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Original Article

Load and Delay Effective based Resource Allocation And Scheduling Model to Optimize Power Distribution in Smart Grid Network

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Abstract *- Smart grid combines the IoT-based distributed network with a traditional power distribution system for intelligent and precise electricity distribution. Two-way communication is performed by predicting the user demand and ensuring an uninterrupted power supply. This paper defines a decisive rule-based model for optimizing resource allocation in the smart grid environment. Two-way communication over the grid is established by adapting the grid environment. The decisive measure is applied in the load forecasting stage for allocating the resource based on the requirement of consumers. Intelligent processing is defined as handling the overload situation and ensuring the load-balanced usage of available resources. The proposed rule-based decisive model achieved higher performance with lesser delay, lesser power switches and lesser. The proposed power distribution model is compared with existing FCFS, SJF and LJF algorithms. The work is tested against heavy and low-load situations. The analysis results show that the proposed model reduced the power delay, power failures and power switches over the system. The effectiveness of the proposed model is higher for the peak time.*

Keywords *- Smart grid, Load forecasting, Load balancing, IoT.*

1. Introduction

A smart grid is one of the technological advancements for improving the utilization of energy resources. A smart grid ensures the effective distribution and consumption of electricity. It also provides better energy distribution and utilization sustainably at a lower cost. A grid network is a real-time network that is been improved by adapting the IoT technology. The users and devices collect the data through IoT sensor nodes. The adaptation of IoT technology enhances the security, reliability, flexibility and efficiency of the traditional system. Communication and data management in maintained in IoT [5] systems by adapting the cloud or fog technology.

Electricity distribution is a real-time network that requires continuous supply in sensitive areas such as hospitals. As the number of users over a power station or controller increases, congestion or high-load situations can occur. In this network, smart meters [11][23] are used for collecting real-time electrical data. The electricity consumption and requirements can be predicted through these smart meters. Various load forecasting, load balancing and fault-tolerant algorithms were investigated and applied by the researchers to optimize the performance of the smart grid network [1][6][24].

A smart grid network is a combination of electrical and communication networks. The infrastructure devices include the devices for data capturing, data management and distribution. It is a public network in which the power and data flow between the power station and consumers. Multiple methods, equipment and processes are applied at the supplier end to generate the power through different sources. The smart grid network is responsible for the distribution of generated electricity based on the requirements of the consumers. It provides a controlled flow of power over the network. The effectiveness of a smart grid system can be measured in terms of customer satisfaction, QoS, cost of service and fault proneness.

Figure 1 shows the basic architecture of a smart grid system. The figure shows that the functioning of the smart grid system is the device at a basic and intellectual level. The basic level of the smart grid includes the devices and functioning related to power generation, power transmission and power distribution. It is considered the traditional system. The advanced and intelligent part of the smart grid system is the intelligent level. In this level, electrical load forecasting, demand forecasting and wireless communication are performed [2][8][9][12].

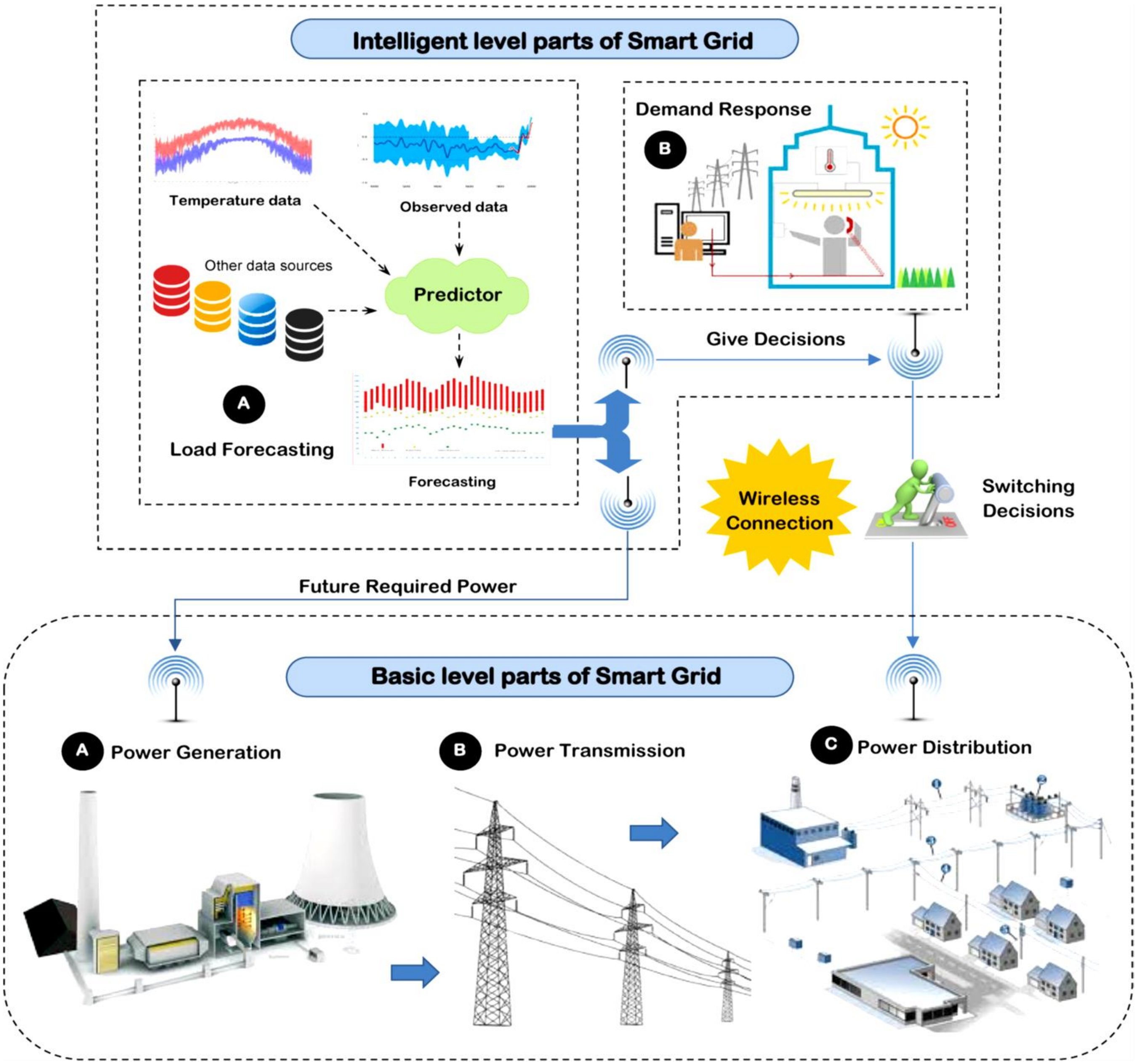

Fig. 1 Two-Level of Smart Grid System [1]

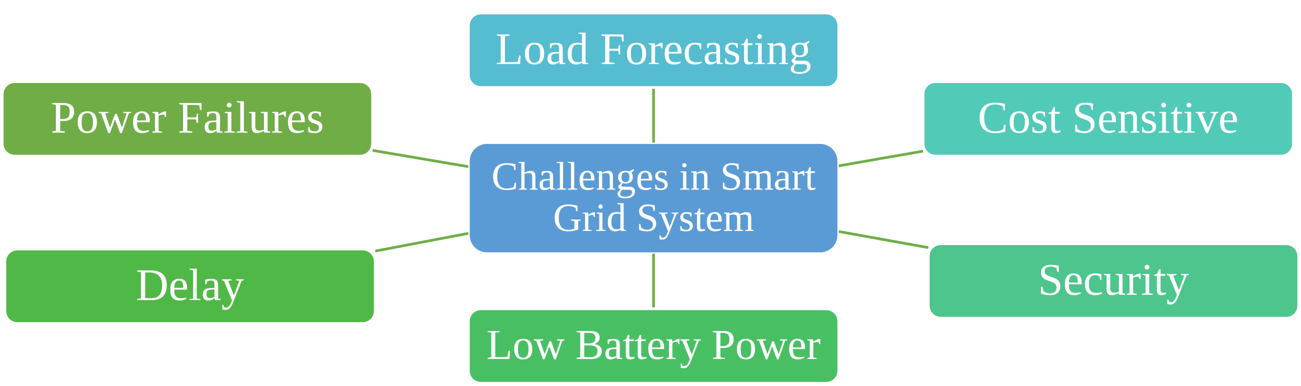

Fig. 2 Challenges in Smart Grid

Smart grid systems' performance and reliability affect consumers' satisfaction as the system is real-time and has variable demands based on timings, work and environment. The smart grid network has to predict consumer needs and should provide a continuous electricity connection. The limited battery of smart equipment, load forecasting, and demand management are the common challenges faced by the smart grid. The researchers defined various algorithms, measures and methods for fast and accurate load forecasting. Actual load forecasting is the key to achieving a balanced electricity distribution without power failures [2][3][10]. Some of the common challenges to the smart grid are listed in Figure 2. The grid system should be equipped with functional behaviors that can handle these issues and provide a reliable, safe and customer-oriented power distribution. An intelligent load prediction and load balancing method are required to avoid power failures in the real environment.

This paper proposes a rule-driven mapping between power requirement and availability for allocating the consumer request to the appropriate power station. The objective of the research is to avoid the overload situation at the earlier phase. The requirement and load predictive and load-balanced model is presented in this research to avoid the chances of power failure. This section defines the basic smart grid architecture and describes its components. Various challenges in the smart grid system are also explained. Section II also describes the work provided by earlier researchers for optimizing the smart grid environment. Section III presents the proposed rule-based load predictive and load-balanced model. In section IV, the simulation results with scenario specifications are provided. In section V, the conclusion of the work is delivered.

2. Related Work

Rabie et al. [4] proposed a load forecasting method and applied it within 3-tier IoT-based smart grid architecture. The proposed method included a preprocessing stage with a load prediction phase. The fog architecture was implied in this work. The author collected the data at a cloud data center. The preprocessing stage was defined for filtering the data to avoid outliers. In this work, the process was performed only on essential features and predicted the load. A fuzzy-based feature ranking and selection method was suggested for optimizing the electrical subsystem. The analysis results identified that the proposed method achieved accurate and effective electricity distribution. The comparative results identified the improvement in precision, recall and accuracy parameters. Another work on extending the fog system for the smart grid was provided by Yu et al. [7]. The author explored service development architecture for smart homes and buildings. The author used the cross-layer infrastructure for optimizing the service architecture. A management layer was introduced to manage objects and devices' functional behaviours. The session-specific control and energy distribution were defined in this proposed architecture.

The results identified that the proposed model achieved significant precision and recall even during peak hours. The author did not provide work on load prediction or load balancing. Apoorva et al. [13] combined IoT and AI processing to enhance the security and automation of e-meters in smart homes. The proposed system applied the IoT concept for tracking electricity consumption. The proposed system also verified whether the charging against the electricity consumption was fair. The proposed system achieved higher reliability and accountability. An advanced and smart energy management system with an IoT framework was designed by Pawar et al. [25] in a smart grid environment. The model provided an effective controller based on consumer preference and partial load shedding. The demand response event was also defined with limit constraint specification. The cost optimization algorithm was described to enhance the smart grid's performance and reliability.

Khan et al. [15] provided an IoT-based smart grid system for effective power monitoring. The proposed monitoring method tracked the voltage, current and energy consumption parameters for generating the analytical observations. The real-time data of consumers was captured and took the decision to reduce energy consumption, and electricity bills was made. Rahman et al. [16] proposed a cloud and fog-based smart grid system to avoid electricity wastage. The microgrid architecture was defined for connecting the fog components. This low-level grid captured the information from multiple sources at the consumer end. The clustering was performed to categorize the consumers based on their electricity requirements and utilization. The smart meter was used with each cluster for optimizing communication. Once the requirement is predicted, the optimized bubble sort algorithm for allocating the virtual machines is based on the load. The proposed model achieved effective resource utilization with the least response time. Another fog computing-based smart grid architecture [26] was provided for handling overload situations. The author applied Round Robin, Odds and Throttled algorithms for achieving the load balancing. The results identified that the Odd algorithm outperformed the Round robin and throttled algorithms regarding the evaluation of response time and processing time. But in overload situations, round-robin and throttled algorithms provided better results. Zafar et al. [18] applied the bat algorithm to achieve load balancing in a cloud-based smart grid system. The author used the service broker policy for effective resource allocation. The results show that the proposed algorithm achieved effective results against Active VM Load Balancer and Particle Swarm Optimization (PSO) algorithms. Ismail et al. [19] used the artificial bee colony algorithm to handle the overload problem in a smart grid system. The author achieved effective fog resource allocation at the top layer for optimizing the performance of fog-based smart grid systems. The proposed model achieved effective results against round-robin, particle swarm optimization and throttled algorithms.

Barman et al. [20] monitored and controlled energy consumption by introducing a priority adaptive smart grid system. The author used smart meters to control power theft. The results show that the proposed model reduced energy consumption and enhanced the performance of the smart grid. Priyadharshini et al. [21] developed an IoT-based smart metering system for monitoring electricity consumption. Home appliance-based tracking and load-specific usage were suggested in this research. The method was effective in case of overload situations. Raju et al. [22] improved the load forecasting subsystem using a machine learning algorithm. The adequate electric consumption was predicted using a support vector machine and ensemble bagged regression, ensemble boosted regression, Gaussian process regression and fine tree regression methods. The proposed method achieved effective load forecasting with lesser RMSE, MSE and MAE parameters.

3. Proposed Rule-based Decisive Model

In this paper, an IoT and cloud-based smart grid architecture are presented that is intelligent against heavy load and power failure situations. The functional behavior of the proposed research model is divided into two main stages. In the first stage, load forecasting is performed. The paper has presented a rule-based model for predicting consumer requirements and load. This prediction is based on the consumer's history, peak hours and criticality level. Once the prediction is made, the power connectivity is provided through the most reliable and effective power station-integrated virtual machine. The current requirement and electricity consumption are also updated within the centralized data center. The proposed two-stage model is shown in Figure 3.

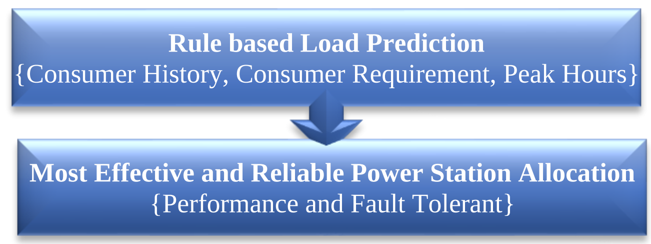

Fig. 3 Stages Of Proposed Rule-Based And Load Balanced Smart Grid Architecture

The proposed smart grid architecture is the composition of electrical and cloud networks. At the lower end, smart IoT devices are equipped at the consumer's end for capturing electricity consumption. The smart grid architecture performs two-way communication for capturing decisive information and providing an uninterrupted power supply. Figure 4 shows the architectural representation of the work. In this figure, N consumers (C1, C2…. CN) are shown at the lowest end. These consumers are defined with small IoT devices for capturing the electricity consumption and submitting the regular readings to the data centers. Smart meters are equipped in this layer as IoT devices.

In the second layer, the power stations (PVM_1, PVM_2…….PVM_M) are integrated with virtual machines. This architecture defines M power stations as accepting consumer requests and satisfying their electricity requirements. These power stations are hybrid and defined with variant power capacities. The number of connections and load should be balanced. The power stations' failure ratio, load and history features are also maintained in the centralized data centers.

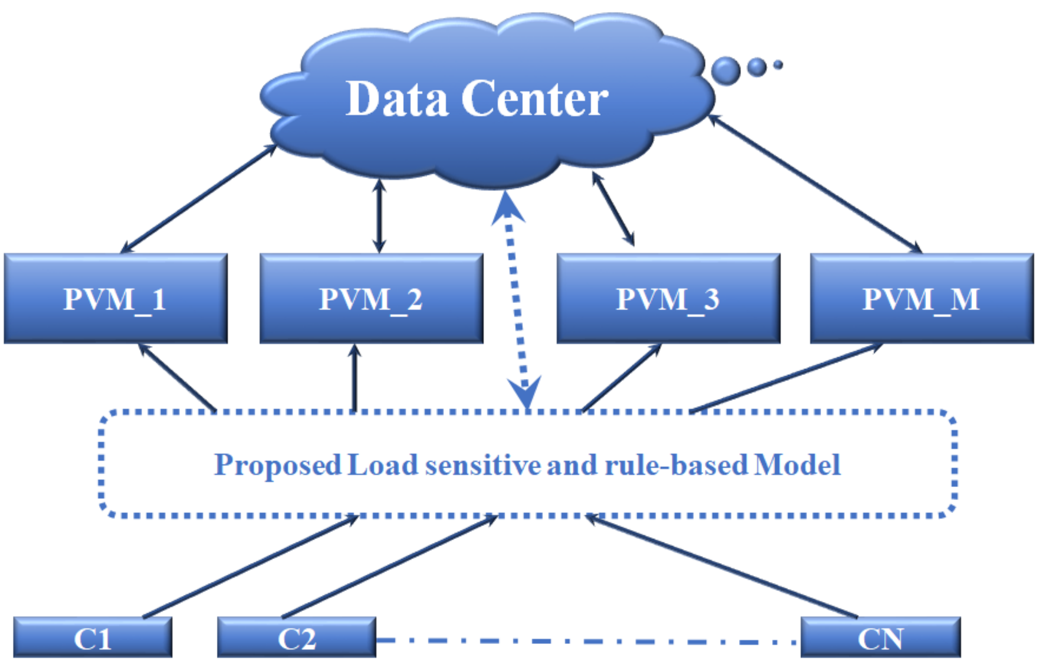

Fig. 4 Proposed Load Balanced And Cloud Based Smart Grid Architecture

The data center is a centralized and large memory space containing complete information and history about consumers' requirements and power stations' capabilities.

The consumer request is submitted to the system and recorded with the current timestamp in the intermediate layer. The proposed load predictive and load-balanced PVM allocation system is integrated into this intermediate layer. This layer identifies the criticality of consumer request and their arrival time as input and collects the history details of consumers from the data center. Based on the available information, the load and effectiveness of PVMs are mapped with the requirements of the consumers.

Once the allocation rule to the PVM is given in equation (1)

$$\sum_{i=1}^{k} PReq_i \leq Cap_m \tag{1}$$

Where k is the number of requests allocated to machine m. Cap_m is the capacity of mth PVM, $PReq_i$ is the power requirement of ith request.

Other than this load factor, the critical power requests are allocated to the most effective PVM. Once the request is allocated to PVM, it is executed by the PVM. Algorithm 1 defines the functional process used in this research for allocating the consumer's request to the PVM and ensures the successful execution of the request. If the request cannot complete within the expected finish time (EFT), then the request is considered a failure. The proposed model is simulated in a Matlab environment with different load specifications. The simulation description and analysis results are provided in the next section.

Algorithm 1: Rule-Based and Load-Sensitive Electricity Distribution (Consumer's request to the PVM)

```
1.  Define the N Consumers (Cn) in Smart Grid Network
    with their requirement, Criticality level
2.  Centralized Data Center (DC) is defined with a consumer
3.  Define the M Power station integrated Virtual Machine
    (PVM) with their
4.  For i=1 to N
    {
5.  [History CInfo]=Cn(i).GetInfo(DC)       /*Collect the
    current and history information of specific consumer*/
6.  For j=1 to M
    {
7.  pInfo=PVM(j).GetInfo(DC) /*Get the characteristics of
    the power station based on its current characteristics and
    past performance*/
8.  If (CInfo.PowerReq<=pInfo.RemainingCap and
    CInfo.Criticality=High and pInfo.Effectiveness=High)
    {
9.  PVM(j).Allocated(Cn(i))
    }
10. Else If (CInfo.PowerReq<=pInfo.RemainingCap and
    CInfo.Criticality=Low and
        (pInfo.Effectiveness=Medium or
        pInfo.Effectiveness=Low)
    {
11. PVM(j).Allocated(Cn(i))
    }
12. Else
    {
13. Cn(i).Info=Failure
    }
14. If (Cn(i).TurnAroundTime>DeadLine)
    {
    Cn(i).Info=Failure
    }
15. Else
    {
16. Process Request Cn(i)
    }
    }
    }
}
```

4. Results and Discussions

The proposed rule-based grid optimization model is simulated in a Matlab 2017b environment. The complete grid network is divided into 4 regions or zones for presenting the work for a wider and load-driven region. The grid network is controlled and distributed using a cloud computing approach. An individual server controls each region in this cloud-based grid environment. The servers are heterogeneous regarding geographically covered regions, resources and technical capabilities. The complete grid environment is having a centralized data center. The information collected from all the consumers and all servers is maintained in this data center. Each of the servers has some power stations integrated with virtual machines. The power station is the electrical controller for ensuring the power supply in the same or other regions. These power station-integrated virtual machines control the technical decisions and the two-way communication over the network. In each region, there can be a different number of heterogenous PVMs. Each PVM is limited to precise load capacity. The criticality of a PVM is also taken based on its earlier performance recorded in the data center. The load, criticality and performance of PVM are the decisive parameters used in this research for allocating the PVM to the requests of consumers. While simulating the work, the different scenarios are taken with the different numbers of consumers.

The analysis is taken with 50 to 1000 requests in peak hours. The analytical observations are done regarding response time, task finishing time and number of power failures. The analysis is conducted against some of the existing scheduling techniques. The techniques used for analysis are First come, First Serve (FCFS), Shortest Job First (SJF), and Largest Job First (LJF). FCFS is the simplest scheduling method in which the requests are handled respectively to the arrival time of the request. As the power distributor receives a power request, the request is processed without considering the power requirement or a load of a request. In SJF, the requests are sequenced respectively to the power requirement of these requests. The requests with smaller power requirements are handled and processed first. This starts reducing the load from the power distributor. But as the number of requests increased, the delay in fulfilling the power requests with larger power requirements increased. The function of LJF is reversed to SJF. In this algorithm, the power request with power requirement is first allocated and processed. Because of this, fewer requests can be handled in parallel. In peak hours, there are more chances of power faults in the system. The proposed power allocation and distribution model is compared with these methods. Figure 5 provides the analysis results using the power delay parameter. This measure defines the difference between the time of power request and the actual time of power allocation.

Figure 5 shows the comparative and analysis results obtained for the power delay parameter. The power requests are taken here in a fixed time slot to analyze the peak and normal load hours. The power requirement and arrival time are input with each request. The algorithmic models are applied based on these parameters to decide the sequence of power station allocation.

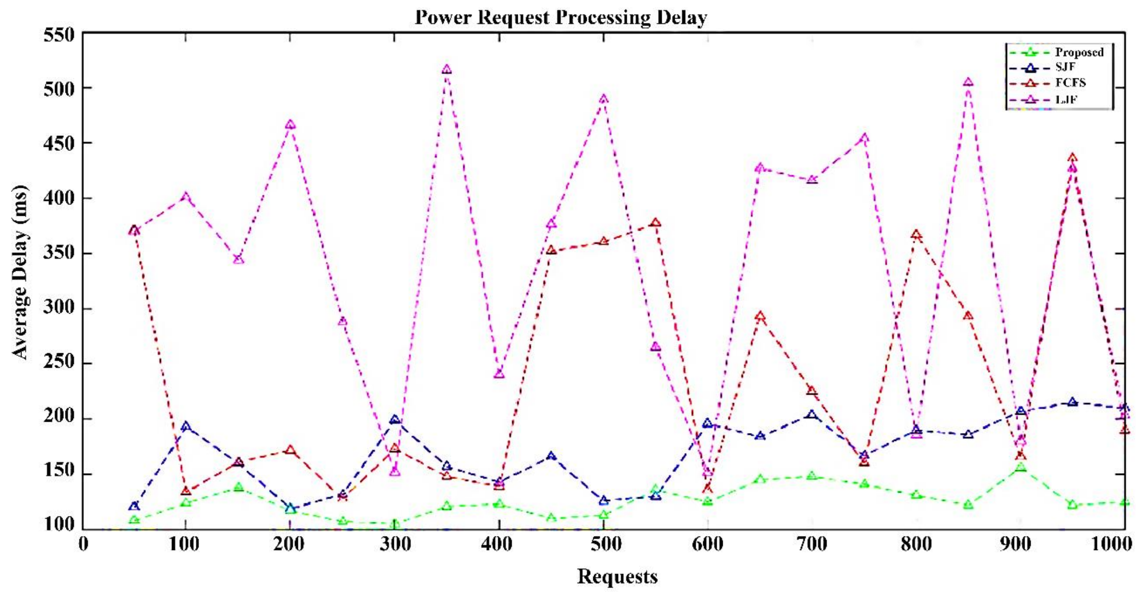

Fig. 5 Power Delay Analysis

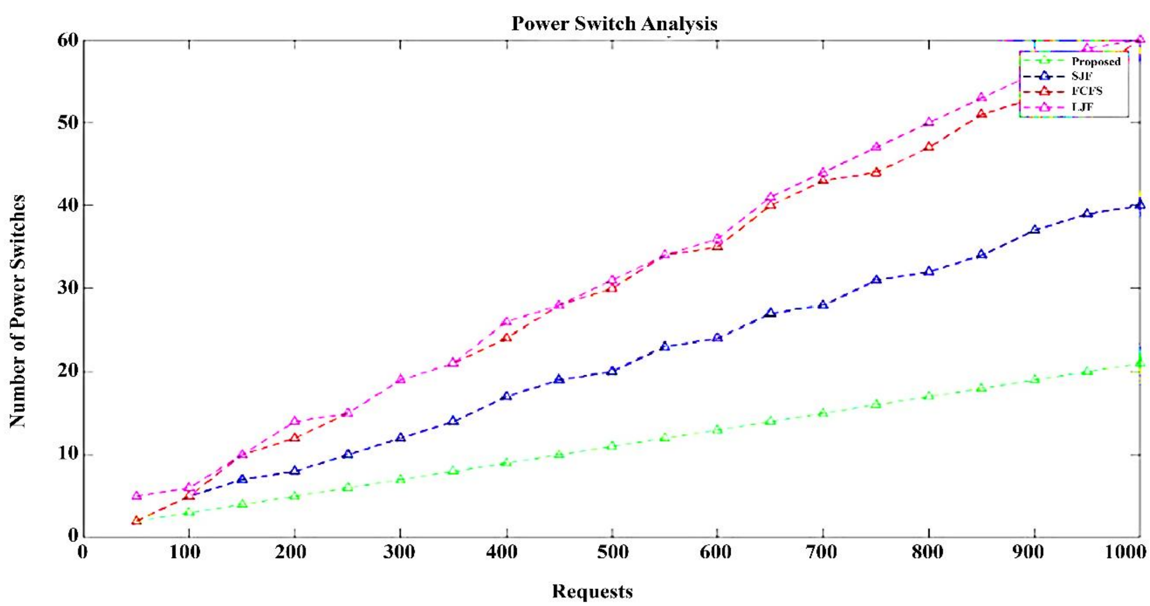

Fig. 6 Power Switch Analysis

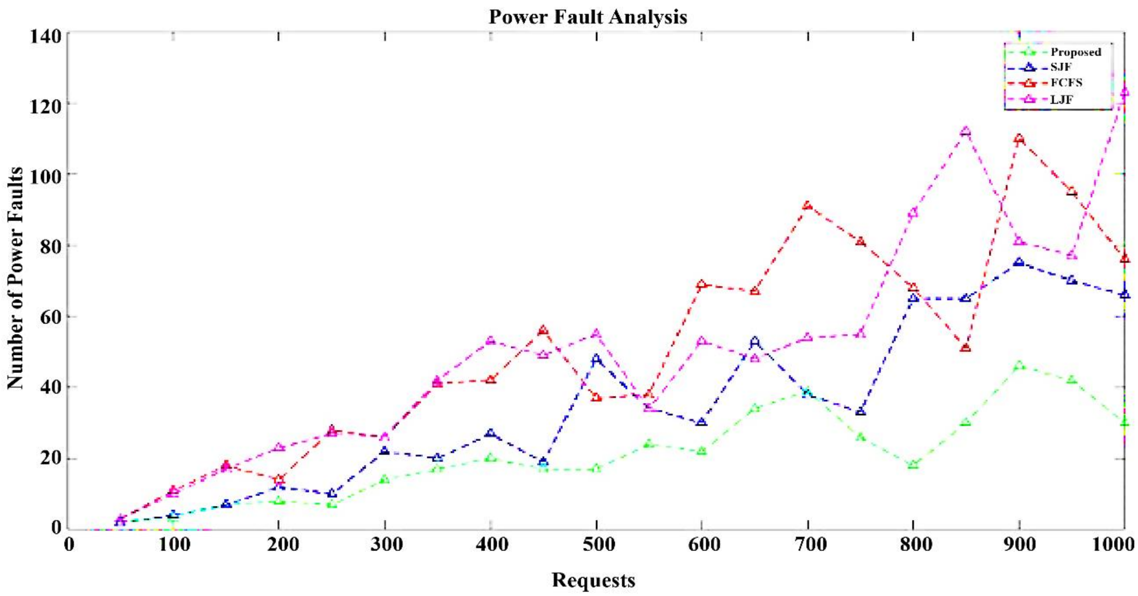

Fig. 7 Power Fault Analysis

The x-axis of the figure shows the number of requests processed in each time slot. The parallel and different load situations are handed. The average delay of power requests is analyzed against the conventional scheduling and resource allocation methods discussed earlier. The delay is analyzed in milliseconds. The figure shows that the proposed model's average delay is much less than the existing methods. The power delay obtained by LJF has given the worst results. In LJF, when the request with a larger power requirement is allocated, other requests wait. This increased the average wait time for all requests of that slow.

Similarly, the average wait time of FCFS is also higher than the proposed model. The average wait time of SJF is close to the average delay of the proposed model. The line graph shows that the proposed model achieved effective results with the least average delay.

Figure 6 shows the comparative analysis of the number of power switches generated by the proposed and existing methods. The results are collected respectively to the number of requests generated for a specific time slot. As the requests are generated, these requests allocate to a particular power station. But if the power station load is heavy and it cannot provide more power to the user, then the request can be switched to another power station.

The figure shows that the increase in power requests also increases the number of power switches in the system. The figure clearly shows that the number of power switches is much less in the proposed model compared to the existing method. It shows that the proposed rule-based power station allocation is an effective and decisive method that reduces the number of power switches.

The number of switches is very high for SJF, FCFS and LJF methods. The results of FCFS and LJF are the worst among all methods. The line graph shows that the proposed model reduced the power switches and improved the system's reliability. The lesser power switches also reduced the wait time of the process and lesser chances of a power fault. The power fault-based analysis results are provided in Figure 7.

Figure 7 provides the analysis results for a number of power failures that occur over the smart grid-based system. If a user requests a specific power load for a specific period and the system cannot provide the power for the given interval on time, it is considered a power failure. A power system with high power failures is regarded as a non-reliable system. This figure provides the fault analysis against the number of user requests. These requests are performed over the given time slot. Each of the existing and proposed methods is analyzed under the power failures. The figure shows that the number of power failures in the case of FCFS and LJF algorithms is much higher than in the proposed model. The proposed model achieved reliable results with the least number of power failures.

5. Conclusion

The paper has presented a smart and rule-based power distribution system to improve the effectiveness of an intelligent grid system. The work aims to reduce the system's power delay, switches, and failures. The proposed rule-based power distribution system analyzed the environmental information, user requirement information and power station characteristics. The load forecasting is performed before allocating the resource to the users based on their requirements.

The system is designed to allocate resources in an overload situation effectively. The proposed model is simulated with normal and heavy load situations. The comparative analysis is done against FCFS, SJF and LJF algorithms. The analysis results show that the proposed model reduced the power delay, power failures and power switches. The reliability and performance of power distribution are improved in the smart grid environment.

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