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Research Article

An Optimized Framework of the Integrated Renewable Energy and Power Quality Model for the Smart Grid

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The smart grid's structure is distinctive because it incorporates numerous cutting-edge communication and sensor technologies. It is challenging to manage smart grids using conventional power grids' unified optimum delivery strategy effectively. This work offers a smart grid power production and maintenance collaborative optimization framework with renewable energy based on power generation and maintenance analysis. The operating costs of conventional units, the price of generating solar or wind power, and the cost of maintaining units are the problems of objective functions; the constraints taken into account are primarily system constraints. The genetic algorithm (GA) is used in this research to examine the optimization solution strategy. Depending on the properties of the system, various loads, power sources, and constraints are considered. The difficulty of adjusting load scheduling is transformed into a control problem by developing an efficient objective function. When uncertain system components are considered, the real-time control system can dynamically alter load scheduling to meet the needs of the actual system. In this study, the real-time algorithm put forward in this research is based on a strategy that satisfies the load optimization requirement and achieves dynamic compensation for unpredictable changes in renewable energy power generation. Moreover, the simulation compares the proposed algorithm capabilities with the existing algorithms/study, demonstrating the effectiveness of the suggested approach.

1. Introduction

Demand of energy has increased day by day cumulatively. The number of devices/equipments are exponentially increasing in today's hex. The ministry of power has proposed the National electricity ten-year action plan to supply the electricity across the country. The proposed plan ensures whether the supplied power is efficient or not. According to the world resource institute, India produces approx. 6.7% carbon emission. As per the prediction of the world energy council, the peak of electricity will be attained by 2030 [1]. In the world, India is the most significant coal consumer and importer of fossil fuels. The electricity generated by coal produces carbon emissions after analyzing the different reports provided by different organizations [2]. It has come to mind that an alternate source or solution is required urgently for generating electricity. The motivation behind this study is observation of the unused device (which needs to be on but cannot due to brownout/blackout) and inappropriate scheduling. Devices are under running condition even though they have accomplished their allocated task. That is why we came up with this impression and reconfigure the framework.

The main contributions of this research article are as follows:

(i) This article provides the critical factors of non-conventional energy sources.

(ii) This article also provides the vital components for managing the energy and forecasting the load.

(iii) The key point of this article is to propose a smart framework for a smart grid that can maintain power quality and availability.

(iv) The study not only simulate the framework but also performs the comparative analysis of the proposed framework with available existing latest research.

(v) This article also marks the work progress for future researchers who are seeking opportunities in this field.

1.1. Renewable Energy Resources. The energy is collected from various resources such as wind, wave, tide, and solar which are available naturally. The energy collected from these sources is converted into the desired energy with the help of transducers and electronic circuits [3].

A photovoltaic or solar cell, where the sunlight is fallen on the P-N junction, has a voltage across this junction. It has a two-layer structure consisting of a P-type semiconductor, known as the base, and an N-type semiconductor, known as the emitter. On the cell's periphery, an anti-reflection coating is coated so that incident light does not reflect. Metal contacts are provided at the surface for the electrical connection, depending on crystal solar cell efficiency described in the form of Table 1.

There should be a value for the wind. The generation of the power is performing at a specific wind speed. Below the rated speed, no power output will be obtained. The max power is obtained from wind power generation [4]. There are some limits to any system. While collecting the energy from a wind turbine, there is a limit to the power generated from the wind power system.

$$0 \leq P_W(t) \leq P_W^{\mathrm{Max}}(t), \quad (1)$$

where Pw is wind energy and upper limit of generation from this source is $P^{\max}$ with respect to time. In particular, when renewable energy sources are included, the available power sources for power generation on a per-grid basis may differ due to environmental factors, so it is necessary to integrate and operate them [5].

1.2. Management of Energy. Integrating of energy (solar, wind, hydro, storage system, etc.) improves the smart grid's capability to fulfill the demand of energy. Integration is applied, or the different energy sources are summed up; some challenges such as frequency and waveforms have arisen. Furthermore, intelligent technologies are used to overcome such challenges to make the system intelligent, efficient, secure, and stable [6]. The system may be identifying the brownout periods due to the unexpected availability of solar and wind.

$$\text{Maximum Demand} = \text{Connected Load x Diversity Factor}. \quad (2)$$

However, the present research focused on the sophisticated framework, algorithm, and model to reduce blackout, brownout, and energy costs [7]. The maximum demand is calculated using equation (2) [8], where connected load is referred to summation of all active equipment connected at time t.

1.3. Energy Management Tools. Most of the appliances were manual and followed basic automation control system techniques. Nevertheless, in today's hex, the Internet of Things (IoT) has become an excellent evolution for making systems smart and automated. Several information and communication technologies in the grid make the grid operation fast, secure, and efficient. The electrical energy converted from renewable, nuclear, fossil fuels, and other sources can be mapped with the help of energy management tools [9], as described in Figure 1. The tools mostly used to manage the energy are shown in the following figure:

These tools help us out to monitor, control, and manage energy [11]. These tools can implement the tariff plans, demand-supply calculations, and mapping of the circuits [12].

1.4. IoT in the Smart Grid. The traditional grid is one-way communication, but the smart grid emphasizes to adopt smart technologies. The internet-based smart grid ensures the power quality and availability of the power. The electrical grid is a network of electrical generation, transmission, and distribution, like the internet, which is a network of networks [13]. The internet-enabled smart grid makes it easy to monitor, control, and operate the grid functions.

Figure 2 shows the power flow management along with its associated operation i.e., old pattern (generate, transmit, and distribute) and latest pattern (control, monitor, and store). After the introduction of IoT, power can be monitored and controlled easily [14]. Traditionally, after generation of power, it can be transmitted and distributed in a usable manner. The technology provides storage for later use after conversion of energy.

The rest of the article is organized as follows: Section 2 deals with the literature review of load optimization and cost minimization. Section 3 discusses about the implementation parameters, configurations, and constraints. Section 4 emphasizes on the proposed work along with the implementation and comparative analysis. Finally, Section 5 concludes the study.

2. Related Work

Through the recent development of power conversion technology and changes in the environment of the power industry, microgrid-based systems are recognized as latest version of power systems. With the increasing interest in environmental protection in the country, there is a growing interest in using various renewable energy sources. Many researchers have presented different optimizations and integrated energy source frameworks. Some of them are given as follows:

Kumar and Majid [15] provided an overview of the current status and challenges of renewable energy for development in India. They summarized many different reports and provided statistics on current trends, prospects, and opportunities in India's energy sector. Furthermore, they projected the consumption and production status in India as well. Installed capacity and demand also describe

Table 1: Solar cell efficiency.

Sr. no	Material	Efficiency (%)
1	Mono crystalline silicon cell	15–18
2	Poly crystalline silicon cell	14–16
3	Amorphous silicon cell	6–8

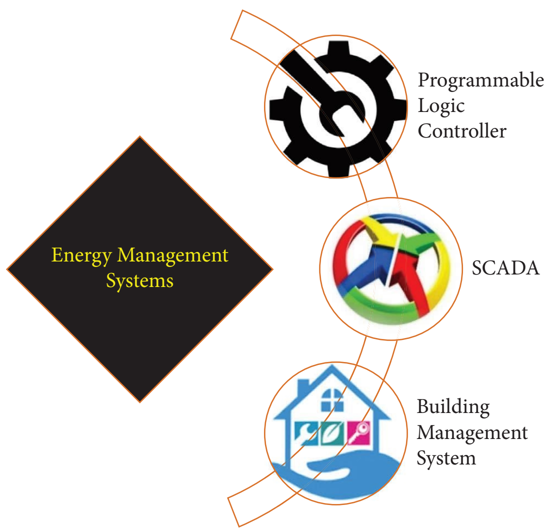

Figure 1: Energy management tools [10].

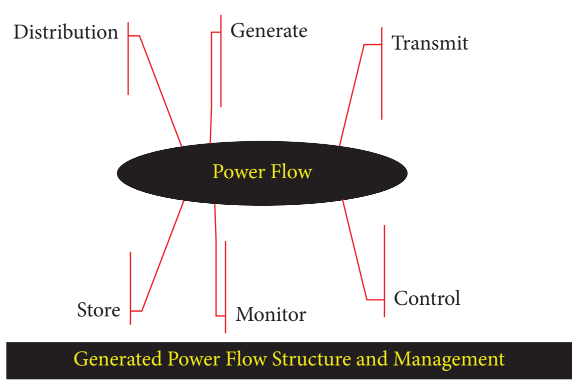

Figure 2: Power flow.

the investment and contribution of different sources. They suggested the comprehensive policies and regulation framework required for integrating renewable energy resources.

Meyabadi and Farajzadeh [16] provided the theoretical directions for optimization and planning for long-term power systems. They analyzed the photovoltaic and wind energy against the parameter availability and usability. Furthermore, they presented an overview of PV and wind energy in Shaanxi city and framed a plan against different parameters. It has been determined to avoid abandoning wind or PV and to promote the integration of different energy sources.

Worighi et al. [17] proposed a smart grid architecture. The proposed architecture consists of the smart grid controller, ESS, large scale integration, transmission, renewable energy system, distribution, and service provider. They tried to balance the demand-supply equation. In order to implement the proposed architecture, MATLAB/SIMULINK is used. They demonstrated the architecture using the system of system technique. For analyzing the system with load, they consider the intermittent duties as well as short-term duties of machines.

Cinar and Kaygusuz [18] described a large-scale internet data center using the stochastic optimization technique. An enhanced technique to minimize the electricity cost was proposed. The method's goal is to change the power consumption of electronic devices. Moreover, the study has also explained the dependencies and operating time effects.

Jiang and Wu [19] focused to minimize the peak load through the Min-Max objective function. A method prevents system outage but limited to small scale. However, this technique only works to reduce cost. The scheduled electronic devices are scheduled at the unscheduled time. A technique with peak load minimization as an objective function is proposed. Efforts have been made to balance power use, but it has a limitation that does not take into account the inconvenience of time.

These optimization algorithms are likely to explore the optimal global solution, but they have several problems in dealing with the algorithm's constraints of convergence time, accuracy, and complexity.

3. Methodology and Implementation Configurations

This section describes the methods and related constraints to implement the problem. In order to setup the testbed and simulation configuration, this section provides the key factors of simulated results. The overarching strategy to achieve the objective of the study is discussed in subsections.

3.1. Load Shifting Module. This module deals with the load and is configured to read the status and properties of the load. If flag one and load are fancy, the device is moved to the waiting queue and the load status is stored as flag 0. This module is directly embedded with user comfort and availability of power. The user decides all the properties and categories/priorities of the load. This module allowed the optimization independently and did not affect the load population.

3.2. Experimental Setup. The experimental setup is nothing but summarizing the data, constraints, and environment variables taken while setting up the experiment. During the experiment setup, it is required to identify the control variables, parameters, and standard frequencies. Such type of parameters is described as follows:

3.2.1. Data Parameters/Configuration. The module configuration is high end setting, and without these settings, the system is under red flag and idle condition [20].

Table 2: Constraints.

Sr. no.	Source/resource	Constraints
1	Solar	$0 \le E_{PV} \le E_{PV}^{\text{Max}}(t)$ $P_{PV} \le A_{PV} * f * sf(t)$
2	Wind	$0 \le P_W(t) \le P_W^{\text{Max}}(t)$ $P_W = 0$ if $u_f < u_{ci} \& u_f > u_{co}$ $u \leftrightarrow v$ $P_w = P_{\text{rated}}$ if $u_r \le u_f \le u_{co}$ $P_W = P_{\text{rated}} * u_{f-u_{ci}}/u_r - v_{ci}$ if $u_{ci} \le u_f \le u_r$
3	Smart grid	$E_{\text{Grid}} + E_{PV} + E_W + \sum_i^{\text{NEV}} E_{EV}^{\text{Disch}}(t,i) + E_B^{\text{Disch}}(t)$
4	Electric vehicle	$P_{EV}^{CH} \le P_{EV}^{C\max} * w(t,i)$; $\forall t \in t_{-}(\text{home})$ $P_{EV}^{CH}(t,i) = 0$; $\in t \ne t_{\text{home}}$
5	Storage/inverter	$P_B^{CH} < P_B^{C\max} * y(t)$ $P_B^{\text{Disch}} \le P_B^{D\max} * z(t)$

3.2.2. Control Variables. The control variable is *Ci*, directly sending the instruction to the work storage end-use *i* for the operational module. It is the dimension of z with i-th devices and flags zero where devices are under the idle condition at time t. When the flag one is at time interval-*t*, it is considered that an appliance completed its assigned task.

$$E_{\text{Generated}} = E_{\text{Dissipated}}, \quad (3)$$

$$E_{\text{Grid}} + E_{\text{PV}} + E_W + \sum_i^{\text{NEV}} E_{\text{EV}}^{\text{Disch}}(t,i) + E_B^{\text{Disch}}(t), \quad (4)$$

$$0 \le E_{\text{Grid}} \le E_{\text{Grid}}^{\text{Max}}(t), \quad (5)$$

$$\text{Min } f(\text{cost}) = \sum E_{\text{Grid}} + C_{\text{Grid}}(t) + E_{\text{PV}} * C_{\text{PV}} + E_W * C_W(t) + \sum_{i=1}^{N}\left(E_{\text{EV}}^{\text{Disch}}(t,i)\right) * C_{\text{EV}}^{\text{Disch}} + E_B^{\text{Disch}} * C_B^{\text{Disch}} - E_{\text{Inject}} * C_{\text{Sell}(t)}, \quad (6)$$

$$P\_\text{Consumption}_{\text{Shiftable}} = \sum_{T=1}^{T}\sum_{\text{Shiftable}}^{N} \text{Load}_{\text{rating}} * \text{Load\_status}(t). \quad (7)$$

Equation (3) is indicating balance of energy, as we already know that energy neither can be created nor be destroyed but we can transform energy from a form to another. In equation (4), E_{grid}, E_{pv}, *Ew*, and E_{ev} represent the grid, solar, and wind energy, respectively. Equation (5) represents the grid capacity, *t*-interval, and *i* for iteration or number of intervals. The system used various variables as per requirement of loads and source dataset configuration. The system configured various types of operation, mode, and user requirements for considering real-time scenarios. Equation (6) indicates the cost function, and equation (7) returns the status of appliances.

Table 2 represents constraints for the interconnected energy sources for the proposed framework as follows:

Where E_{pv} is indicating the photovoltaic energy and $_E{}^{\max}$ indicates the upper bound of solar. A_{pv}-is average power and can vary between the defined parameters. *Pw* indicates wind power, and *u* indicates the density of air. Energy generated by wind with respect to time is equal to the rotor area. The smart grid constraint represents the power generated by other conventional energy sources. The electric vehicle's constraints open for future plugins to transfer the power for an electric vehicle. P^{CH} indicates the charging of storage, and P^{Disch} indicates the notation for discharging of storage in case of faults and energy source failures.

3.3. Dataset and Inputs. The dataset contains various attributes, cases, properties of real-time operating devices, and critical points for the test beds [21]. The dataset is available openly, provided by different research organizations such as IEEE and Data Repositories for power [22, 23]. In order to achieve the salient objective of the study, following datasets have been used:

(a) NREL Develops Sub-Hour Solar Power Data Set, NREL Fact Sheet (2012)
(b) Grid Optimization-real-time data-2015
(c) Network model and scenario information-2015
(d) Optimization of operating cost reduction of under real-time pricing-IEEE-DataPort

These datasets are used to operate the system. The solar dataset is inserted for taking solar output as per weather conditions defined in the dataset, and constants are used for the wind energy.

4. Proposed Framework

This section introduces the solution of existing problems and provides the steps to overcome the problem. The smart framework integrates the quality model and integrated renewable energy sources. This framework integrates the models and provides a comfortable platform for concord

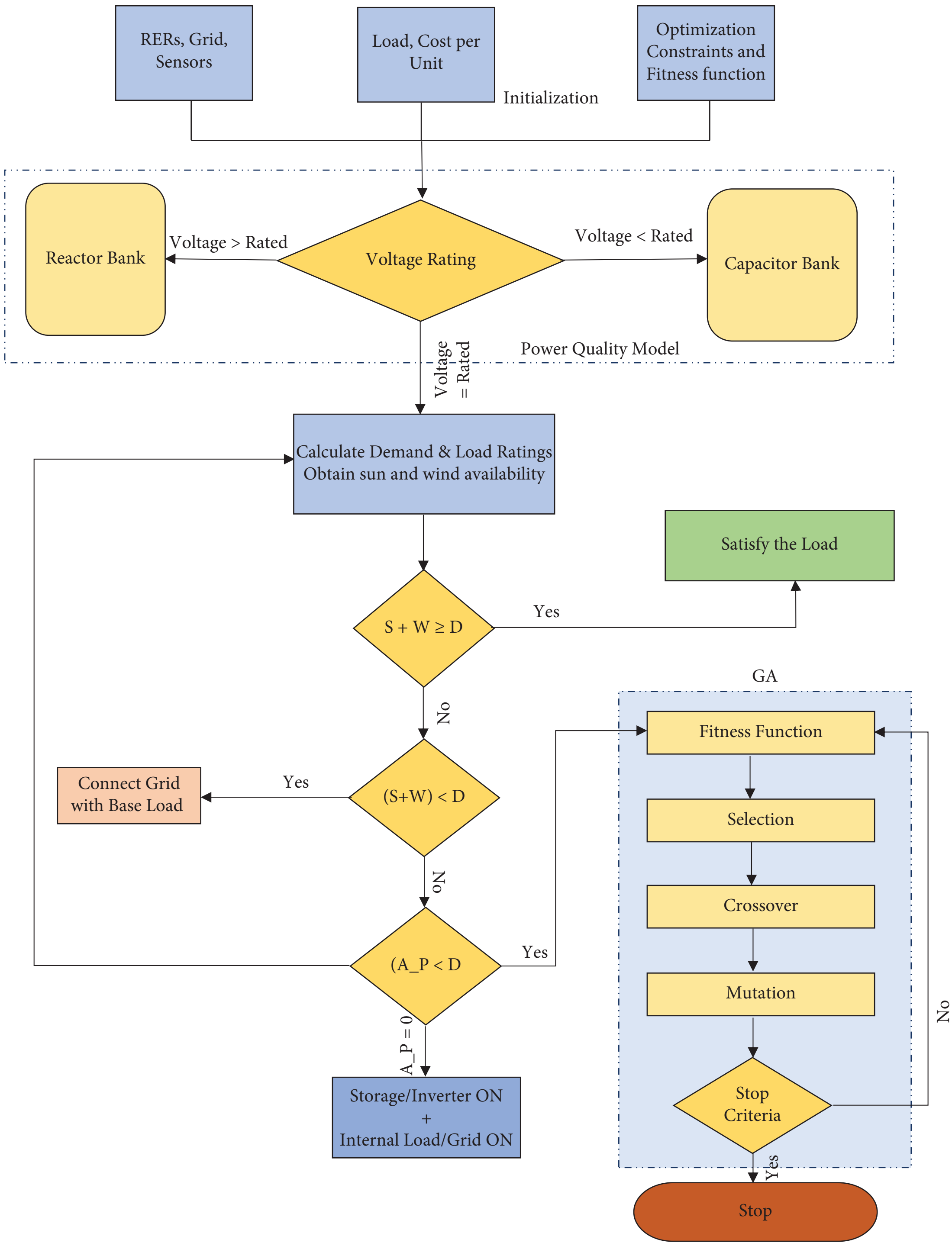

Figure 3: The flowchart of the proposed framework.

between them. As an alternative, a GA with some modifications is offered. The chosen optimization procedures apply the objective functions and their constraints to develop reasonable solutions. During the first stage of GA, a random population is generated, which consists of chromosomes that are 0/1 states of the various appliances. The objective function is calculated every time using the RTP pricing scheme, and the equations are presented in Section 3. This framework integrates the models and provides a comfortable platform for concord between them.

4.1. Proposed Smart Framework. The proposed framework is as follows:

Input: Fitness Function, Constraints, Load Population, Population Ratings

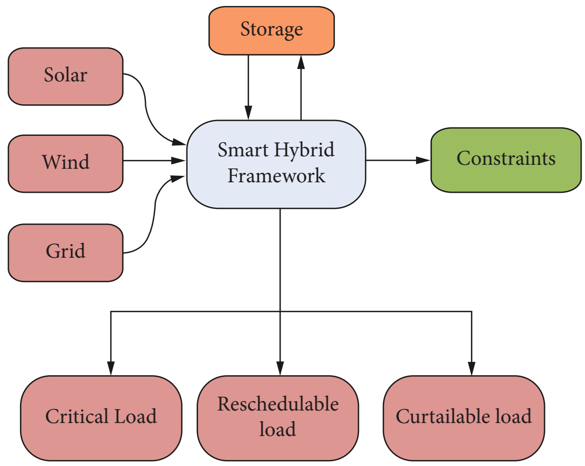

Figure 4: The block diagram of the proposed framework.

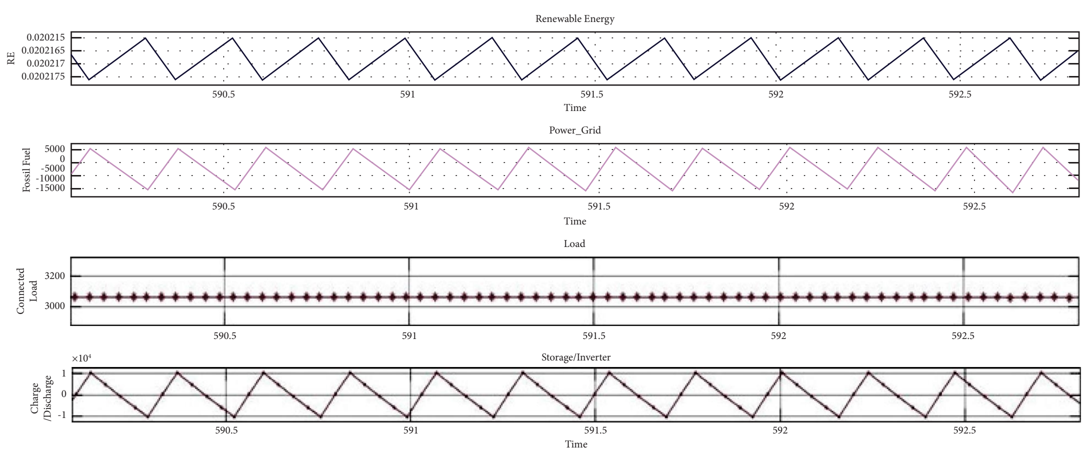

Figure 5: Experiment results.

1 Initialize Renewable Energy Sources along with Grid, Weather Forecasting, Sensors, Power Quality Model

2 Calculate incoming from Renewable Source, affordable load, and Display

3 If Source_Incoming < Rated_Voltage

CB = ON;

Voltage = Rated Voltage;

Flag = 1;

Elseif

Source_Incoming > Rated_Voltage

RB = ON;

Flag = 1;

Else

Flag = 1;

End If

4 If Flag = = 1;

Switch (D)

Case 1:

$S + w \geq D$

⟶Satisfy the load

Case 2:

$S + w < D$

⟶Connect Grid

Case 3:

A_P = = 0

⟶Apply GA

⟶Population = Population []–GA(Result)

Case 4:

⟶Storage ON for Grid Internal Circuitry

End Switch

End If

5 Synchronize

Calculate:

Maximum Demand = Connected Load x Diversity Factor

X = Demand–Supply;

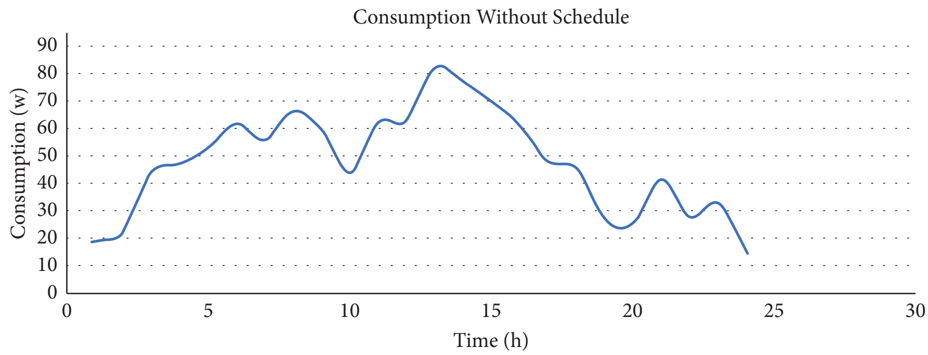

FIGURE 6: Consumption without scheduling.

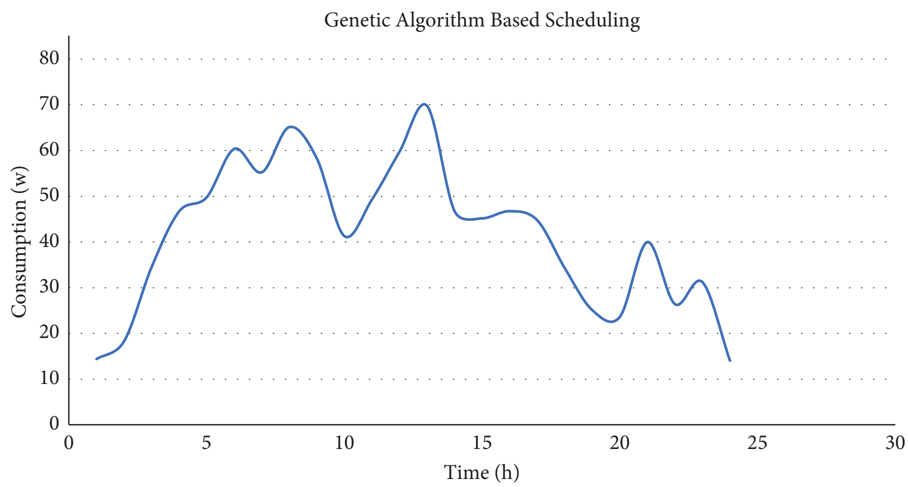

FIGURE 7: Consumption with scheduling.

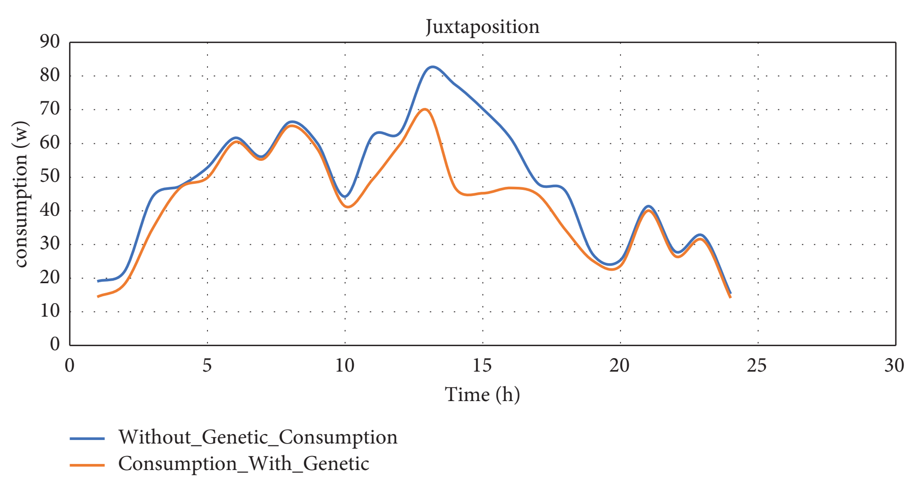

FIGURE 8: Comparative analysis.

TABLE 3: Cost saving comparison.

Appliance	Without framework per day (rupees)		With framework per day (rupees)		Saving (%)/day
	4 hours	Per day	4 hours	Per day	
SA-I	3.5	21	3.1	18.6	11.4
SA-II	3.72	22.32	3.55	21.3	4.56
SA-III	3.65	21.9	3.42	20.52	6.30
SA-IV	3.43	20.58	3.25	19.5	5.24

*SA-smart appliance.

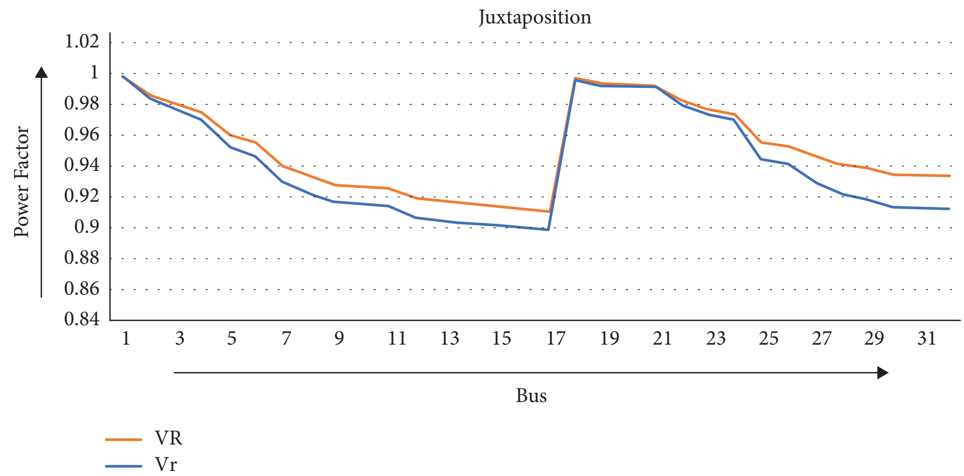

Figure 9: Comparative analysis of the voltage profile.

Stop

Note:

S: Solar, w: wind, A_P: All Power

D: Demand, CB: Capacitor Bank

The proposed framework represented by Figure 3 has an input section, where system required the inputs such as fitness function, constraints, load rating i.e., voltage, current, power, preference, type, and price and pricing scheme.

Firstly, all the sources are initialized either it is conventional and nonconventional. Weather forecasting is also enabled for information about availability of the sun and wind. The sensors are associated with systems such as voltage, current, and other sensing devices. A power quality model is also integrated with source end for maintaining the power quality.

After the initialization process, the system calculates the available power, affordable connected load, and how much load can be turn on at the same time within the defined range. Then, the power quality model comes to picture, and the voltage profile is checked. If the voltage profile is the same as the device required profile, then without any correction it will pass to the next block. If the voltage profile is less than the required power, the capacitor bank is enabled and enhances the power up to suitable format. And if the voltage profile is greater than required, then a reactor bank is enabled and corrected it up to usable manner.

A programmable bus supports the multicommands/load and can switch load as per instruction received from the parent node. A switch is performed for multiple cases, and the above framework has considered four cases. Case 1 defines that if only renewable energy (solar + wind) can satisfy the load, then no need to take power from the grid and satisfy the load. Case 2 defines that if Case 1 did not satisfy the load, then connect the grid. And Case 3 defines when some faults/disaster occurred, it will satisfy the essential load only. If load is greater than affordable load, then a GA handles the situation and optimize the load upto a condition. The Case 4 defines that if all three case fails, then the system goes into troubleshooting mode and connect the storage for internal circuits. The complete log file along with latest data is synchronized with cloud.

Figure 4 indicates the used elements and their connection preferences. In this framework, solar and wind energy sources were considered renewable, while the grid represented energy generated by fossil fuels or other sources. All the energy sources are integrated and connected with the proposed programmable framework. There is also a storage area for the grid's internal circuit troubleshooting, fault location, and route location to the targeted load. The framework is configured with constraints on energy sources and load parameters for the grid to be smart, stable, and without a saddle point. The load is allotted in three categories, i.e., critical, reschedulable, and curtailable. The critical load is essential and must be ON in all circumstances. However, the rescheduled load shifts to available local energy sources. At the same time, the curtailable load is fancy and needs to be configured to connect with the system during peak hours. The disconnected load has shifted into a queue, and the sorting algorithm sorts the load according to their preference. The sorted load is moved to the ready queue, where it can be connected again. In order to optimize the load, the GA is used. The result of the GA is disconnected from the load population array and updates the status of the load for calculating the demand of the connected loads.

4.2. Experimental Results and Discussion. The simulation results demonstrate the superiority and efficiency of the proposed optimization framework in terms of consistency, convergence rate, operating speed, cost, response, power quality, and finding better plausible optimal solutions.

4.2.1. Discussion. The simulation results show the various variable outputs, i.e., consumption, scheduling, cost, and power quality. Figure 5 clearly shows the framework's performance. There is no breakdown in the scheduled simulation, and all the framework elements are fully utilized.

Table 4: Comparison with existing work.

Sr. no	Reference	Objective	Pricing scheme	Optimization technique	Integration of renewable energy	Integration power quality	Load restore management
1	[28]	Cost reduction	RTP	Fractional programming approach	✓	✓	×
2	[29]	Enhancement in overall utility	ToU	Mixed-integer nonlinear programming	×	×	×
3	[30]	Bill reduction	RTP	Heuristic optimization	×	×	×
4	[31]	Peak hours demand reduction	RTP	Enumeration/set theory	✓	×	×
5	[32]	Cost minimization	Fixed price	PSO	✓	×	×
6	[33]	Making load flat and cost reduction	RTP	Multiobjective	✓	×	×
7	[34]	Cost minimization	Fixed price	Game theoretic approach	✓	×	×
8	[35]	Demand reduction during peak hours	RTP	PSO	✓	×	×
9	Proposed	Cost reduction, power quality	RTP	GA	✓	✓	✓

Note. RTP: real-time pricing, PSO: particle swarm optimization, TU: time-of-use.

Figure 6 shows the consumption without scheduling, while Figure 7 shows the consumption with scheduling. The above waveform represents the output power received from the different energy sources, i.e., solar, wind, and other fossil fuels. The continuous wave represents that the carried experiment has no breakout and that the system works smoothly. The power received from solar has less harmonic distortion, so harmonic deduction devices are ignored for the deduction of solar harmonics. The frequencies of all sources are considered to be 50 Hz with ±5%. The development of the integration of GA along with the framework shows excellency and efficiency in terms of coding simplicity, fast convergence speed, and accuracy. To minimize the operating cost of a grid system line constraints and renewable energy sources are to be considered.

4.3. Comparative Analysis. This section performs a comparative analysis between the proposed framework and the frame of related work. The frame of related work includes the themes, ideas, theoretical/practical questions, and problems [24]. The frame for comparison is constructed using globally indexed databases. This frame validates the results. Moreover, it is also remarking on the proposed framework's superiority, efficiency, and stability. This analysis performs against the three parameters i.e., power consumption, cost, and quality.

4.3.1. Consumption. Figure 8 shows that using a GA, the device's power consumption is optimized. The scenario represents the device usage in a day. The timeline is in hours (0–24). It indicates that the best result is provided during its peak hours. It increases the availability and reliability of the smart grid. It affected the curtailable and shiftable load. It plays a crucial role when the load increases during peak hours.

4.3.2. Cost. The savings on electricity price and improvement in the system load factor greatly depend on various factors, including real-time pricing, weather, the flexibility of loads, set-points, available control equipment in the building and distribution grid, and accuracy/availability of the forecasts. Real-time pricing and weather variations also affect the customer's cost savings and system load [25].

Table 3 shows that how the cost module performed and how much cost is saved (4.56 to 11.4 per cent per day). The Smart Appliance-I have included for the different high rating loads, while SA-II includes various load operating ranges from 5 to 20 watt, SA-III includes the operating range from 20 to 50 watt, and SA-IV includes the self-impedance.

4.3.3. Power Quality. The quality module ensures the quality power for equipment and user devices [26]. Vr indicates the energy received from the integrated sources, and VR represents the energy received by devices/appliances. Comparison Figure 9 shows the voltage profile before and after compensation. It is marked that after using compensation, the technique voltage profile improved significantly.

This power quality analysis shows the importance of the quality module in the proposed framework.

Optimization of operating cost under real-time pricing and time of use has applied to analyze the optimal values and compare them with the optimal values of various existing frameworks [27]. Table 4 illustrates the various features of the different existing and proposed approaches.

5. Conclusion

This work offers a collaborative optimization approach for smart grid power generation and maintenance with distributed renewable energy based on the power generating plan and maintenance plan analysis. The operating cost of traditional units serves as the problem's objective function in the collaborative optimization setting. Power balance constraints, unit output upper and lower limit constraints, maintenance constraints, and relevance constraints between maintenance and start-stop status were all considered. It examines the optimization problem-solving approach with the power quality model and introduces the genetic optimization algorithm used in this article. The MATLAB simulation experiment confirms the usefulness of this framework. This proposed work is more practical and can ensure the full use of power resources while also assisting in maintaining the stability of the power system because it overcomes the limitations of traditional algorithms that only satisfy specific loads and do not consider power supply constraints. The GA can obtain a load close to power supply when the conditions are on power supply. The simulation experiment further validated the genetic optimization algorithm by comparing it to the traditional load scheduling approach. The GA is more accurate and practical than the existing techniques i.e., which can only be applied in ideal circumstances without power supply constraints. The power supply resources of the power market may be fully utilized when the proposed work is used for real-time load dispatch, benefiting the secure and efficient operation of the power system.

Data Availability

The data supporting the findings of the current study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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