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Original Article

An Exposure on Functional Behaviour of Demand Response Framework in Smart Home Environment

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Abstract *- Smart home issues are effective enough to control and minimize electricity demand and consumption. This architecture works at different levels to capture the power consumption information, process the data, take the forecasting decision, set up the sequence of requests, manage the load and reduce the chances of peak load hours. Various load balancing, allocation and scheduling methods and models were proposed by the researchers. Most of these models were based on demand response-based analysis. The parameter-based or optimization algorithms were integrated into the main model for optimizing the performance of smart home environments. In this paper, a behavioural and functional study is conducted on the demand response framework under different constraints. The paper defined a standard framework of demand response analysis based on scheduling and resource allocation methods. The author also identified the objectives and contributions of researchers to handle the load and higher price situations. Different forms, constraints, and behaviour of the demand response framework are discussed in this paper.*

Keywords *- Demand response, Load balancing, Power usage, Scheduling, Smart home.*

1. Introduction

A smart home[14][15] environment is a user-specific environment in which electricity usage is done by using different kinds of appliances and devices. Either appliances used in the region are smart, or some actuator is integrated to gain information regarding electricity usage and requirement. User-specific or generalized automation and monitoring are accomplished within the environment. Various controllers and monitoring devices are integrated within the environment to reduce environmental emissions and enhance the consumer's comfort. The smart meters are the middle layer of equipment that connects the smart grid and smart home environments. The smart meter identifies the user requirement, records usage, creates a bill and informs the supplier about the electricity requirement. Smart home automation is required to ensure an uninterrupted power supply, reducing power failures and availing electricity in peak hours. This automation and management system ensures an integrated task to identify the supplier with lesser cost, peak hours indication, intelligent load handling and mapping the demand-supply effectively[3][40][41]. Figure 1 shows the integration of the smart grid and smart home in terms of power and information flow. The Figure shows that the smart grid is connected to the smart home using a smart meter.

Smart meter collects the smart grid's power supply, supplier and market price information. This information is helpful in identifying the load-related aspects. The peak load interval, the maximum cost of power at peak time and normal time, and the power availability are taken from the smart grid. This information is communicated to the smart home to take decisions about power consumption[26]. The expected bill information is also evaluated by using this information. The information is communicated from generators to the smart meter, and the smart meter provides information regarding the load. All kinds of information are maintained in Energy Storage System (ESS). Smart meters connect to this storage system to collect and update information. Along with the information, power communication is also performed between the utility grid, smart meter and different components of the smart grid environment [2][6][42].

A smart home and smart energy management system benefit both the electricity consumers and the suppliers. It optimizes electricity usage in the smart home environment and reduces electricity wastage and bills. The smart home system uses various models and methods to automate and optimize the environment. The profile-based matching is one of the effective approaches in which the automation system observes the user behaviour and activities. The appliance usage is recorded along with a user description to identify the energy requirements for an individual in a specific time slot. The profile-based mapping also suggests that a consumer reduces the bill by shifting his activities to some other time slot. The demand and supply-based mapping is another framework used by researchers to reduce the load in smart home environments and to improve reliability [9][19][22][43].

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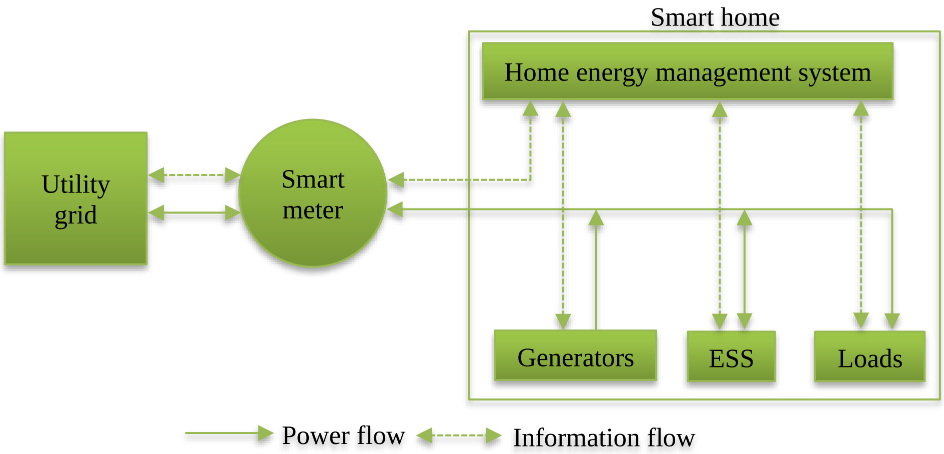

Fig. 1 Integration of smart home and smart grid

Demand response is a consumer comfort-based method that reduces energy consumption and bills without affecting the comfort of an individual. It uses an analysis of the on-demand power supply and schedules the requests based on controllable loads. The load or electricity use can be shifted to control the demand for electricity in peak hours [35]. The price and incentive is one major criterion for deciding the sequence of user request processing. After setting up the demand side, the response or supply side is also defined and managed under price constraints. The electricity supply in different time slots is managed with price consideration. The historical data of appliance usage is considered while dealing with electricity supply. The charging, supply, cycling and mode switching is analyzed with appliances to control and monitor the appliances [28][32]. The demand-response-based method uses different targets and constraints to control the load and enhance flexibility for the demand side. The storage capability is also maximized with the effective utilization of electricity. The load behaviour is analyzed with the decision-making method to reduce the pricing [29][39][44].

This paper explored the smart home architecture and its interconnection with the smart grid environment. The basic component, functions and responsibilities of the smart home environment and the behaviour of different associated components are also explored in this paper. The load allocation and scheduling methods are also discussed with associated features and objectives. In this section, an internal view of a smart home is described with the functional responsibility of its components. The energy management, storage system and its integration with the smart grid are described. In section 2, the work proposed by the earlier researchers on smart home optimization and architectural improvements is discussed. New models and algorithms proposed by the researchers are included in this section. In section 3, a standard multi-stage architecture of a smart home environment is described in this section. The elements and responsibilities of each stage are described. In section 4, the load issue is discussed with some inclusive scheduling and load balancing methods. In section 5, the conclusion and future scope of this study are provided.

2. Related Work

The common issues faced by the smart home environment are the load and high power consumption. It also affects the electricity bill and causes power failure in peak hours. Various models and algorithms were proposed by the researchers to handle the real-time issues of the smart home environment. The researchers defined the demand response analysis based on various models to minimize the load and maximize the energy consumption. In this section, the models and frameworks proposed by the researchers on scheduling and resource allocation are provided and discussed.

Abdalla et al.[12] presented an Electric vehicle and photovoltaic generation-based method to minimize the load and usage cost in a smart home environment. As the electricity usage increases, the load approaches the peak limit, and the pricing of the electricity usage also increases. The power demand-based profile mapping and parametric analysis can be performed to identify the minimum and maximum load situations. In this work, multiple operating modes were defined based on power usage and situations. The availability of PV and load situation control the energy requirement and absorption in the smart home environment. A study was provided to identify power usage from different sources, and based on its load situation was identified. The profile-based load situations were also identified in this work. This work performed the demand and response-based analysis to flatter the load situation in the smart home environment and reduce the cost of electricity usage. Ghosh et al.[14] used the artificial bee colony optimization method on Non-intrusive appliances using a load monitoring technique. This work defined an improved method using computational analysis and a machine learning approach to identify the load. Once the varying load situations are defined, updating the load distribution is defined using the artificial bee colony method to balance the load situation. The proposed method analyzed the real-time situation of the household system and improved its suitability in the smart home environment. It used the demand response-based integrated analysis using bee colony optimization to optimize the load situation in the smart home system. Debadarshini et al.[16] proposed a decentralized system for IoT-based smart home networks to synchronize communication. The communication coordination with peak load analysis was proposed in this work. The proposed model identified the sudden changes in the user requirements and minimized the peak load situations. The average load, peak load and load variations were reduced in this research. A high ratio of user request execution was achieved.

Parsa et al.[17] designed a hierarchical framework to control home appliances. A decision-driven supervisory controller, as defined in the network, to identify and handle the load shedding. A central controller with a smart meter and a few commands was defined to control and optimize the usage of appliances. The integrated control through commands was defined to consider load shedding and to control and reduce power consumption and cost. The brute force-based optimization was applied for implementation in compliance with all associated constraints' specifications. The proposed framework achieved better control and reduced electricity consumption. Swalehe et al.[20] proposed whale optimization-based load management and scheduling algorithm for renewable energy integrated smart home environment. The demand and supply-driven analysis was defined in the system for optimizing the appliance scheduling. The integrated method identified the peak load situation and reduced the cost. The operational management and utility control was achieved based on user preferences. The proposed method achieved effective time-of-use in peak hours and reduced the electricity bill. Molla et al.[21] proposed a multi-restricted scheduling method with integrated scheduling to perform energy management in a smart environment. The grey wolf algorithm was used in this work for optimizing and formulating the problem. The objective of the word was to control the time-of-use pricing and reduce energy consumption. A load appliances-based time scheduling method was proposed to avoid the heavy load situation in smart homes. The demand and response analysis was controlled by the optimization method and improved the performance and reliability of the system.

Zhao et al.[37] presented a demand-driven based optimal power scheduling method for effective power management in the smart grid environment. The energy management controller was defined with an effective analysis of the peak-to-average ratio for peak load reduction. The inlicing block rate-based real-time pricing method was defined for reducing the cost of electricity. The genetic method was implemented to reduce the average load and price in the smart home environment. An opportunistic scheduling method was provided for effective scheduling in the smart home environment. Day-ahead pricing based distributed scheduling method reduced the energy consumption and load. This scheduling method uses the load shift method from peak to off-peak hours. A constraint analysis-based scheduling method was defined for optimizing the behaviour of scheduling and resource allocation[38]. Ali et al.[23] proposed a novel demand-side management system to optimize appliance scheduling. The appliance preference-based analysis was performed for the effective usage of renewable energy. The branch and Bound algorithm was defined to analyze the load power rating and control the energy consumption. A mixed integer linear programming method was defined to optimize the energy utilization in the smart grid. The method was analyzed and verified in multiple scenarios. The proposed model improved the user comfort and load under user preferences.

Chen et al.[25] identified the load features and performed support vector machine-based predictive measures to identify different states. The power feature analysis-based operation state analysis was defined to optimize the scheduling method. The limited resource and computation method was defined to optimize energy consumption. Smart meters and plug units were installed to capture the energy usage information with a time stamp. The load state information-based method was applied to optimize the scheduling in the smart grid. Tsui et al.[27] proposed a demand response analysis-based optimization model for scheduling the appliance request and controlling the electricity bill. The convex programming-based DR optimization framework was used to identify the load situation in the home network. The regularization method was used for scheduling the appliances under different constraints. The energy scheduling-based resource mapping was performed to optimize the network's performance. The proposed model distributes the load from peak situations and achieves a balanced load. This approach improved electricity usage and reduced the cost. Liu et al.[30] proposed a pricing-based demand response analysis system with customer satisfaction to enhance the performance of the smart home environment. The method was defined to optimize the energy storage system and energy resources. Flexibility was introduced in this work to enhance user satisfaction. The injection limits were defined to control resource allocation and reduce energy consumption. The model was generalized and robust that can be implemented in different scenarios.

3. Functional Behaviour of Smart Home

The effective utilization of electricity and energy is the primary requirement of the smart home environment. A smart home environment can have various smart appliances, electronic devices and vehicles. Consumers use these devices at different times. The usage of electricity in smart home areas is represented as the demand or expected electricity consumption. The smart meter can be installed in the smart home area to identify the electricity consumption and analysis in the smart home. As the availability or supply of electricity is limited, there is the requirement of an effective response framework required that can map the demand and response. The framework should be capable of handling higher and unequal load situations. Various constraints and features can be mapped over the resources and appliances to handle the load situations. Other than load, scheduling is another way that defines the resource usage sequence in the smart home region. The charging/discharging time, peak hour energy usage, and low-power appliances are the key aspects associated with smart homes that can control and analyze the demand response in the smart grid [1]. A standard and functional architecture of electricity usage under demand-response analysis is provided in Figure 2.

The defined standard architecture performs a demand-response-based analysis to optimize electricity usage and consumption in the smart home environment. The demand-driven analysis is conducted in this framework, and the functional behaviour of this architecture is divided into three main stages. These stages are the data acquisition stage, data storage and management stage and the data processing and application-driven decisive stages [1].

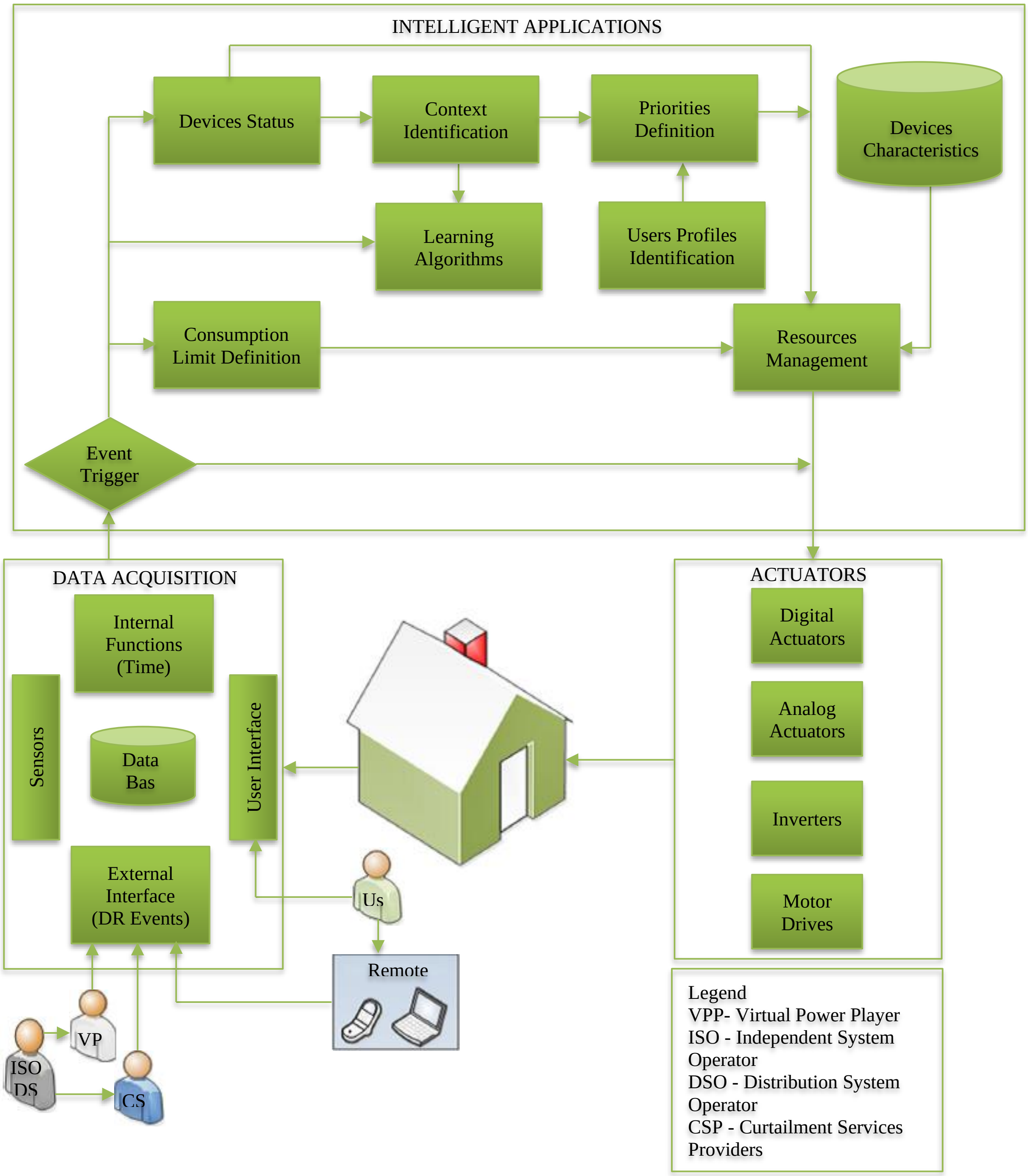

Fig. 2 Demand response analysis based smart home Automation

Figure 2 shows that the smart home is designed with various smart sensors and actuators. These actuators include digital and analog actuators, inverters and motor drives. Various appliances use one or more of such actuators. These actuators are activated using those particular appliances on consumer's interest. The smart meter and controller devices are installed in the region to acquire the sensing information and appliance data. The data acquisition methods and integrated to acquire, manage and control this data in smart storage and controller devices. These data processing and management functions include various aggregative sensors, internal functions database and external interfaces. The external interface is connected to the environment and collects the required information through different sensors and actuators. Once the data is collected, some aggregative, filtration and data processing functions are applied to identify the most significant and effective information. Non-required features can be eliminated, and time-driven information is collected from the environment. Once the filtered and effective data is obtained, this data is managed in a database. It is a larger database that can manage time stamp-driven and sensor-specific information. The usage and demand of each sensor and appliance are managed in this database. The database can handle various queries and identify the load situation situations in the environment [1].

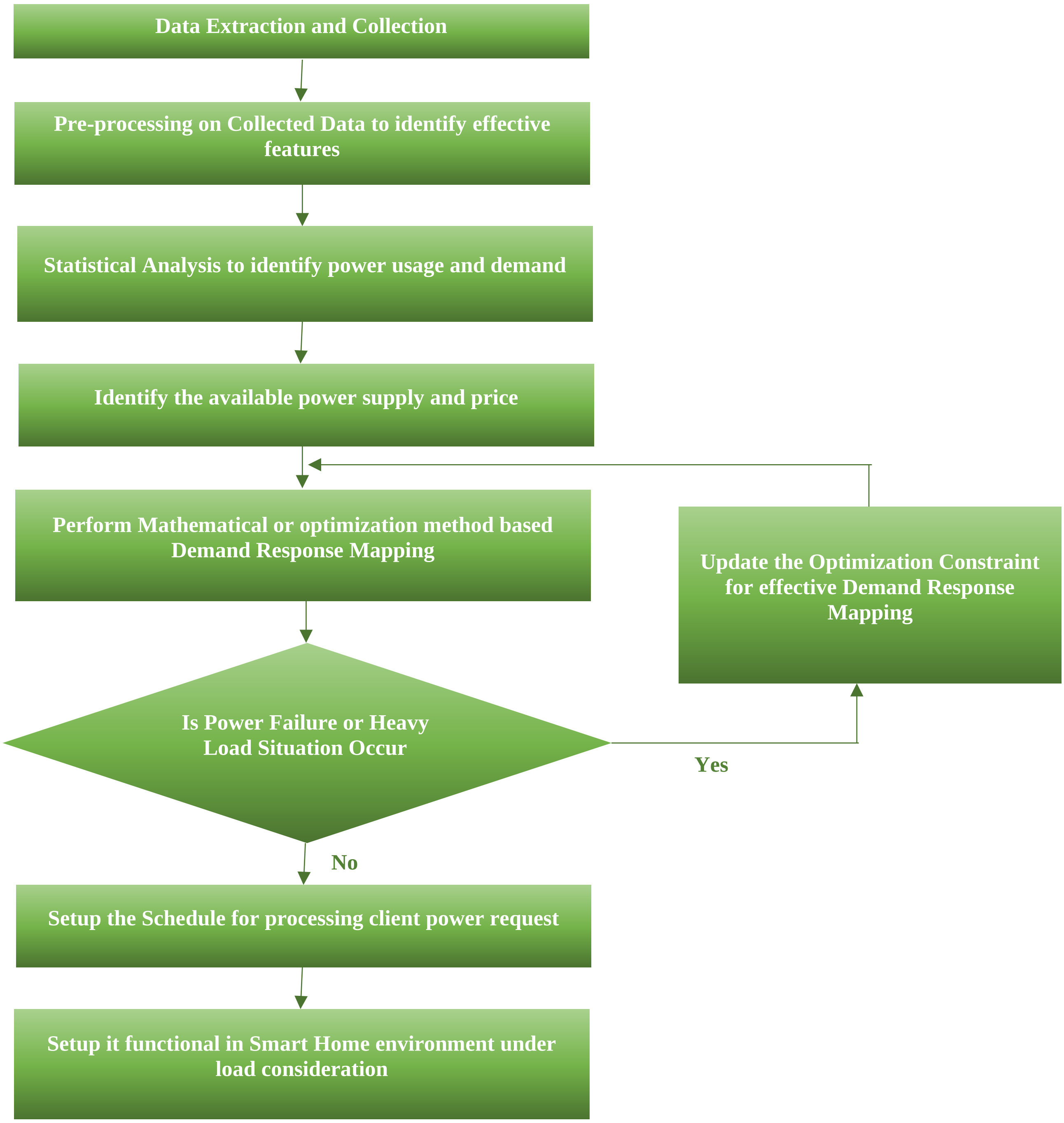

Fig. 3 Process for demand response analysis based load

The third phase or stage of this smart demand-response driven smart home environment is the processing and decisive stage. This stage captures the information from the dataset managed in the smart storage system. The available power supply information is processed collectively to decide about the load and control of the power consumption in the smart home environment. It is an event-based process to manage the resources. In this intelligent and processing environment, application-driven and objective-driven algorithms and machine learning algorithms can be implemented to take the decision about load control. The priority and context-driven analysis-based resource management and electricity consumption methods were applied to effectively allocate and schedule in a smart home environment [1]. A standard process for demand response [10] analysis-based load handling in the smart home environment is provided in Figure 3.

Figure 3 shows the functional flow of load balancing and user request scheduling in a smart home environment. The demand response is a user-driven load analysis and scheduling method. In this algorithm, the data is collected from a smart storage system. This is temporal data that defines the electricity usage with certain voltage and time intervals and parameters. Once the data is collected, the pre-processing method will be applied to identify the effective features. These features effectively identify heavy load situations and peak electricity usage hours. Once the effective features are identified, the statistical measures are applied to map it with the available power supply and pricing features. These associativity-based measures are applied to identify the heavy load situations in the environment. The statistical measures also identify the low-load situations and perform certain shifts to balance the load. In this stage, some mathematical or optimization can be applied to perform load balancing using the load shift method. This mathematical or optimization methods can be applied using multiple parameters. Once the load is shifted, it checks the entire system for any more load situations; if such a situation exists, then the process is repeated with updated constraints. The updation can be performed in terms of constraints or values. This continuous process is repeated until any heavy load situation exists in the system. If there is no such heavy load situation, a mapping between the demand and response is obtained, and the requests are scheduled according to the defined order. This scheduling method is analyzed in terms of cost and energy consumption in the smart home environment [10][11]. In this paper, various methods defined by the researchers in different stages of demand response methods are identified and discussed. The load analysis and scheduling methods used by the existing researchers are discussed in section 4, along with their objectives and behaviour significance.

4. Scheduling and Load Behaviour in Smart Home

The demand response-based scheduling method was discussed in section 3, which defines a consumer-based analysis method to fulfil the electricity demand. The objective of the approach is to reduce energy consumption and electricity bill without affecting the comfort of individuals. More effectively, the demand response algorithm analyzes the behaviour of individual and identify the consumer pattern. The market participation and relative response are also analyzed to regulate supply the demand. The consumer behaviour pattern can be modified by motivating the consumers. The method also analyzes the demand in low and high-price periods. The load and peak load is another measure that is handled by the demand response method. The occurrence probability and peak load can be reduced by paying some incentives and prices[36]. Demand response-based methods use a consumer-based load shift approach to optimize resource allocation and scheduling. Some common load shift models are flexible, periodic, and generic load shift methods. These load shift methods use different constraints to shift load from off-peak time slots[13]. Let the power consumption of an appliance at time t is given by Cx(t). Equations (1) and (2) show the power consumption and power switch. Figure 4 shows the load shift from peak hours.

$$C_x(t)=C_{x0}(t,L_x) \quad (1)$$

$$Switch(C_x,\theta)(t)= C_{x0}(t-\theta, L_x) \quad (2)$$

Where t is the particular time slot or interval,

x,x0 are the states

Cx, Cx0 are the power consumption at particular states x and x0

O is the objective function

L is the period

The switch is the function that defines the load switch under given parameters.

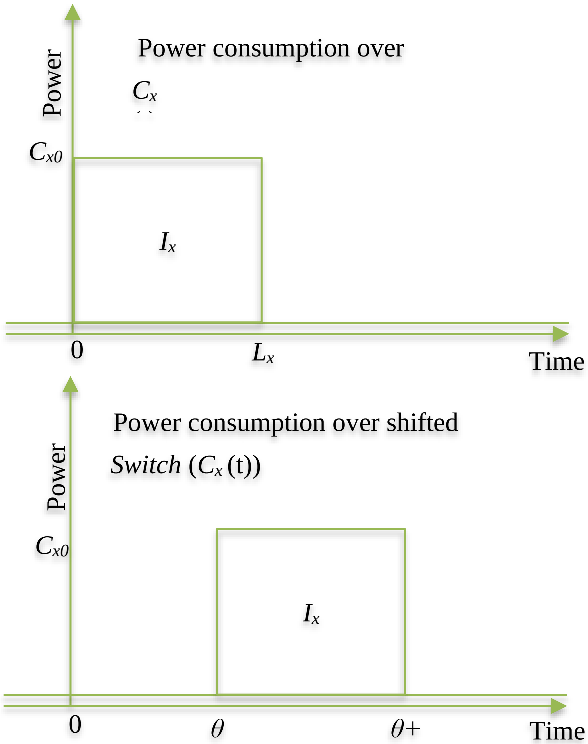

Fig. 4 Generic load shift model for effective scheduling

Table 1. Load management and scheduling methods and behaviour

KeyReference	Function/ Approach/ Method	Main Objective	Behavioural Significance
Wang et al.[2]	Quadratic programming-based optimization was defined for resource and load scheduling.	Load Reduction was achieved in the Photovoltaic system.	• Improved the usage of the PV power system • Reduced the Tariffon Electricity Usage
Yu et al.[4]	Designed a stochastic program with the Lyapunov optimization method. The queue-based analysis approach was used to handle uncertainty issues.	Stabilize the load and energy issues in the smart home environment.	• Minimized the sum of energy cost • Improved comfort level • Feasibility was improved for the real environment
Belley et al.[5]	A load signature-based load monitoring system was proposed and analyzed the study operations and signature based on daily activities.	To reduce and save energy and energy costs by regulating the habits of a consumer.	• Reduced Reactive Load • Reduced active power and load • Reduced cost of power consumption
Ahmadi et al.[7]	Mixed Integer Linear Programming based model integrated with stochastic scheduling was proposed to handle active load situations.	To balance the thermal load, the outcome of a photovoltaic panel, electricity load and generated power.	• Peak electricity demand was decreased • The cost of energy usage was decreased
Teng et al.[8]	Load Profile matching and shifting-based model for load balancing in the smart home. Multiple shifting methods with different constraints are defined to optimize smart home performance.	To achieve fine-scale coordination among home appliances using load profile shifting.	• Large Reduction in Energy Cost and Price • Energy consumption was minimized
Nawaz et al.[18]	Defined a nearest-neighbor-basedmethod for forecasting electricity Price and Load. Feature selection with machine learning was defined for optimizing smart homes.	To optimize the smart home functioning and forecast the price and load in different real-time scenarios.	• Minimize the load situations • The electricity price forecasting reduced the price of electricity usage
Rashid et al.[24]	Three phase model is defined for effective scheduling and load control.	A time schedule modelling was defined with the objective of load balancing and reduction.	• Reduced the peak and average load
Wang et al.[31]	Mixed integer linear programming algorithm-based demand response method to optimize dynamic pricing and load.	Two parameter-based optimization models for maintaining load energy consumption.	• The peak load and average load conditions were handled • Reduced the electricity bill
Chen et al.[34]	Genetic-based Demand Response Analysis Method for Parametric Scheduling under elastic and inelastic intervals.	The price negotiation method was defined to reduce electricity tariffs in heavy and average load situations.	• Reduced Tariff and Elastic Load • Improved Customer Satisfaction

The periodic shifting can reduce the peak situation under consumption constraints. The periodic behaviour and unequal load situations can be used to shift the load. Various scheduling and resource allocation methods were defined by the researchers to achieve different objectives. The main objectives of the work include the reduction of energy consumption and load. The demand response also provides a similar way to optimize the smart home environment and power consumption reduction. Some of the common work with research methods and objectives are provided in Table 1. The behavioural significance and objective achieved by different methods are provided in this table.

5. Conclusion

The smart home is the personalized area of an individual or family. The smart home uses smart appliances and devices to reduce energy consumption and load situations. The scheduling and resource allocation methods can be applied to reduce the load and optimize electricity usage in smart homes. These scheduling and resource allocation methods use constraint-specific analysis to identify the unequal load situation and to optimize the performance of smart homes. In this paper, a study on demand response analysis methods is provided for the smart home environment. It is a consumer-driven method that optimizes the load and energy consumption without affecting the consumer's comfort. In this paper, a standard architecture of demand response analysis is defined. All the work stages of this architecture are described. This approach uses the load shifting method based on some price or incentive to reduce the electricity bill and energy consumption. Various research and objectives associated demand response method are also described in this research.

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