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Original Article

Design of a Rule-based Decisive Model for Optimizing the Load Balancing in a Smart Grid Environment

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Abstract - *The electricity demand of users is increasing day by day. This increasing demand also increases the load on power stations, resulting in frequent power drops or failures. This unequal and increasing energy demand is a growing concern of the power sector. The smart grid keeps track of the user demands over the traditional distribution system and ensures the balanced distribution of electricity. Even though the uninterrupted power supply and heavy load situations are key challenges in the smart grid environment, this paper proposes a demand and load-driven rule-based model to achieve effective resource allocation and usage. The proposed intelligent system will predict the expected overload situation at the time allocation and perform load-balanced usage of available resources. The proposed model is simulated with different load situations and analyzed regarding the number of power failures. The analysis results are obtained in average power delay, power switches and power failure measures. The analysis results identified that the proposed rule-based decisive model optimized the performance of the smart grid in extreme load situations and achieved effective results with minimum delay and lesser power failures. The proposed system achieved the reliable and effective distribution of power.*

Keywords - *Power Distribution, Optimization, Resource Allocation, Rule-based, Smart Grid.*

1. Introduction

The population growth is rapidly increasing the electricity demand. Because of this increasing demand, the power system, management and supply is an emerging research area. The researchers are investigating various power distribution and electricity consumption reduction, models. As a rough idea, 10% of power is lost in transmission and distribution. Out of this, 40% of power loss occurs only during distribution. Because of this, there was a requirement to identify more energy sources and reduce the electricity loss during transmission and distribution. This increasing power demand and high power loss cause energy crises. In recent years, renewable energy sources (RES) are getting popular as new energy sources and contributing to fulfilling the increasing power demand of consumers[15][17].

From the user perspective, one critical challenge is tracking the pricing of electricity suppliers and the usage of appliances. The consumer's location is equipped with a smart meter in a smart grid architecture. The smart meter is an intelligent device that captures real-time electricity supply and consumption information. It is connected through cloud computing and updates the information to the server. As each consumer's usage, demand and consumption information is recorded, it can be further utilized to identify the overload or electricity fluctuation situations. Smart meters are integrated within the smart grid environment to ensure the region's optimised electricity consumption. Voltage, current, power consumption, and load issues can be resolved by using a cloud-enabled smart grid environment[16][20][21][23][24]. Fig 1 shows the functional architecture of the smart meter-enabled energy management system]. Smart Energy Management (SEM) ensures the monitoring and control of power-based functionality through smart meters and appliances. These controller provides local control and avoids the wastage of power. An SEM unit is used in this architecture as the controller device that acts as an interface between the utility and the consumer. This gateway accepts the allocated maximum demand of consumers and is responsible for fulfilling that demand. The usage analysis, load and billing are the main responsibility of this unit. SEM gateway work as controller of power negotiator. It controls the user appliances and sets the priority based on usage or other measures. It can take ON/OFF the usage of devices by a particular consumer. The high pricing and high power consumption-based warnings are also generated through this gateway. The load and energy consumption control are achieved by this gateway and configured priority of appliances. Smart IoT devices are also equipped within the environment to control the individual appliances[18][19][22].

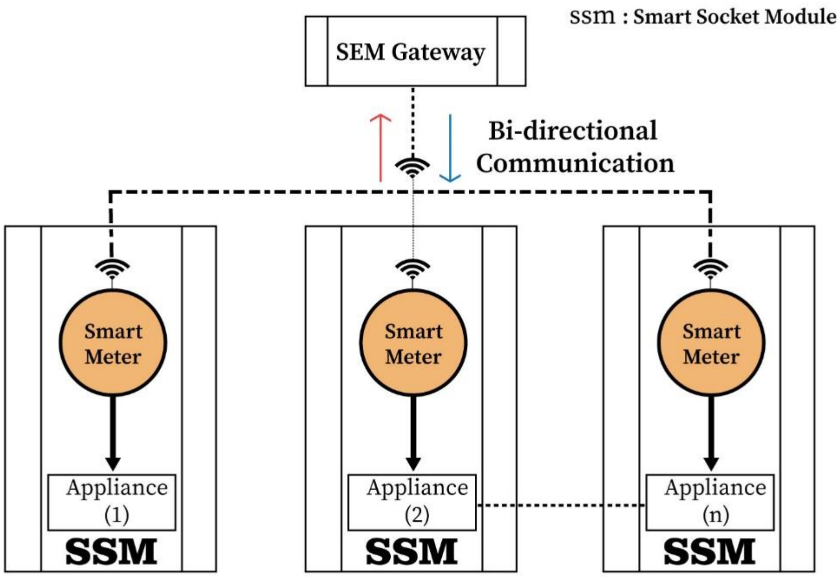

Fig 1. Smart Meter integrated Energy Management System[18]

This paper presents a rule-based decisive, smart grid optimization model to provide effective power distribution in heavy load situations. The proposed model provides an uninterrupted power supply with lesser switching. This section discusses the basic features, characteristics and challenges of traditional and smart grid-based power distribution methods. Section 2 discusses the research work and algorithms provided by earlier researchers. Section 3 presents the proposed rule-based model for handling heavy load situations in smart grid environments. The functional flow and the structural model are provided in this section. In section 4, the description of the simulation environment is provided. The simulation results are provided to present the effectiveness of the proposed using different parameters. In section 5, the conclusion of the work is provided.

2. Related Work

Devi et al.[2] a proposed quantitative method for optimizing a grid network's load balancing and energy distribution. This approach defined a weighted energy allocation to primary and secondary substations based on load category. This method applied a fine calibration at the secondary substation to avoid wastage of energy and to optimize the energy distribution in heavy load situations. The author also applied horizontal block shifting (HBS) and vertical column by column shifting (VC2s) algorithms to optimise energy distribution performance. The analysis results show that the proposed model achieved efficient load balancing and maximized the utilization of resources. Monyei et al.[3] proposed an improved load-balanced grid computing network for enhancing the comforts of the smart home. The proposed algorithm categorized the household hold as reducing the electricity consumption and cost up to 2.9% and 7.%. A demand and load adaptive method is defined for saving energy consumption and improving the performance of electricity distribution. Guo et al.[4] proposed a Long short-term memory(LSTM) based model for effective load forecasting in the smart grid environment. The periodic information of load in the network was processed to generate the input sequence and extract the load's temporal pattern. A multi-layer perception-based accurate forecasting method was defined in this work. The experiment results verify that the proposed model reduces the load occurrence and improves the accuracy over the standard LSTM model. Zhang et al.[5] proposed a non-intrusive load monitoring (NILM) method for optimizing energy conservation in a smart grid. The proposed NILM model uses data processing and energy consumption learning methods to identify appliance interference. Supervised and unsupervised learning is included for load monitoring in the smart grid. The experiment analysis improves the energy accuracy in the smart grid. Avila et al.[6] proposed a simulation framework for energy-efficient load management in the smart home. The period-based load probability analysis was defined and controlled according to user preference. A fuzzy-based priority method was defined for controlling the functioning of the environment. The analysis was conducted under energy consumption, pricing schemes and type of users. The results identified a reduction in peak rates, electricity consumption and electricity bills.

Amarnath et al.[7] proposed skilled monitoring approach for effective energy management and power generation. The load-based analysis was performed to identify the heavy load situations. A dynamic and variation adaptive connectivity method was defined for optimizing the performance of the smart grid. The presented results show that the proposed model achieved load-balanced power distribution compared to existing methods. Antoniadis et al.[8] proposed an overloading prevention problem called Multiobjective mixed integer quadratically constraint program. The combinatorial optimization method was used for effective and load-balanced power distribution. The linear transformation-based usage analysis method was defined for predicting the overload situations. The analysis was performed on 216 scenarios and achieved effective and reliable results in overload situations. Shchetinin et al.[9] proposed a cluster analysis-based energy consumption forecasting method. KMeans clustering was applied to hourly power usage data to analyze the power consumption and to predict the overload situations. The cluster analysis-based consumption forecasting was proposed in this research. The results show that the proposed model achieved effective load forecasting at a lesser error rate. Chiu et al.[10] proposed demand and response-driven load management in smart grid. The multiobjective optimization problem was formulated in this research for handling overload situations. The proposed model was simulated for residential scheduling users. The power consumption was defined for different appliances. The results identified that the proposed model is cost-effective and achieved significant results in overload situations. Kaneriya et al.[11] analyzed the effect of weather conditions on power usage. The author defined a time-based data-driven approach for predicting the energy requirement and load expectation. The climate conditions were adopted for collective load prediction in the real environment. The simulation results identify that the proposed model archived the effective prediction of electricity demand for commercial and residential sectors. Naqvi et al.[13] used the fog computing method to improve the performance of cloud-based smart grid systems. The scenario was defined to divide the six-word regions in N number of clusters. Two clusters and two patches of fog were defined for each region. In each fog, nine virtual machines were defined. The author applied round robin (RR), throttle and ant colony optimization (ACO) algorithms to balance the load in the smart grid.

England et al.[14] proposed a power stability method for reducing the voltage fluctuations in a grid area. The demand response method was defined with load measurement to predict the reactive power compensation. The load estimation was defined with the available maximum to achieve better stability in the grid area.

3. Proposed Rule-based Decisive Model

A smart grid is a real advancement over a traditional power management system that keeps track of user demands and provides an effective power distribution. But, the increasing demand for power supply is a challenge in a smart grid environment and creates heavy load and power drop situations. This paper includes an improved and intelligent smart grid functioning to handle heavy load and power failure situations. A rule-based functional model is presented in this research for optimizing resource allocation and usage. Fig 2 shows the broader view of the proposed model. In this model, the proposed smart grid optimization model's functional responsibilities are divided into two main stages. In the first stage, the rule-based load prediction is performed. In this stage, the consumer requirement, history and peak hours are analyzed. The rules are defined for predicting the heavy load situations and expected failure points. For two-way communication, in the second stage, the power suppliers' analysis is done to identify the most effective resource. The rules are defined for identifying the fault-tolerant resource with the lesser load. As the expected load-driven failure situation analysis and evolvement are done, the load distribution situation is achieved in less time. Lesser load switching and delay are achieved in this research.

The proposed rule-based optimization model is applied to the standard cloud-based smart grid model. The standard IoT-enabled smart grid model is shown in Fig 4. The figure shows that the IoT devices and smart types of equipment are present in the user area and controlled through a user interface. The visualization and configuration interface exist in this interface. The web services are integrated into this layer to control and monitor power requirements and usage. The consumer requirements, usage and load, are managed in a centralized database. This database contains the usage history of the user. This information is used for taking the predictive decision about the load and power failures. The resource information and user access to supply information are maintained in smart grid DB. The availability of resources and power supply on each resource is also managed in tis. The data management unit keeps trans this information for taking the history-based decisions and setting up the rules. The configuration unit is also defined with this data management unit for updating the databases. Based on these configuration units, the decisive rules are generated to identify the expected load and power failure situations. As the situation occurs, the message is dispatched, and resource allocation is done based on the optimization rules. Figure 4 shows the access points that provide the flow of power supply that happens when the resources are effectively allocated.

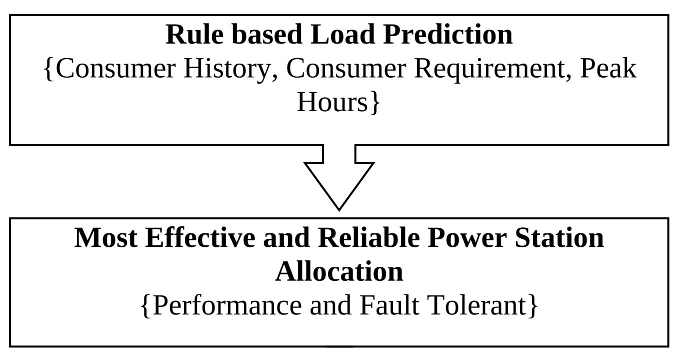

Fig 2. Functional stages of Proposed Smart Grid optimization model

Fig 3 showed an intelligent and rule-based model in which different IoT control units and components are connected in the smart grid environment for predicting load and failure situations. The functional flow of this model is provided in Fig 4. This functional model defines the functional stages based on the simulation and actual environment. This functional flow also defines the deployment of components, the configuration of the device, and the management of the dataset. In this functional model, the server and grid level configuration is first done. In this stage, M power stations are defined by their load capacity. The load, allocation and usage history of these power stations is maintained in the centralized database. N consumers are defined with specific IoT devices to consume the electricity. These consumer-side devices are capable of identifying the load requirements. The consumer information, usage history and expected load requirements are maintained in the centralized database. The consumer side IoT devices and power stations are connected to the centralized database and keep updating the allocation and usage information.

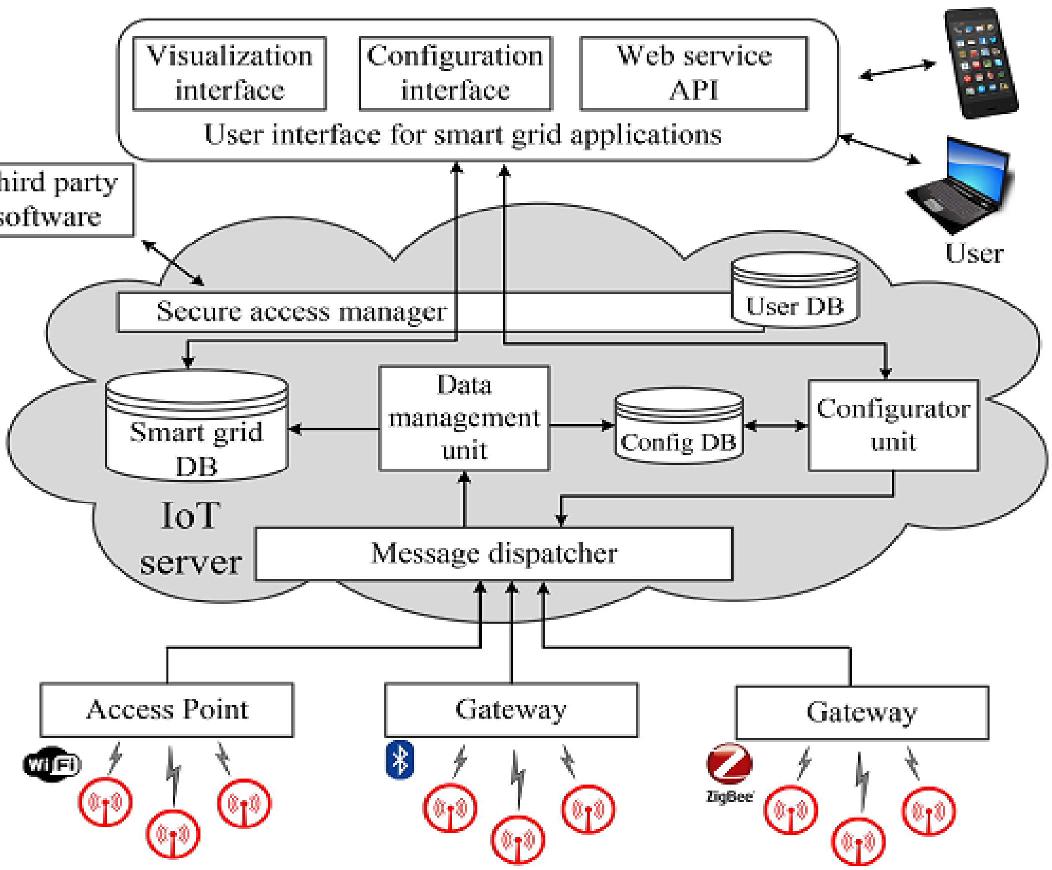

Fig. 3 Standard Architecture for Power distribution in IoT-based Smart Grid

The centralized database is also connected with control and configuration units. The control units generate the decisive rules for power station allocation and perform equalized power distribution. The control unit is responsible for avoiding heavy load and power failure situations. The configuration unit is also connected with the control unit to take action based on the decision taken by the control unit. The actual resource allocation is performed by the configuration unit. The control unit analyzes the requirement, load history and usage history to predict the failure and load situations. The control unit identifies the optimal power station that provides the required power and will not cause the fault. A power station with enough capacity and lesser failure record is allocated to the consumer with critical and high load requirements. The consumers with lesser load requirements can be allocated to a normal power station that is less effective but has enough power capability. Once a fault-prone and load-effective power station are identified, the configuration unit allocates it to the consumer. Even though the allocated power station can also cause chances of failure, the consumer can be switched to another power station. If no power station has enough power supply, then failure can occur. The control unit also records the allocation of the power station and failure cases in different databases as the user and power station history. The proposed work is simulated in a MatLab environment with different loads. The simulation and analysis results respective to different loads are provided in the next section.

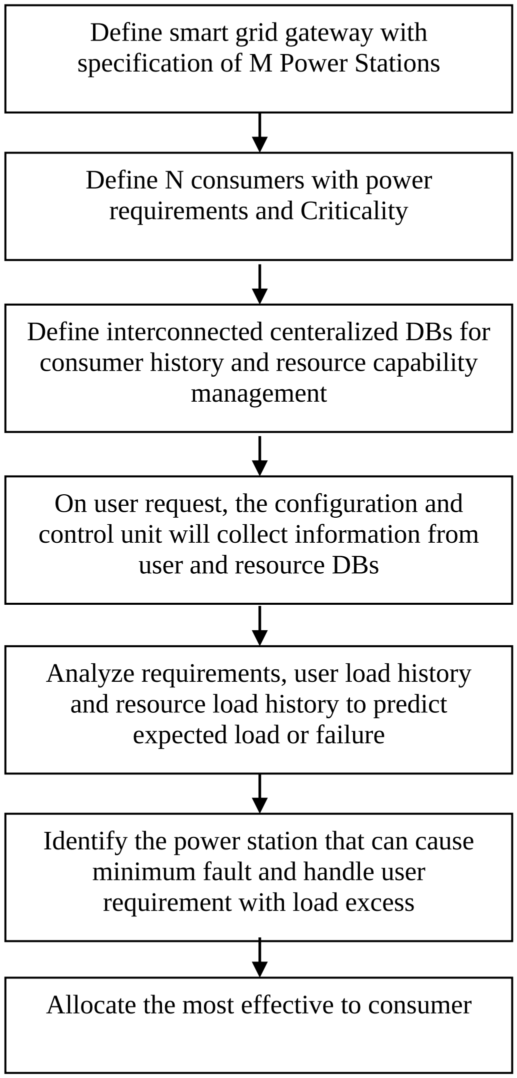

Fig. 4 Functional Flow of Proposed Model

4. Results and Discussion

This paper presents a rule-based model for effective resource allocation in a smart grid environment. The smart grid environment is equipped with smart meters and smart IoT devices. These devices capture the consumer power requirements. The database units are attached to track user and power station history. The allocation and load records are managed in this database. The cloud server-based environment is set up for configuring the server side with the specification of power stations. Each power station is defined by power load. The power stations' configuration and history information are present in the database unit. The consumers are the end users connected to this grid network with specific power requirements. The consumer history and requirements information is maintained in the database. The control unit is defined to decide on the load and fault effective allocation. In this section, the simulation results are provided. The smart grid is configured with N power stations and M consumers. The analysis results are taken in terms of the number of power drops, wait time and finish time of consumer requests. Each consumer can perform multiple requests in an hour. These requests are respective to the load and requirements of the consumers. The load or power requirement of the consumer is 0 to 7 kWh. We have simulated the work with three stations, each configured with a load capacity of 100 kWh. As multiple consumers can generate the power requests simultaneously, the main objective of the proposed smart grid optimization model is to distribute the available power to the consumers effectively. To analyze the effectiveness of the proposed model, the model is simulated with the different number of power requests performed over an hour. The work analysis is performed according to the number of request failures, several request switches, and the average delay observed for each request.

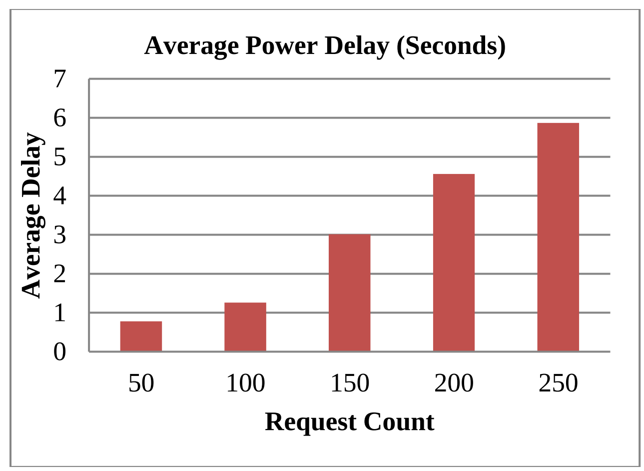

Fig. 5 Average Power Delay (Milliseconds)

Fig 5 provides the average delay recorded for processing the consumers' requests. The delay of a request is identified as the difference between the time of power allocation and power request. This time is analyzed for all requests performed within one hour. The average time is computed and analyzed in seconds. In this figure, the x-axis shows the number of requests performed in five experiments. In each experiment, the number of requests is 50, 100, 150, 200 and 250, respectively. As multiple requests are performed, the proposed model collectively analyzes the consumer history, load and requirements. The results show that the average delay is 0.78 seconds on the load of 50 requests. As the number of requests increases, the average delay is also increased. The bar graph shows that the average delay raised to4.5 and 5.87 seconds for 200 and 250 requests loaded. The results identified that as the number of requests increases, the average delay increases. But the proposed model provided a controlled and effective power allocation. In the extreme case, the average delay is less than 6 seconds. It shows that the proposed smart grid model satisfied the power requirements of the consumers with minimum delay.

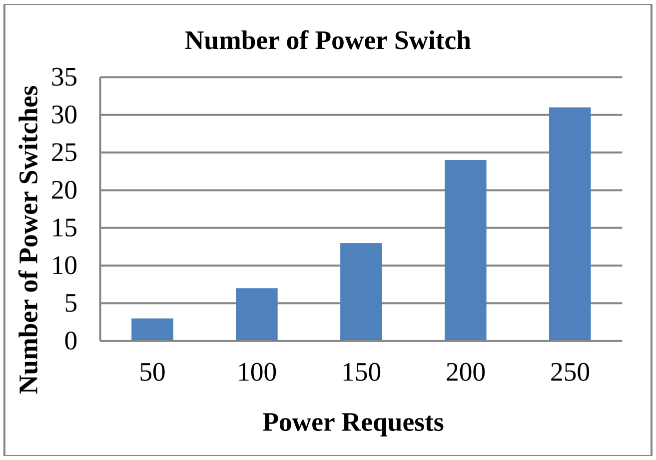

Fig. 6 Number of Power Switches

Another parameter in this research to analyze the performance of the proposed model is the number of power switches as a consumer has the coverage or the power service of M power satiations. Each power station is defined with a certain capacity and current load. The power supply's cost, capability and reliability can differ based on the supplier. In the proposed smart grid allocation and distribution model, allocation of the power station is done based on the history, load, and requirement measures. But if the optimum power station is fully occupied or the failure occurs in the allocated power station, then the proposed model has defined a list of prioritized power stations. The priorities are decided based on the failure rate and average delay. If the optimum power station is occupied, then the request can be switched to the next power station. Fig 6 provides the analysis results regarding a number of power switches. In this figure, X-axis shows the number of power requests performed by the consumers in an hour, and the y-axis shows the number of switches. The number of power switches is 3 for 50 power requests. As the power requests increased to 200 and 250, the number of power switches increased to 24 and 31. The results show that the proposed model effectively executes the consumer's requests on the allocated power station.

If any of the available power stations cannot provide the power on demand of the consumer or the total parallel request cannot be processed in parallel in the available capacity of all power stations, then the situation of power failure occurs. In such a situation, the specific consumer's power supply is cut off for a specific interval. The services can be resumed, as the load of the power station is vacant again. A smart grid method is effective if it can provide power services with a minimum number of power failures. Fig 7 shows the analysis results for analyzing the number of power failures in the system when the number of power requests increases. The figure shows that the proposed model provided an effective power distribution with fewer power failures. The maximum number of failures observed by the proposed smart grid allocation model is 8 in case of extreme load.

These results identified that the proposed model achieved effective and reliable results with lesser delay, power station switching and request failures. The proposed rule-based decisive model effectively handled the heavy load conditions with lesser power failures and delays. The overall capability of power allocation and distribution is improved in this research.

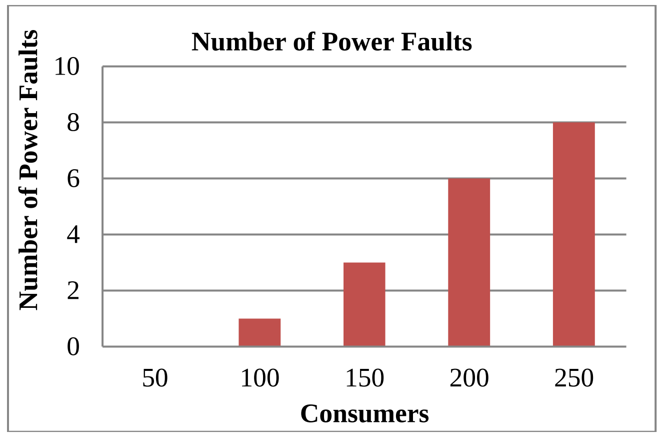

Fig. 7 Number of Power Faults

5. Conclusion

In this paper, a decisive rule-based model is designed to optimize the performance of the smart grid. The proposed model is designed to allocate power resources or stations effectively. The power stations cannot fulfill the peak demand as the power load increases. In such heavy load situations, the chances of power failures increase. In this paper, a rule-based model is designed that will observe the power requirement and capabilities of available power stations. The power requests are allocated to the specific station based on the load and history of the power station. If a heavy load or failure occurs, the proposed model switched the request to another power station to reduce the failure chances. The proposed model is simulated with 50 to 250 power requests. The analysis showed that the proposed model reduced the power failures, power station switches and delays. This model improved the reliability and effectiveness of the traditional system.

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