duration of /179/ second. Figures (23-24-25) illustrate the values of each appliance consumption and the response time for each cluster of appliances

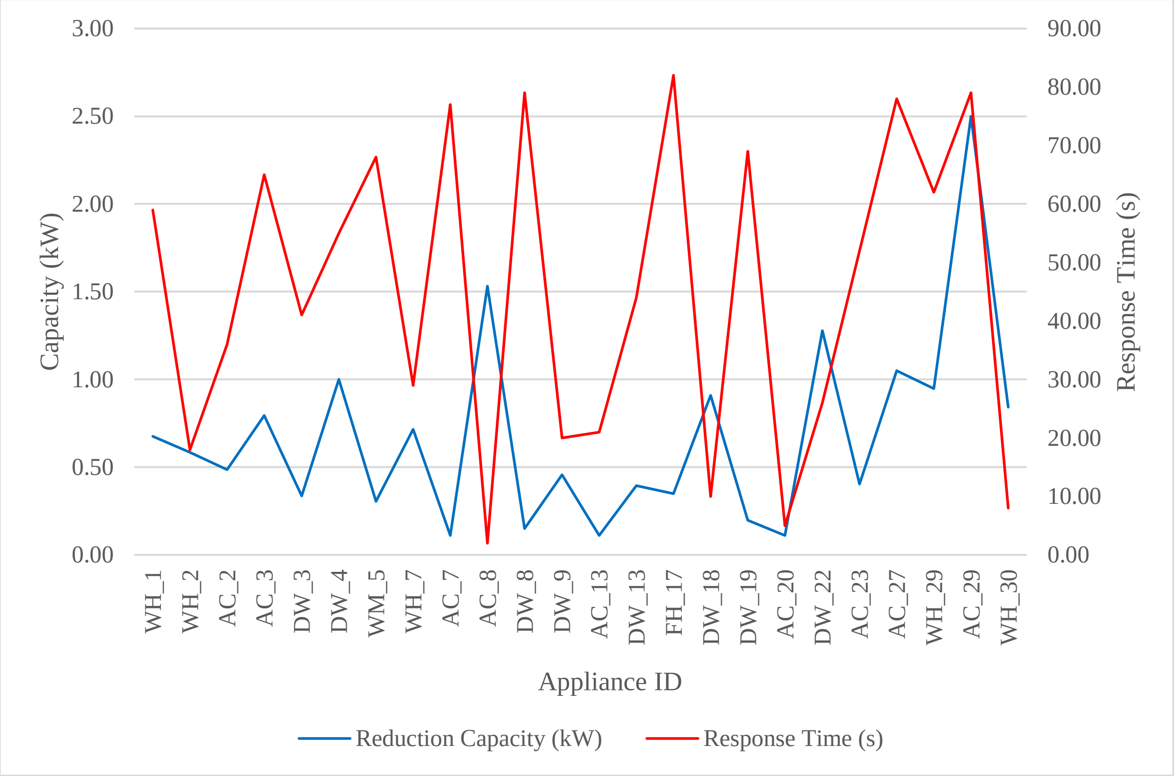

Figure 23: First clustered group/ Village I.

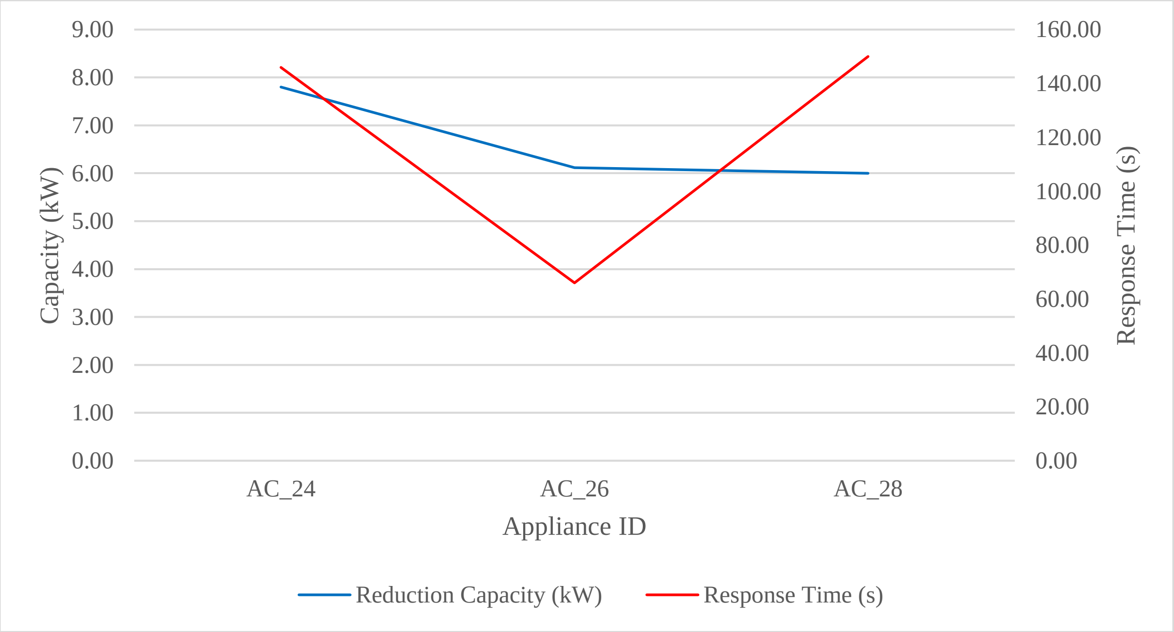

Figure 24: Second clustered group/ Village I.

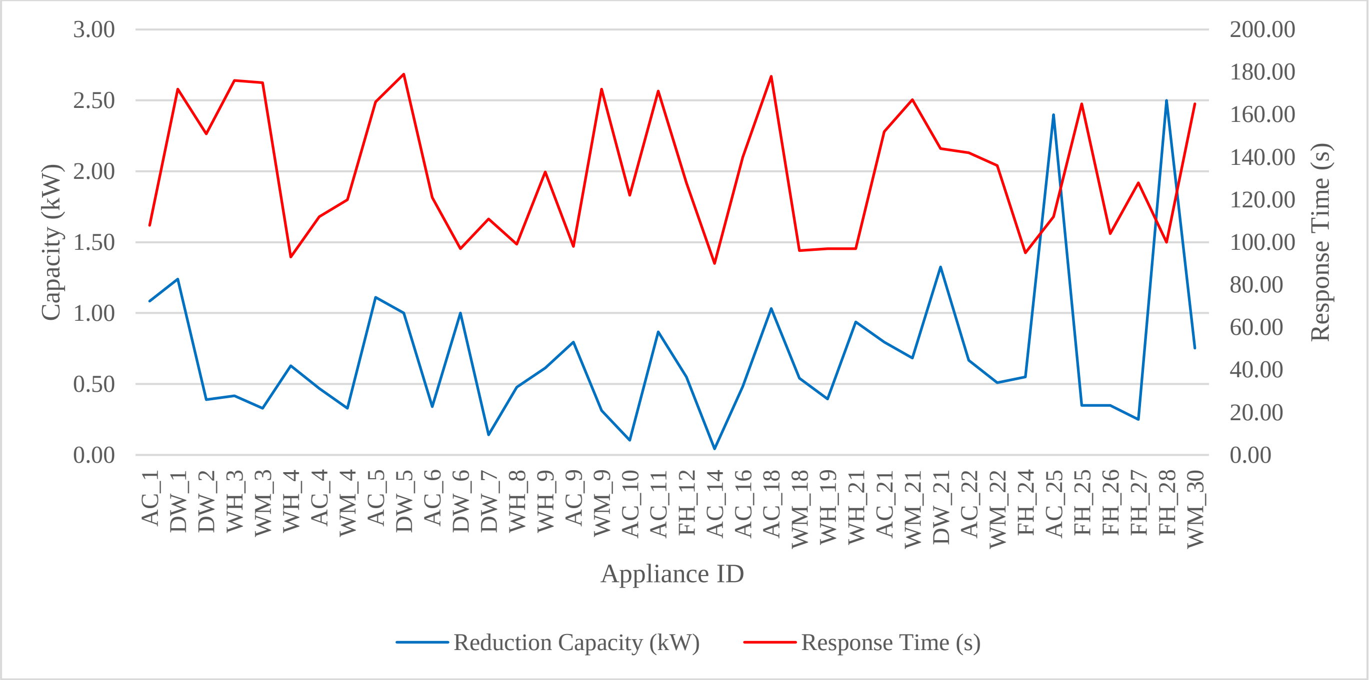

Figure 25: Third clustered group/ Village I.

For scenario C, the clustering mentioned in the previous subsection and the clustering groups is shown in table (10).

Table 10: The clustered grouping of the appliances in scenario (C).

Group 1	Group 2	Group 3	
WH_1	AC_24	AC_1	FH_12
WH_2	AC_26	DW_1	AC_14
AC_2	AC_28	DW_2	AC_16
AC_3		WH_3	AC_18
DW_3		WM_3	WM_18
DW_4		WH_4	WH_19
WM_5		AC_4	WH_21
WH_7		WM_4	AC_21
AC_7		AC_5	WM_21
AC_8		DW_5	DW_21
DW_8		AC_6	AC_22
DW_9		DW_6	WM_22
AC_13		DW_7	FH_24
DW_13		WH_8	AC_25
FH_17		WH_9	FH_25
DW_18		AC_9	FH_26
DW_19		WM_9	FH_27

Group 1	Group 2	Group 3	
AC_20		AC_10	FH_28
DW_22		AC_11	WM_30
AC_23			
AC_27			
WH_29			
AC_29			
WH_30			

Figures (26) presents the response of the system to engage in the DR event for the first cluster; the response of this group (Small capacity/Small response time) reduced the consumption levels and helped to smoothen the load curve at the peak periods, besides that, and because of its features, it may consider an efficient response regarding the volume of reduction capacity involved.

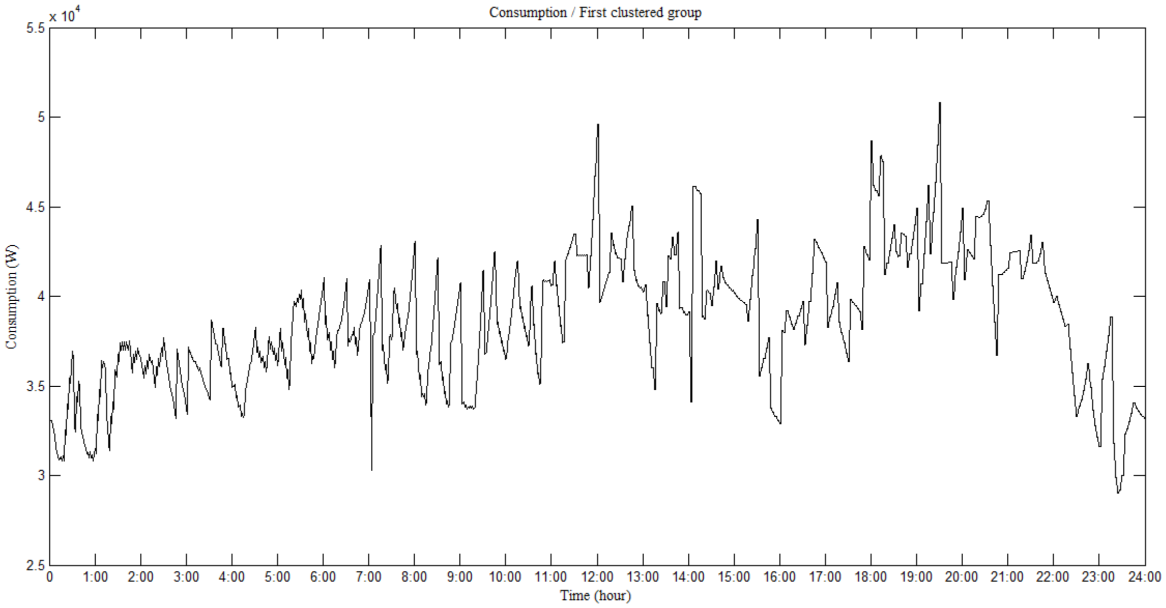

Figure 26: Consumption first clustered group / Village I.

On the other hand, figure (27) presents the response of the second clustered (Big capacity/Big response time) which reduces the consumption significantly, this reduction is useful when the system operator requests a huge reduction in the consumption. however, in the case of using this cluster at the wrong time, it may cause instability issues in the system.

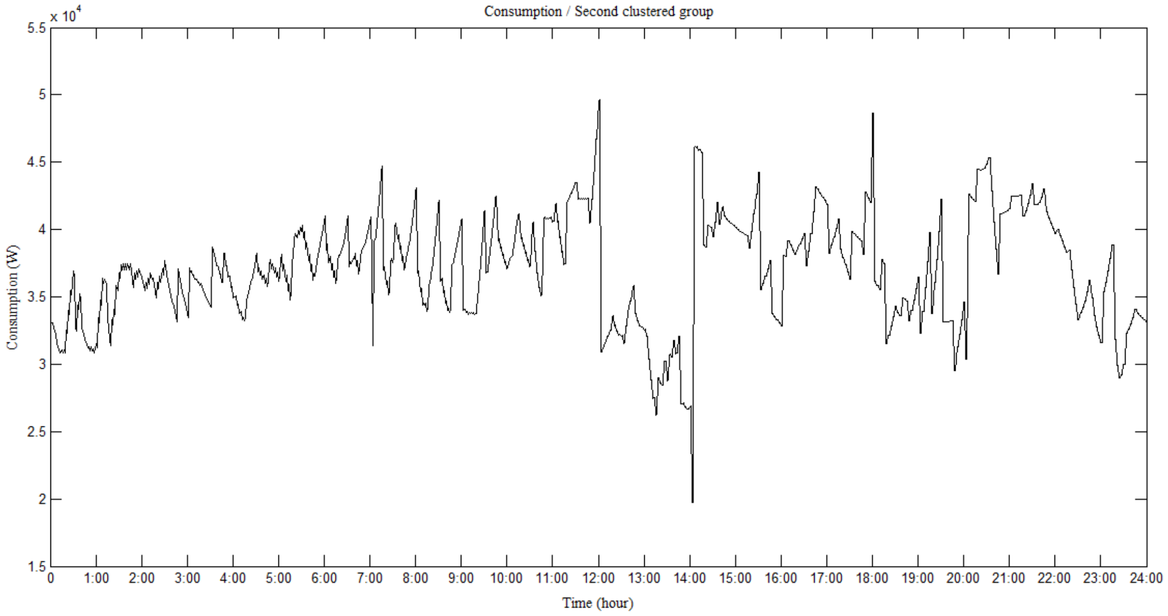

Figure 27: Consumption second clustered group / Village I.

Figure (28) shows the network's response to the third cluster (Small capacity/Big response time), which indicates a good response and enhance the load curve relatively, with some durations of high consumption levels.

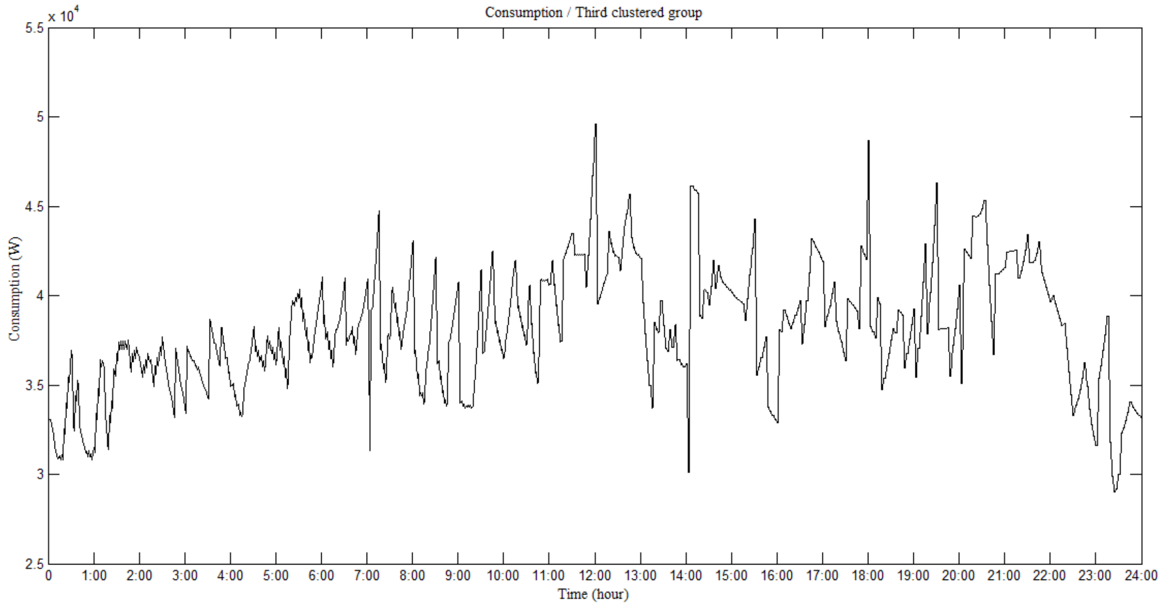

Figure 28: Consumption third clustered group / Village I.

Figure (29) gives a clear view of the different responses of this scenario (C), Through those responses, it is apparent that according to the reduction level that the SO will request, the LA will be able to choose the suitable group to engage due to the prior knowledge that the

LA acquires through clustering, data collection and prediction. Consequently, an enhanced load profile and system risk minimization.

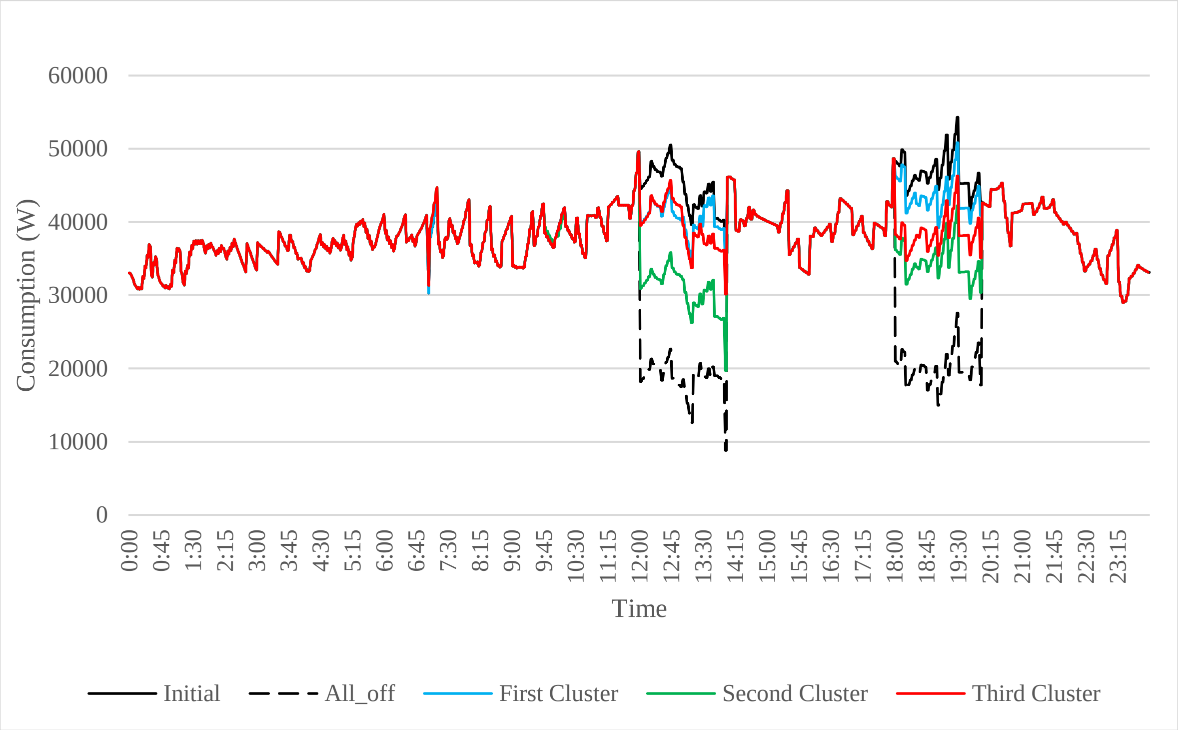

Figure 29: Comparison - Scenario C / Village I.

However, as presented, clustering the appliances in this case study gave us the flexibility and the advantage of choosing only certain appliances to turn off to meet the system needs and optimise the DR participation.

5.2. VILLAGE II

Village II presents a network model consisting of /96/ domestic consumers with two rooftop solar systems; the simulation of the load profile in the initial state is performed, then the same previous scenarios are executed. This case considers larger than the first one but the data available from the DR participants is limited to the install power for the consumers.

5.2.1. SCENARIO A (ALL THE DOMESTICS RESPONSE TO THE DR EVENT)

In this scenario, all DR participants respond with the total capacity; therefore, the load curve profile suffers from a colossal decrease in consumption, which means it is not suitable to use in the peak reduction process and the implications of it are critical, the network response is shown in figure (30).

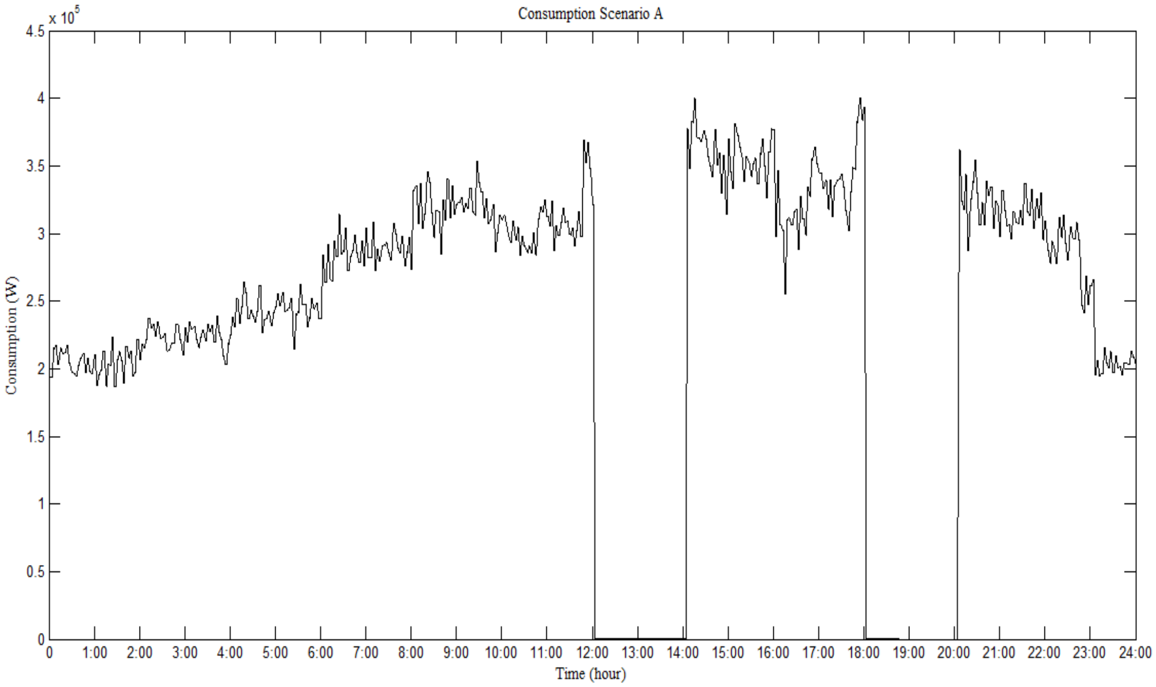

Figure 30:Consumption in Scenario A / Village II.

5.2.2. SCENARIO B (RANDOM DOMESTIC GROUPING)

To perform scenarios B and C, the grouping process is an essential step; therefore, for scenario B, the appliances are grouped randomly as follow; the first group includes /40/ consumers, the second group includes /30/ consumers, and the third one includes /26/ consumers, Although the arrangement of the DR participants for this scenario is done in ascending order according to the participants' ID, this does not mean it is not random, where there are no actual values or preference assigned to the ID, therefore, It can be considered as a simple random way of arranging the participants. Table (11) shows the three random groups for scenario B.

Table 11: The random grouping of the DR participants in scenario (B).

Group 1		Group 2	Group 3
Domestic_1	Domestic_21	Domestic_41	Domestic_67
Domestic_2	Domestic_22	Domestic_42	Domestic_68
Domestic_3	Domestic_23	Domestic_43	Domestic_69
Domestic_4	Domestic_24	Domestic_44	Domestic_70
Domestic_5	Domestic_25	Domestic_45	Domestic_71
Domestic_6	Domestic_26	Domestic_46	Domestic_72
Domestic_7	Domestic_27	Domestic_47	Domestic_73
Domestic_8	Domestic_28	Domestic_48	Domestic_74

Group 1		Group 2	Group 3
Domestic_9	Domestic_29	Domestic_49	Domestic_75
Domestic_10	Domestic_30	Domestic_50	Domestic_76
Domestic_11	Domestic_31	Domestic_51	Domestic_77
Domestic_12	Domestic_32	Domestic_52	Domestic_78
Domestic_13	Domestic_33	Domestic_53	Domestic_79
Domestic_14	Domestic_34	Domestic_54	Domestic_80
Domestic_15	Domestic_35	Domestic_55	Domestic_81
Domestic_16	Domestic_36	Domestic_56	Domestic_82
Domestic_17	Domestic_37	Domestic_57	Domestic_83
Domestic_18	Domestic_38	Domestic_58	Domestic_84
Domestic_19	Domestic_39	Domestic_59	Domestic_85
Domestic_20	Domestic_40	Domestic_60	Domestic_86
		Domestic_61	Domestic_87
		Domestic_62	Domestic_88
		Domestic_63	Domestic_89
		Domestic_64	Domestic_90
		Domestic_65	Domestic_91
		Domestic_66	Domestic_92
			Domestic_93
			Domestic_94
			Domestic_95
			Domestic_96

The figures (31-32-33) illustrate the network responses to the DR event when performing scenario B with three random groups. the first group causes a massive reduction in consumption, and it does not serve its objective in enhancing the load curve. while for the second group, the response is less aggressive, but still dangerous to the system and also does not achieve the purpose of consumption reduction. The response of the third random group may consider best than the previous groups, but still not good enough to achieve the system goal with enhancing the load curve.

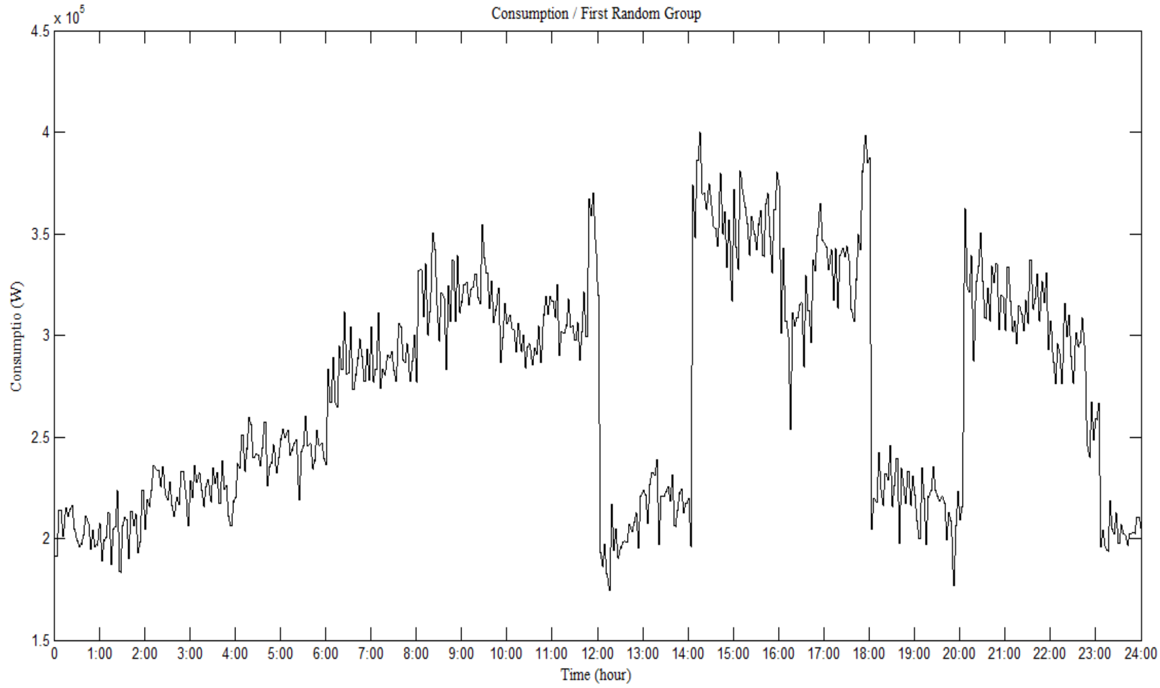

Figure 31:Consumption in first random group / Village II.

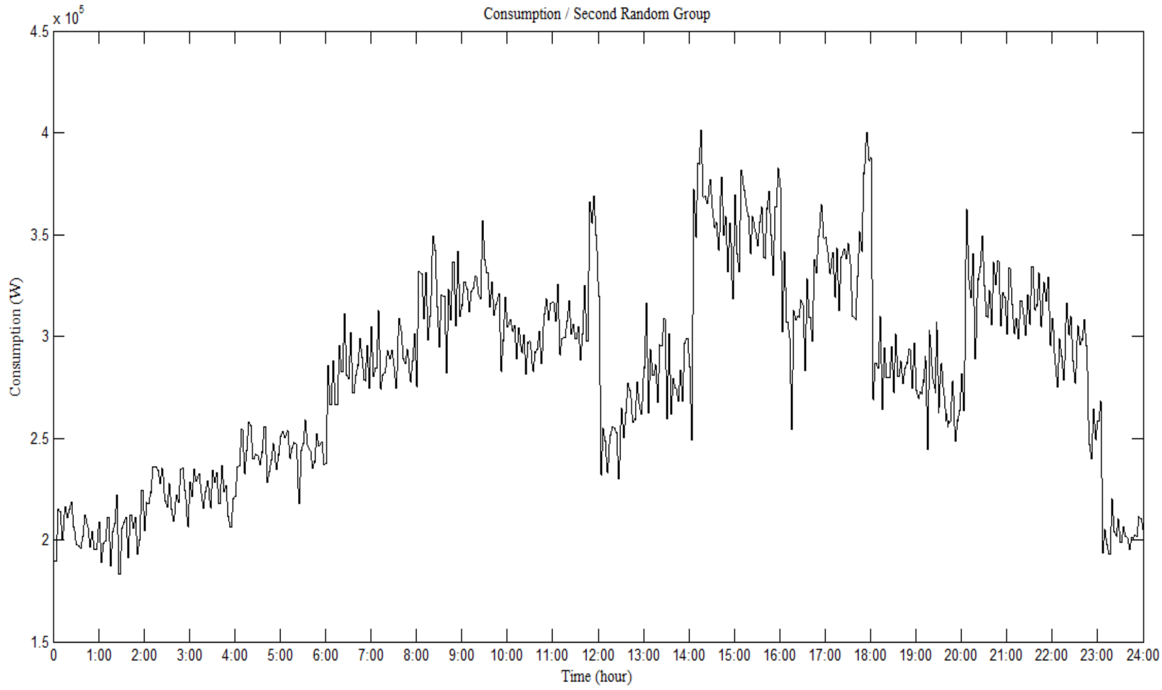

Figure 32:Consumption in second random group / Village II.

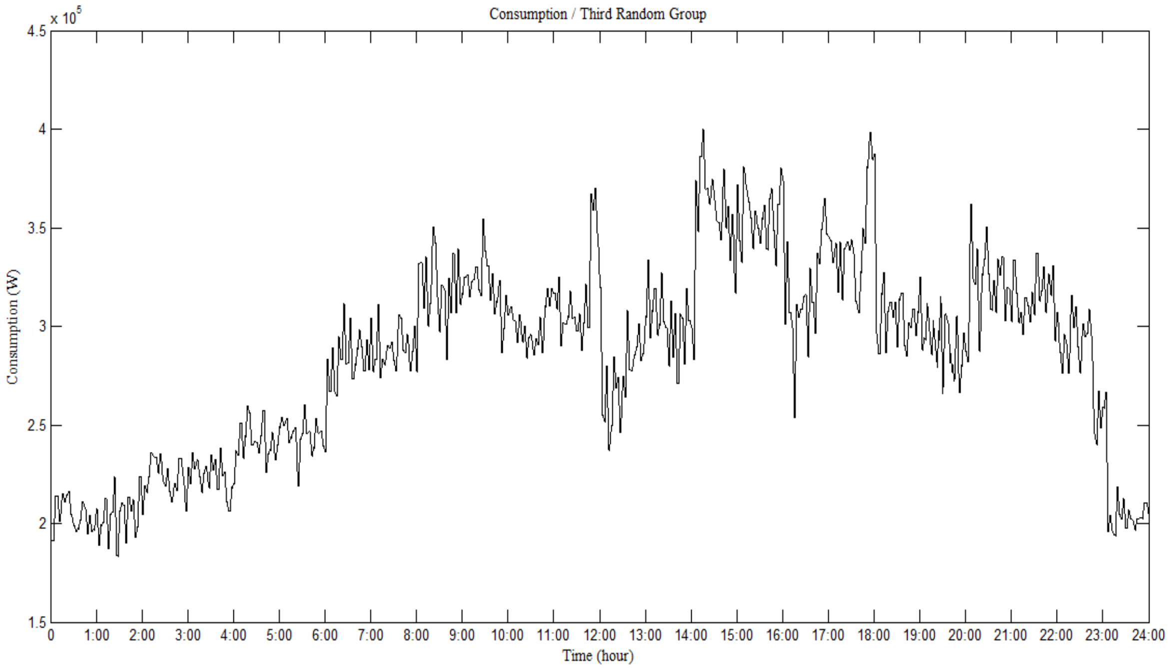

Figure 33:Consumption in third random group / Village II.

Figure (34) compares the scenario B responses, where the reduction in the consumption happened in different levels; however, after grouping, there is no prior information for the loads' consumption; thus, there is no clue to the suitable time of using these groups.

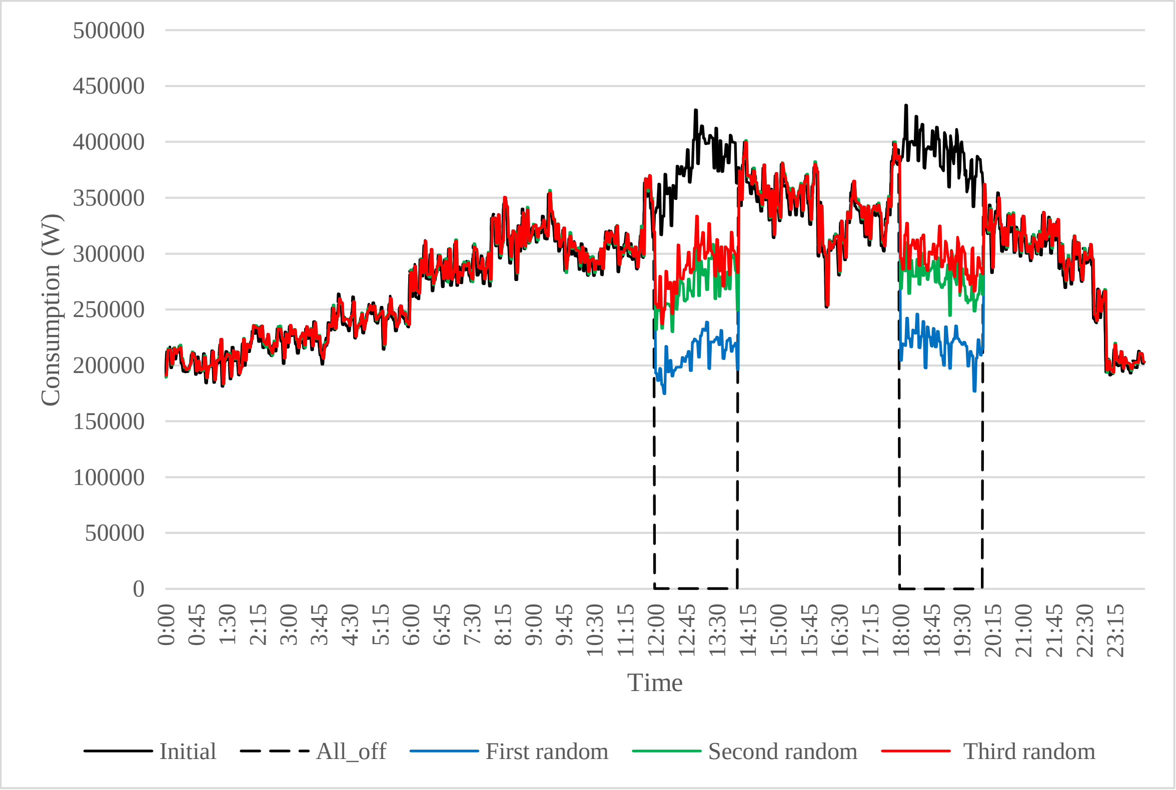

Figure 34: Comparison – Scenario B / Village II.

5.2.3. SCENARIO C (CLUSTERED DOMESTIC GROUPING)

For village II, the clustering method is k-means, and it is performed according to the installed power for each consumer only, and not to each appliance as the first case. Also, it is important to choose the number of clusters (k) before the clustering process.

To choose the number of clusters of the consumers, the elbow method is applied to obtain the optimal number of k, but there are three installed power levels in the network (10350 – 6900 – 3450 W), and it would not be possible to have more than three clusters; hence, the method does not give a clear result for k. Figure (35) shows the elbow method plot.

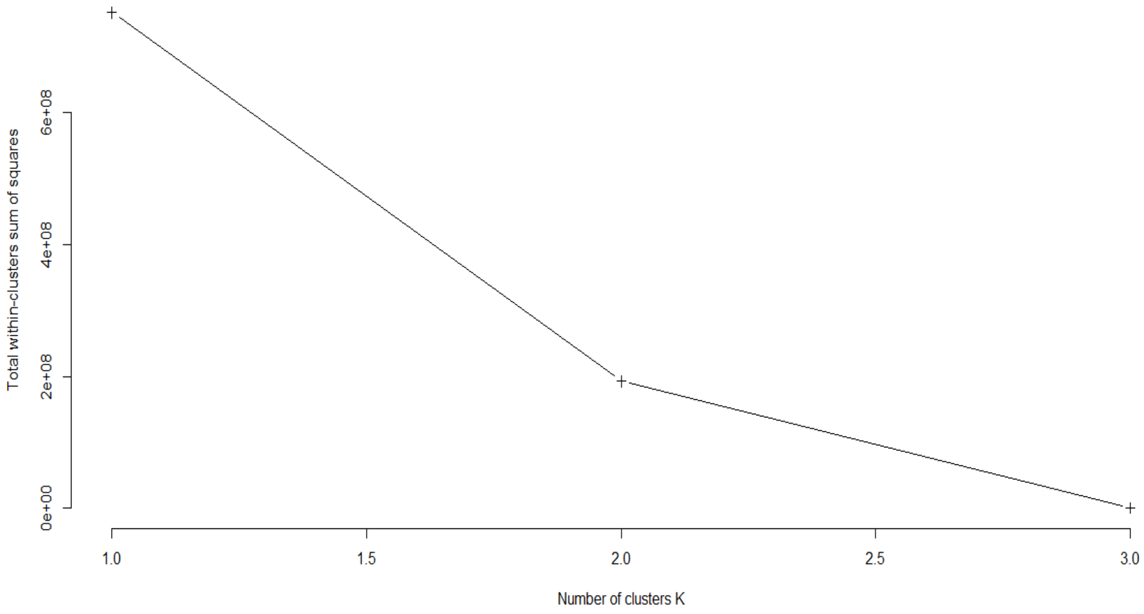

Figure 35: Elbow method plot / Village II.

Therefore, two clustering processes are performed for (k=2,3), and the distribution of the elements is illustrated in figures (36-37) consecutively. The result of elbow methods shows that the similarity percentage between the clusters (between_SS / total_SS) for (k=2) is 74.4%, while for (k=3) is 100%, which indicate that k=3 is a more accurate number of clusters for this case. hence, the number of k is three clusters; and the consumers are grouped into large, medium and small capacity reduction.

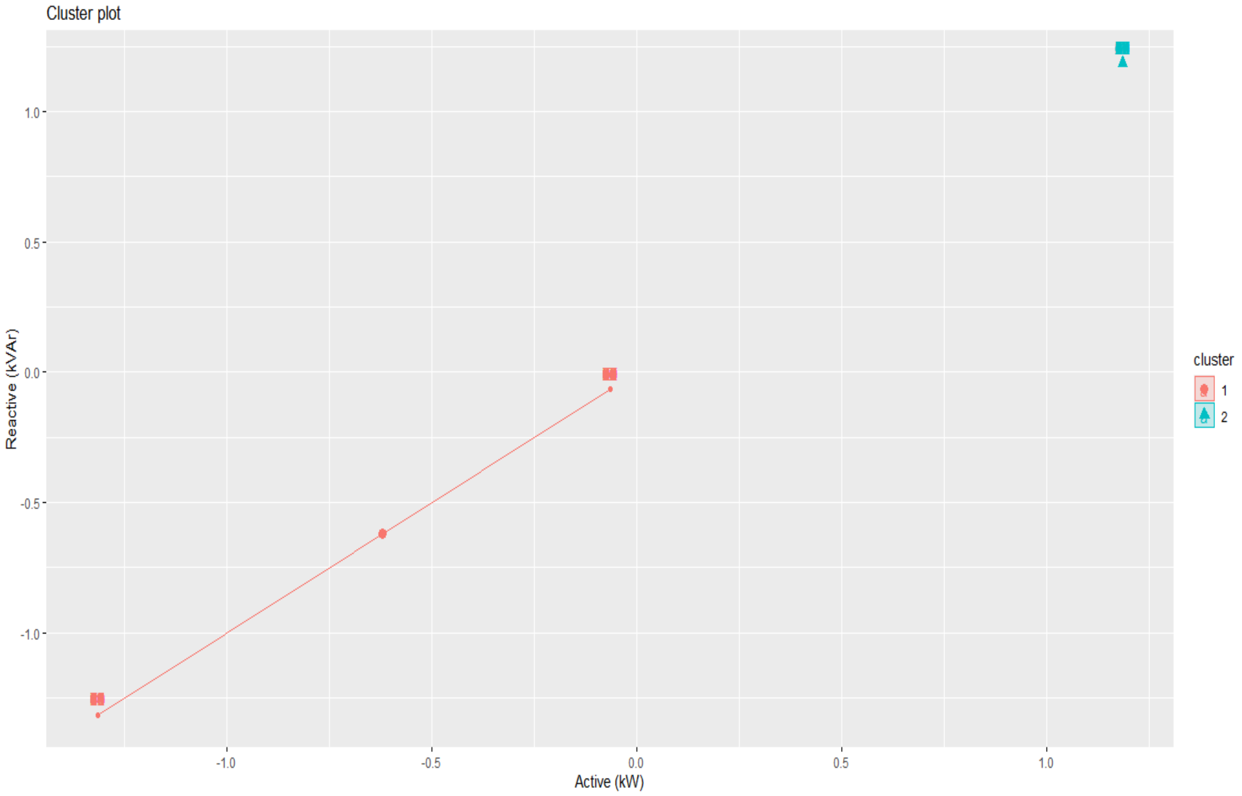

Figure 36: Clustering Groups, K=2.

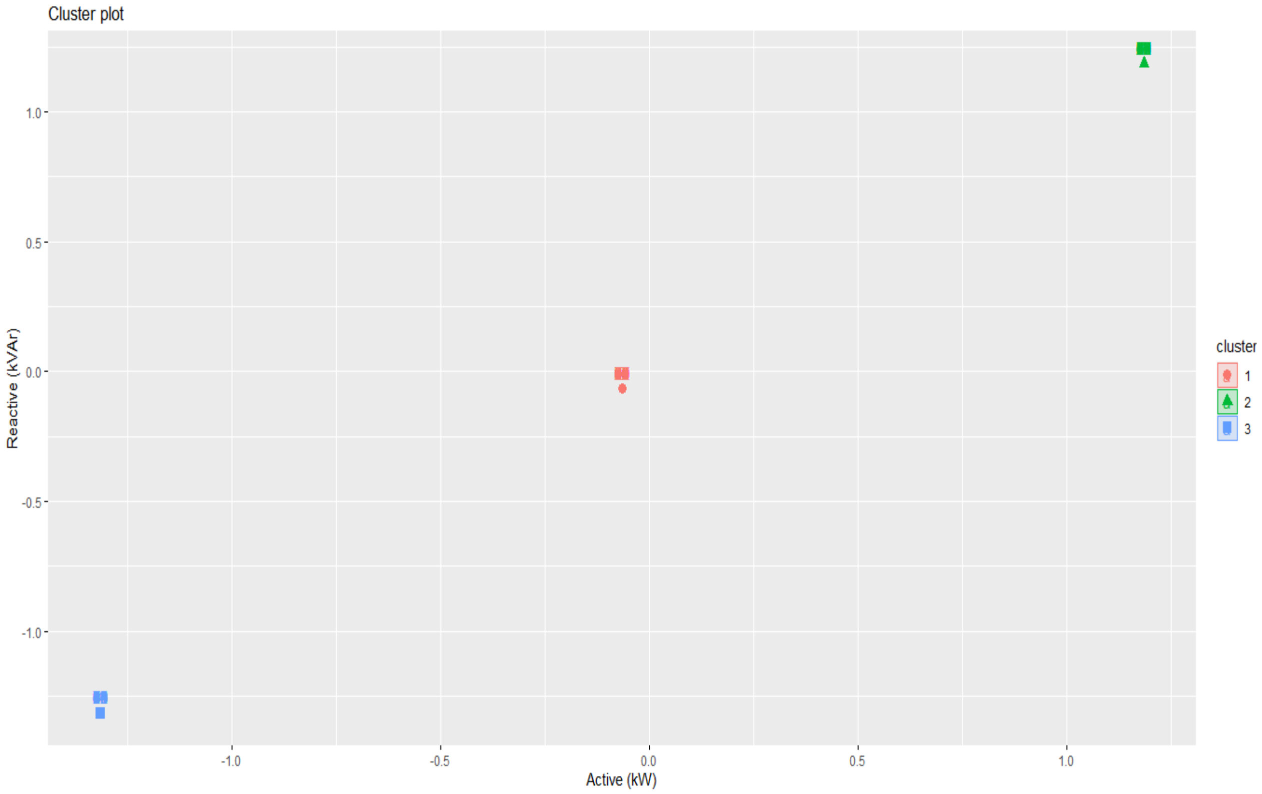

Figure 37: Clustering Groups, K=3.

For scenario C, the consumers' groups are presented in table (12) according to the k-means algorithm into medium, large and small. The first cluster (small capacity) has /24/ consumers, the second cluster (medium capacity) has /35/ consumers, and the third cluster (large capacity) has /33/ consumers.

Table 12:The clustered grouping of the DR participants in scenario (C).

Group 1	Group 2	Group 3
Domestic_4	Domestic_2	Domestic_1
Domestic_11	Domestic_3	Domestic_7
Domestic_15	Domestic_5	Domestic_10
Domestic_16	Domestic_6	Domestic_12
Domestic_19	Domestic_8	Domestic_13
Domestic_21	Domestic_9	Domestic_14
Domestic_30	Domestic_17	Domestic_18
Domestic_31	Domestic_22	Domestic_20
Domestic_41	Domestic_23	Domestic_24
Domestic_42	Domestic_28	Domestic_25
Domestic_44	Domestic_33	Domestic_26
Domestic_46	Domestic_34	Domestic_27
Domestic_51	Domestic_36	Domestic_29
Domestic_53	Domestic_37	Domestic_32
Domestic_54	Domestic_40	Domestic_35
Domestic_56	Domestic_45	Domestic_38
Domestic_60	Domestic_49	Domestic_39
Domestic_69	Domestic_50	Domestic_43
Domestic_70	Domestic_55	Domestic_47
Domestic_71	Domestic_61	Domestic_48
Domestic_75	Domestic_62	Domestic_52
Domestic_81	Domestic_64	Domestic_57
Domestic_83	Domestic_66	Domestic_58
Domestic_85	Domestic_67	Domestic_59
Domestic_86	Domestic_72	Domestic_63
Domestic_88	Domestic_76	Domestic_65
Domestic_93	Domestic_77	Domestic_68
Domestic_95	Domestic_78	Domestic_73
	Domestic_79	Domestic_74
	Domestic_80	Domestic_84

Group 1	Group 2	Group 3
	Domestic_82	Domestic_91
	Domestic_87	Domestic_92
	Domestic_89	Domestic_94
	Domestic_90	
	Domestic_96	

The network’s responses in scenario C are shown in figure (38-39-40), the variation among the responses is obvious; for the first cluster (small capacity), the peak reduction is achieved, and the load curve is relatively enhanced, while for the second and third clusters, the reduction is much larger than the first one. however, the second and third clusters are not suitable for peak reduction and enhancing the load curve, but at the same time, they might be useful for serving other purposes such as certain types of ancillary services (reserves).

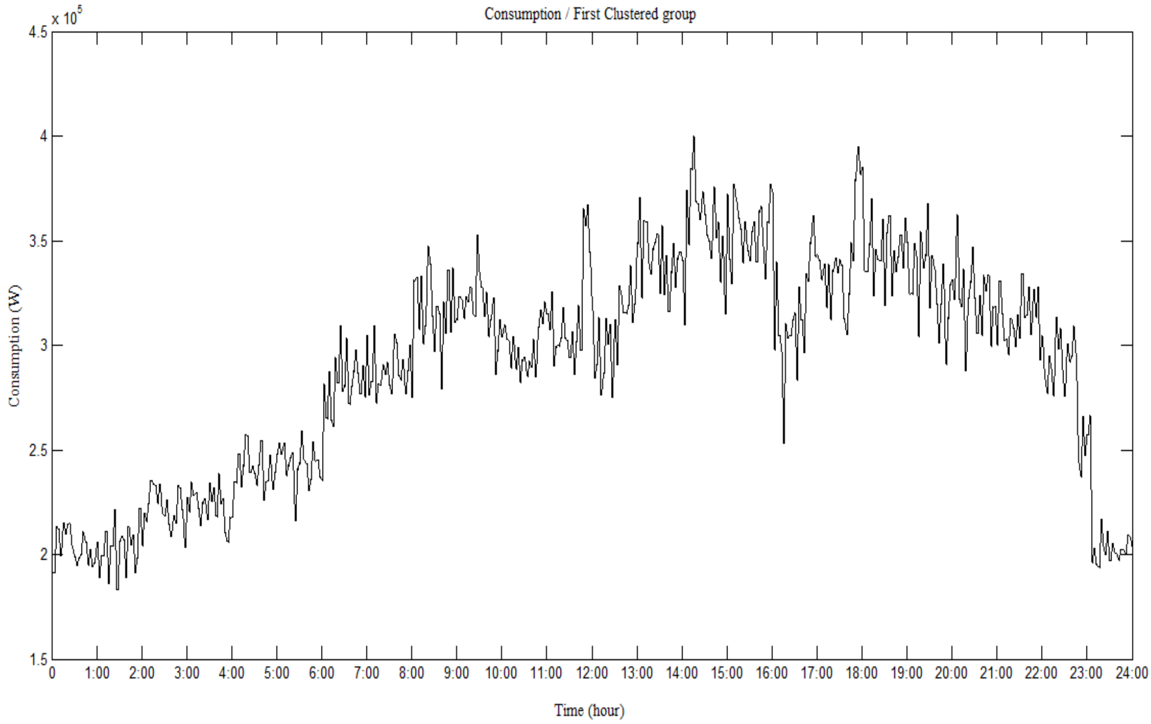

Figure 38: Consumption first clustered group / Village II.

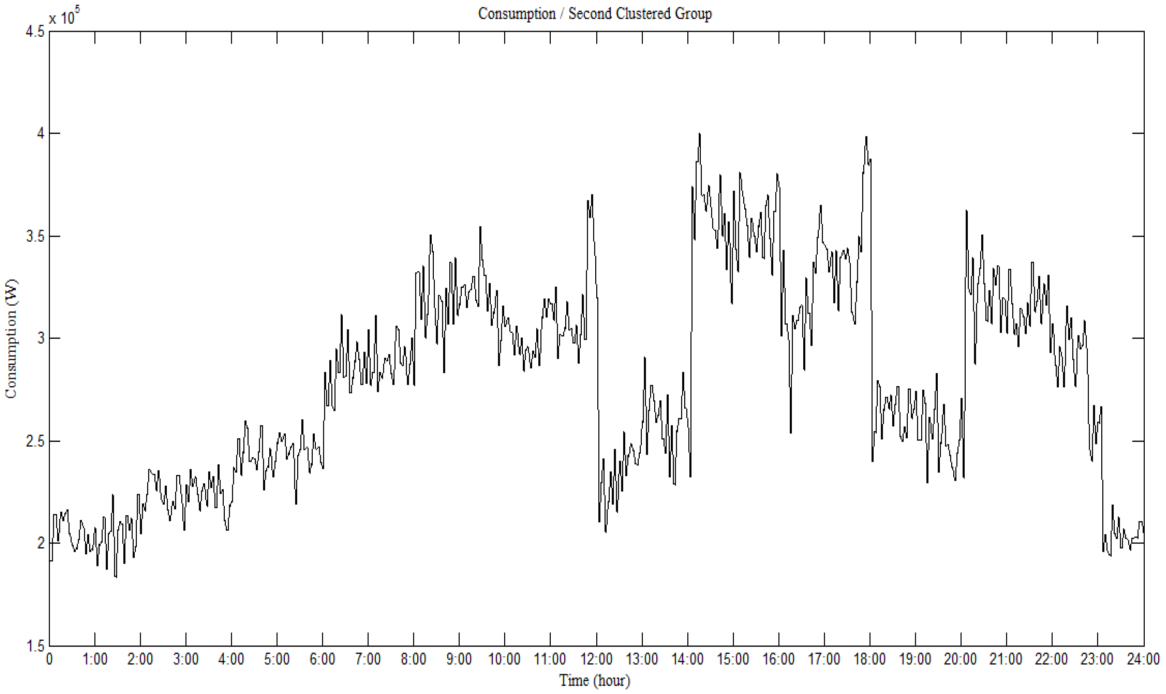

Figure 39: Consumption in second clustered group / Village II.

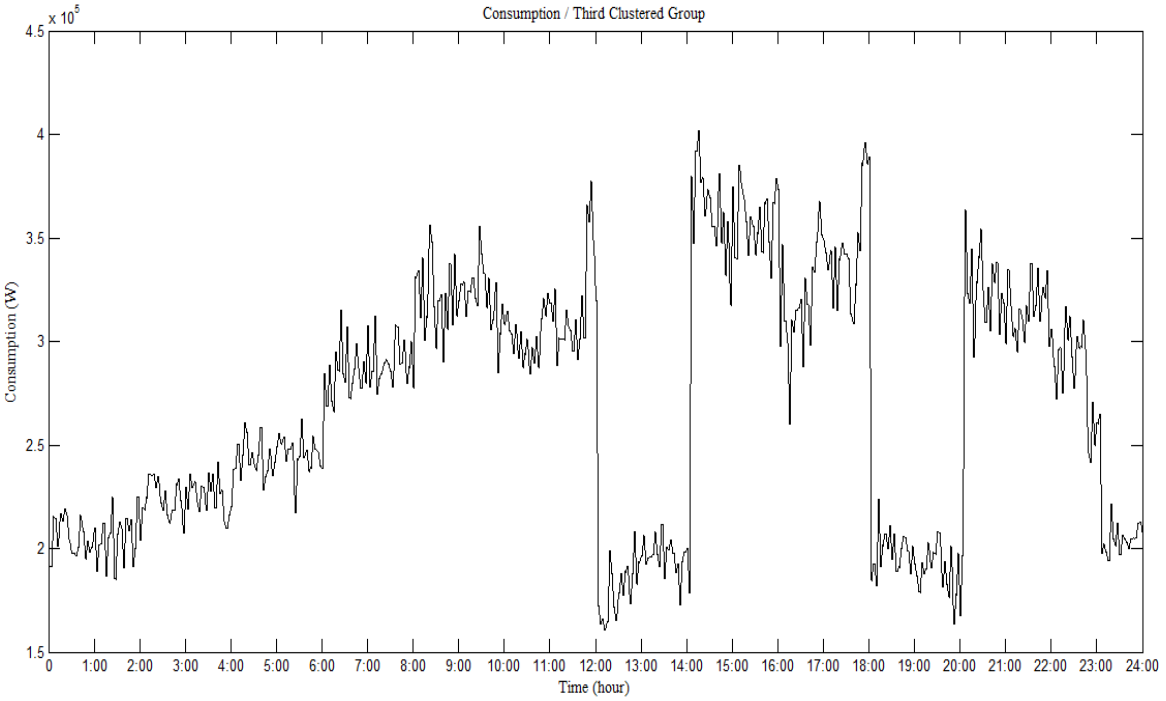

Figure 40: Consumption third clustered group / Village II.

However, comparing the three responses together in figure (41), the LA can determine consumption reduction from each group and engage the group according to the wanted reduction; unlike the same scenario in the FCS, the installed capacity only is not enough to ensure achieving the objective of the DR events, therefore, acquiring more data about the DR participants enhances the response of the LA to the DR events.

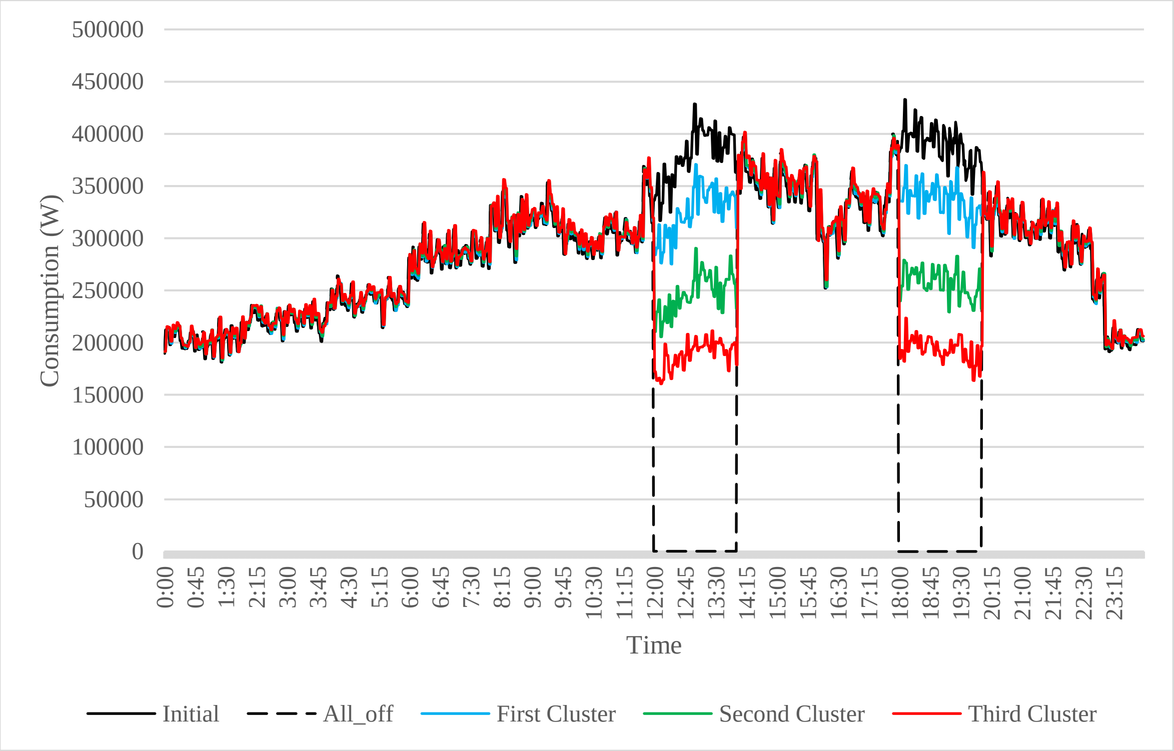

Figure 41: Comparison –Scenario C / Village II.

5.3. CONCLUSION

This chapter presented the simulation results of the proposed case studies, and from these results, we saw that the LA could reduce the demand significantly and provide the system with peak reduction. Moreover, the reduction can be more harmful to the power system when there is no previous information about the DR participants. In both cases, the responses of different LA models provided the objectives of reducing consumption but not enhancing the load curves. While at the same time, some of the responses were highly aggressive when one LA is engaged in the DR event. On the other hand, applying the cluster analysis on the DR participants gave more reasonable outcomes, especially when choosing clusters with more known features. However, it was clear that the more information we acquire about the DR participants, the more accurate clustering results we get, hence the better response from the LA.

6. CONCLUSION

This chapter finalizes the thesis by providing the main conclusions of the present work in section 6.1. Section 6.2 identifies several paths for future research work to be explored.

6.1. MAIN CONCLUSIONS AND CONTRIBUTIONS

This thesis proposes a residential energy management system to discuss the role of different load aggregator models in the process of peak reduction in small networks. The primary approach in the thesis employs the available controllable loads on the consumers' side to implement load reduction based on the loads' features. The load reduction is based on the implementation of DR programs and load aggregation models supported by the clustering method.

In other words, the proposed models have been reduced the power demand during peak hours periods in the electrical system through power reduction implemented based on taking advantage of the mutual characteristics of the DR participants in three different scenarios. DR programs provide an essential tool to provide the system with the necessary reliability, especially in case there is a lack of supplies or during unexpected events. However, this work shows that the impact of the DR event is significant to the load profile from the point of smoothing and flattening the load curves during high demand periods, nevertheless, the incentives that the consumers get to benefit from those programs. Furthermore, this work shows that the load aggregator has the potential to play a key role in creating value that benefits the power system, combined with clustering which is another key factor in this thesis's approach for power reduction. DR program has been implemented in two different case studies to show their behaviours in the loads' consumption patterns. In those case studies, different features of the DR participants are considered: for the first one, the appliances consumption profile and the response time to DR event are considered to cluster the DR participants into different load aggregators, while for the second one, the installed power on the consumer side only.

It is observed that aggregating the small-scale DR participants is effective in the process of consumption reduction. Also, the results demonstrated that loads clustering is adequate to determine the amount of reduction prior to the DR event and return the system to a balanced state. The case studies show that load aggregators can reduce energy consumption in peak hours reasonably. On the other hand, aggregating domestic DR participants through load aggregators provides the system operators with the ability to better control and optimize the management processes for the available resources in the system. Also, aggregation gives prior knowledge of the available reduction capacity, enhancing the load profile and shifting it to the desired levels.

6.2. FUTURE WORK

The obtained results from work developed in this thesis provide several future research paths worth exploring. The following list includes relevant ideas for future work:

- Developing the models with a two-way communication approach between LA and DR participants for real-time data processing;
- Improving the models to provide specific certain products of ancillary services.
- Improving the models to cover the consumers comfort side and include their preferences without affecting the efficiency of the system;
- Integrate a higher number of DG units or larger capacity units and study their impact;
- Exploring more Data mining techniques implementations to improve network responses to DR programs;

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