

# INTELLIGENT SMART GRID MONITORING AND ENERGY ROUTING USING IOT TECHNOLOGIES

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DOI: [doi.org/10.34293/shanlax.9789361631474.ch010](https://doi.org/10.34293/shanlax.9789361631474.ch010)

## **Abstract**

*Generation, distribution and transmission of electricity have undergone an unparalleled transition as a result of the expedited progression of global energy networks. Power sector is witnessing a transformative shift toward decentralized, adaptive and renewable-driven Smart Grids (SGs). This paper presents an efficient IoT based smart grid framework with the monitoring of parameters for its efficient functioning and regulation. The smart grid framework has hybrid renewable energy systems including battery storage , wind system along with grid and PV system. In need of monitoring, an efficient hybrid classifier is proposed which aids in the identification of the shortest path enabling improved transmission of monitored data. Effective and dependable data routing is crucial for smooth communication in IoT based physical system and smart grid. As the networks size increases and complexity, conventional routing models frequently fall shorts of offering the best possible balance over computing efficiency, performance and adaptability. Owing to its capacity to find near optimal solution in extremely dynamic and resource constrained contexts, a solution to such issues is nature*

*inspired optimization strategies. PSO is a popular metaheuristic for several optimization problems. PSO-RF based routing model, its operation and its use in smart grid communication networks are implemented in this paper. Additionally, parameters affecting PSO-RF's performance are described and its routing efficiency is assessed.*

## **1. Introduction**

An advanced, decentralised power generation architecture that combines two or more RESs, usually solar PV, WECS, hydro units and bioenergy systems, as well as auxiliary storage and backup units is HRES-based MG. Hybrid MGs combine the complementing qualities of several renewable resources to guarantee continuous electricity availability regardless of environmental variations, in contrast to traditional grids that mostly rely on centralised fossil fuel-based generation. MG functions in islanded and grid-tied modes while preserving stability, dependability and excellent PQ due to integration of DG,

flexible converters and storage. Modern SG infrastructure is built on this multi-source design, which also facilitates the smooth integration of IoT-enabled monitoring and control systems for advanced operational intelligence.

### **1.1 Significance of Hybrid Microgrid Systems**

Hybrid MG systems are essential for resolving the environmental issues and operational constraints of traditional electricity networks. Their importance stems from their capacity to combine several renewable sources that work well together in a variety of climates to produce a cleaner, more dependable and more robust energy supply. For example, solar power performs best during the day and during periods of high irradiance, whereas wind energy peaks in the evening or during seasonal fluctuations. An HRES-based MG decreases reliance on the availability of individual resources, minimises intermittency, and provides smoother power supply by combining these sources. A standard hybrid MG's architecture includes a network of AC and/or DC loads, storage systems, power converters, control units and integrated renewable energy sources.

## **2. Optimized Data Routing in Smart Grids**

In distributed SG communication networks, routing finds the paths through which data packets travel from field devices to control centres or cloud servers. Efficient routing is essential

because the communication infrastructure is often composed of thousands of interconnected IoT nodes, wireless sensors, Advanced Metering Infrastructure (AMI) devices and DER-level gateways that operate under dynamic network conditions. Poor routing decisions can lead to congestion, excessive latency, packet loss, increased communication overhead and degraded monitoring accuracy. In real-time applications such as voltage regulation, frequency stabilization, fault isolation or adaptive protection, delayed or missing data can severely impact system reliability. Furthermore, SGs often span geographically dispersed locations, requiring multi-hop communication through energy-constrained wireless nodes. Thus, reliable routing ensures continuous data delivery even during node failures, harsh environmental conditions or fluctuating network loads. In essence, routing forms the backbone of distributed SG communication, enabling stable and uninterrupted interaction between sensing devices and decision-making units.

## **3. Overview of IOT Based Smart Grid Framework**

In order to manage and optimize various energy generation and storage components, an IoT based smart grid monitoring system is used in a modern power grid. In this system, renewable energy sources like PV systems, wind turbines are used. Batteries are also integrated in these systems for energy

storage purposes. A real-time control is facilitated by the IoT connectivity and these distributed energy resources are monitored which in turn makes the system adapt to varying requirements of energy and environmental conditions. The parameters like output power, current and voltage of PV and wind generation systems are monitored continuously. This enables tracking of energy harvesting performance and detection of any degradation or anomalies in renewable energy sources. The basic representation of an IoT based smart grid monitoring system is shown in Figure 3.1.



**Figure 3.1 IoT Based Smart Grid Monitoring System**

Monitoring of the battery system is also carried out for the transmission of parameters. The charging and discharging cycles are optimized by transmitted data which in turn assures increase in the life span of battery along with reliable stored energy utilization. Also, the main utility grid is integrated with the IoT based smart grid monitoring system. This ensures continuous tracking of potential

disturbances, voltage levels and power flow of grid. With this entire framework, power supply from grid, utilization of renewable energy sources and battery storage discharge are decided.

#### 4. Proposed System

The proposed system presents an IoT-enabled smart grid monitoring and secure communication model designed to support energy-efficient and intelligent relay selection. The architecture begins with the Energy Sensing Layer, where electrical parameters such as photovoltaic voltage and current, grid voltage, load current and battery state-of-charge are continuously measured from multiple energy sources including battery storage, PV systems, WECS and the utility grid. The sensed measurements are forwarded as raw sensor data to the Data Aggregation and Pre-Processing Layer, where an aggregator node performs raw data reception, aggregation, cleaning, synchronization and feature extraction followed by normalization, thereby generating routing-ready feature sets.

The processed data is transmitted through a Multi-hop IoT Relay Node Layer, which forms a distributed communication topology between sensor nodes and the IoT gateway. To ensure efficient data forwarding, an Intelligent Relay Selection and Routing Layer is employed, in which RF classifier evaluates candidate relay nodes based on routing-related features. The hyperparameters of RF model are

optimized using the PSO algorithm to improve classification accuracy and routing stability.

**4.1 PSO-RF Based Shortest Path Selection in Smart Grids**

In the proposed PSO-RF based intelligent routing framework, the RF classifier is engaged to evaluate and rank candidate relay nodes, while the PSO algorithm is integrated to optimally tune the RF hyperparameters. The routing-ready features obtained from the data aggregation and preprocessing layer, such as residual energy, transmission delay, link quality, trust level, packet delivery ratio, and queue length, are used as input attributes for the RF classifier. These features jointly characterize the forwarding capability and reliability of each relay node in multi-hop IoT network. The performance of the RF classifier is highly influenced by its hyperparameter settings. Therefore, PSO is utilized to search for an optimal RF configuration in the hyperparameter space. In the PSO-RF model, each particle represents a candidate RF hyperparameter vector, defined as,

$$\theta = [n_{tree}, d_{max}, f_{sub}, s_{min}]$$

Where,  $n_{tree}$  specifies the number of decision trees,  $d_{max}$  represents maximum tree depth,  $f_{sub}$  indicates the feature subset size and  $s_{min}$  minimum number of samples required for node splitting. Initially, a population of particles with randomly initialized RF hyperparameters is generated. For every particle, an RF model is constructed using the corresponding hyperparameter set

and trained using the available routing feature data. The trained RF model is then assessed using a routing fitness function, which reflects key performance objectives such as minimizing end-to-end delay and energy consumption while maximizing packet delivery reliability and trustworthiness of the selected relay nodes. Based on this assessment, a fitness value is assigned to each particle.

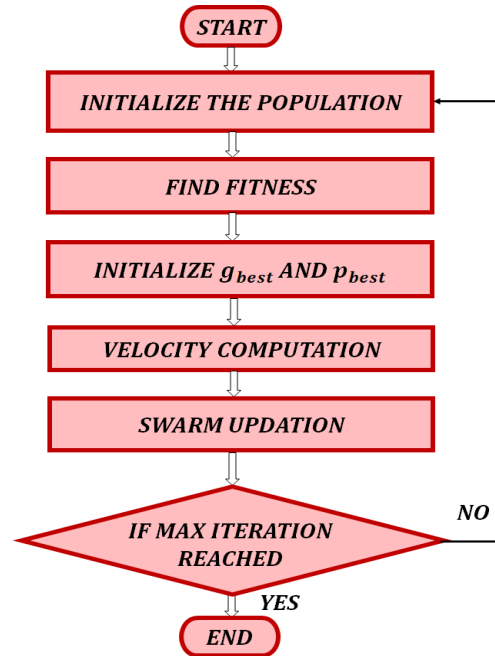


Figure 4.1 Flowchart of PSO

**5. Results and Discussion**

Here the results of finding shortest path using PSO is explained elaborately. The system is examined with the utilization of specification listed in Table 5.1.

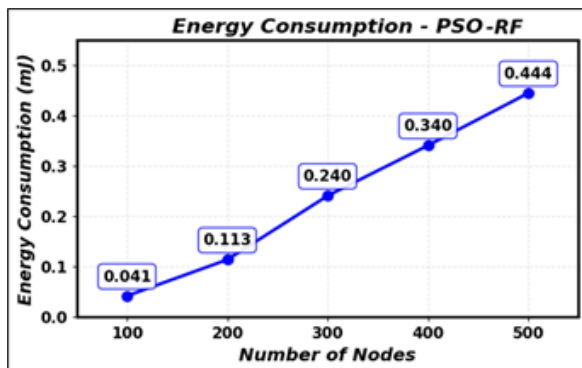
Table 5.1: Design Specification

Parameters	Values
Simulation Tool	NS2 Simulator
Routing Algorithm	PSO-RF
Data Rate	4 Mbps
No of Nodes	100-500

Communication Range	400m
Packet Size	400 bytes
Deployment Area	400m × 400m

### 5.1 Energy Consumption

Energy consumption is the total amount of energy used by all sensor nodes for transmitting, receiving and processing data in smart grid communication network. It is a crucial parameters because smart grid nodes adequately function on limited power and most conditions monitoring of electricity infrastructure.



**Figure 5.1: Energy consumption value using PSO-RF**

As illustrated in Figure 5.1, the energy consumption raises as number of nodes grows, from 0.041 at 100 nodes to 0.444 at 500 nodes. This raise occurs owing to the more nodes generate more data traffic and need more communication rounds, which raising total radio energy usage. Energy consumption is typically defined as

$$Energy (E) = Power(P) \times Time(t)$$

The outcomes shows that PSO-RF based routing efficiently manages energy load even in high density smart grid

deployments, though total energy still scales with network size.

### 6. Conclusion

This paper introduces PSO-RF based routing model to improve communication efficiency and adaptability in IoT enables smart grid system. Highlighting the mathematical model and velocity, position updates and suitability for shortest routing path. The system combines IoT sensing to ensure both efficient routing . Performance evaluation demonstrated that PSO maintains low energy consumption as node density rises. Overall this paper shows that PSO-RF provides an effectual and secure routing solution for modern grid communication network.

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