Chapter

New High-Speed Directional Relay Based on Wireless Sensor Network for Smart Grid Protection

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Abstract

The production of energy from water represents large amounts of clean and renewable energy. However, only 30% of this energy has been developed so far. Hydropower, particularly hydropower plants, is not only environmentally friendly but also economical, and operates more efficiently than any other renewable energy system. Hydropower plants are largely automated and have relatively low operating costs. The main components of the power system must be continuously monitored and protected to maintain the quality and reliability of the power source. This task is provided by the data collection, monitoring and protection system. Turbines must be protected not only by short circuits but also by abnormal conditions. The proposed protection has been designed to avoid damaging the original power (motor or turbine), this usually happens when the generator fails, and the machine operates as a synchronous motor connected to the power system. In this case, the generator becomes an active load, causing a rise in temperature and severe damage to the main turbine, and hence it becomes a need to quickly detect these conditions. This study proposes a new controller for Neuro-Fuzzy to prevent reverse power flow and to keep the quality and reliability of supply. Fuzzy system network has attracted various scientific and engineering researchers. The new feature of this work is to adjust the membership function as a reverse mechanism derived of the Fuzzy Logic Controller. The smart meter network is the basis of the smart grid. In this study, smart grid meters were implemented using ZigBee technology based on wireless sensor networks. The ZigBee network of wireless sensors due to its low battery, low power consumption, become more useful than other wireless communication systems to provide a high-performance measurement. This study shows the ZigBee network using the OPNET simulation. Depending on the performance, parameters were analysed to understand the operating characteristics of the star, tree, and mesh.

Keywords: smart grids, ZigBee IEEE 802.15.4, neuro-fuzzy network, directional relay

1. Summary

Literature reviews play a vital role in improving renewable energy because science is still a cumulative effort in the first place. As with any discipline, the synthesis of rigorous knowledge becomes indispensable to keeping up with the is growing searched pace of smart grid domain, which is developing exponentially by academics and engineers and scientific searched in the content of many papers, evaluated and synthesized [1–3]. The proposed study could provide a theoretical basis for confirming the need for investigative questions, proving that research methods have increased accumulated knowledge. Besides, high-quality reviews have made researchers look for a lot of literature when conducting empirical research.

In addition, high-quality reviews have made researchers look for a lot of literature when conducting empirical research. To conclude, our main objective in this chapter is to develop solutions to improve the spread of distributed energy and with high-speed synchronisation communication, that is central to the continuous development of the smart grid field. We hope that ours. This chapter will serve as a valuable source for those conducting, evaluating or engineers in this important and growing domain. The future distribution network may include a large-scale distributed power generation penetration into the smart grid. This scenario is aimed at the transition from a passive distribution network to an active distribution. The integration of DG units has a significant impact on the operation of power flow, voltage distribution, and protection systems in the distribution network [1]. (1) Explore issues that drive the demands of future rapid Intelligent protection systems, (2) design and develop a protection strategy that can be applied to any grid equipped DG. The concept of innovative protection must ensure the selectivity of protection in case of failure, (3) apply the new concept of intelligent protection algorithm.

As a result, the performance of the existing distribution network's traditional inverse-time protection system was evaluated. In this way, we have identified the problems faced by the current applicable protection strategies; the results of the simulation prove that the traditional protection system is insufficient to provide a satisfactory level of protection selectivity. This chapter introduces the transformation of the traditional protection strategy to the future intelligent distribution network protection system. This shows how unprecedented advances in sensor technology and the emergence of new communication protocols have stimulated innovation in protection systems. The latest technological advances have enabled existing protection systems based on local information to be transferred to innovative security systems, In Addition; the details of the new communication mechanism for the application of high-speed protection systems were discussed. Clever's protection strategies are fast, flexible and offer a high level of selectivity protection.

This chapter designs and develops a new concept of intelligent protection strategy. This approach applies to any network administered by DG. The proposed intelligent protection system aims to reduce the time to eliminate failures, to ensure the selectivity of protection and to enhance the availability of the units of the DG throughout faults. The new scheme of realising a protection scheme using advanced sensor, neural fuzzy scheme and ZigBee network is expounded. The intelligent algorithm ensures the selectivity of the protection by minimising the time of failure and eliminating the problem of the large time disconnection in the system [1].

2. Introduction

The smart grid (SG) is the next generation of power grids. Its purpose is to overcome the problems that exist in the conventional power grid. Smart grid technology has been used, such as sensors and communication networks, and advanced software and sensors to provide control and enhance the protection and optimisation of all network components, including production, transmission, and distribution.

Although neural networks implement to solve tuning problems, the fuzzy logic controller is intended to use structured knowledge in the form of rules [4, 5].

The combination of Fuzzy Logic and neural networks provides the ability to solve optimisation problems. This new method consolidates the established advantages of both approaches and avoids the limitations of both approaches. Control algorithms are used to prevent unexpected fluctuations in voltage and frequency. Smart grids use energy storage systems and communication networks to ensure total coordination between power generation and energy use. Reduce the energy loss of the network to minimise demand and energy costs [6–8]. A reliable, real-time information flow among parts of the network is critical to the success of the smart grid self-regulation process. There are many wireless standards for technical applications [9]. One of the most popular technologies is ZigBee wireless sensor network (WSN), which is distributed on the smart grid structure, which has a lot of equipment to communicate with each other through the wireless network. These electronic devices are called Sensors/Detectors/Transducers [9]. Sensors are devices that can recognise several of the physical units, such as current, voltage, impedance, etc. Also, the ZigBee system is featured by low energy consumption. It is also more economical than other communications because it provides flexibility and scalability [10–12].

The construction of this chapter is as follows: Section 2 confers a study of the SG communication system. The proposed protection system and results are analysed in Section 3; Section 4 the wireless sensor network using OPNET and simulation results; In Section 5, the conclusions are discussed.

3. The smart grid communication network architecture

The old communication system is characterised by limited efficiency and limited information exchange; the intelligent metering network is the backbone of a smart distribution network. It is essential to select the appropriate communications to facilitate the real-time flow of bi-directional information. It is mainly used by the main transmission point and a limited number of sensors on the transmission line for control and fault detection. Compared with the traditional network, an intelligent system contains a much larger number of sensors. Sensors are used to exchange information between terminals devices and data centres to handle such a large data stream, the SG must-have reliable communications and security infrastructure. The communication infrastructure must be self-managed and configured to change automatically [13].

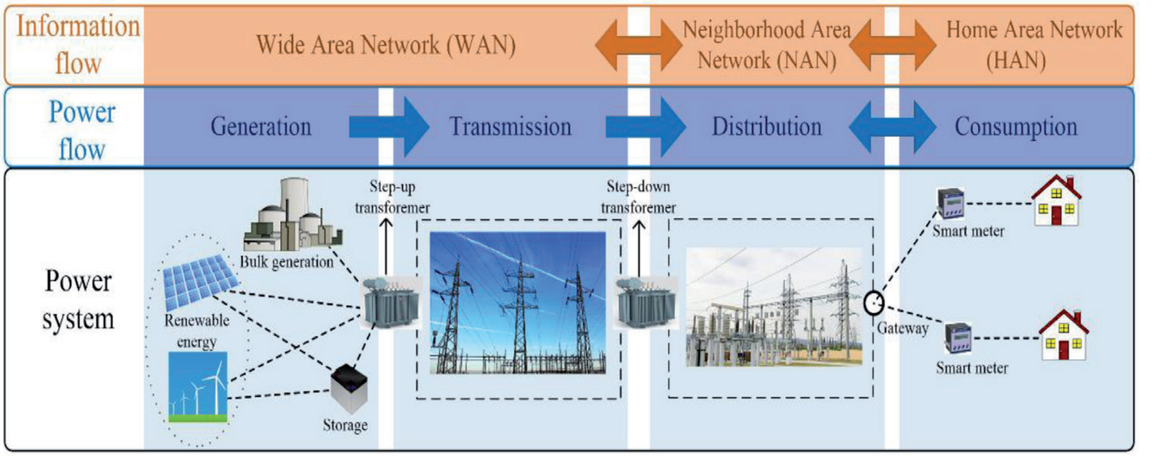


Figure 1.
Communication network architecture [14].

Figure 1 shows the smart grid communication architecture, including the neighbourhood network (NANs), home LAN (HANs), wide area network (WANs), substation and data centre. These networks as follows will be displayed briefly [14–16].

3.1 Wireless area network (WAN)

It serves as backbones that help the power grid that provides communication between utility systems and substation systems. The can help prevent power outages by providing real-time information from the electricity grid. It supports real-time control and protection. This system is useful when dealing with unforeseen contingencies, and it is essential to avoid interruptions and failures [17–20]. This application helps in performing a generator process and provides support for large power systems. The main disadvantage of this kind of WLAN is the possibility of devices interfering at the same frequency is high. The network operates between 2.4 and 3.5 GHz. Among its advantages are low-cost equipment, the use of which has spread across a wide range of applications.

3.2 Network home area (HAN)

Some technologies introduced in the Home Network System are ZigBee, WLAN with PLC. The construction of a Building Area Network (BAN) is considered to be more complicated than the Home Area Networks (HAN). The HAN can be classified as a part of the customer network structure; HAN is often used by consumers in the housing and business sectors, using power tools to communicate [21]. It is a combination of connected devices, management software and dedicated LAN. HAN supports communication between smart meters and appliances used in homes, industries or buildings. It supports several other services, including Demand Response, pre-payment, real-time pricing and load control. The essential of the HAN communication system is to include low-cost, low power consumption with secure communication [6, 10, 22].

3.3 Neighbourhood area network (NAN)

NAN is best described as a bridge between WAN and HAN and used in a NAN to collect data of points adjacent with the help of intelligent electronic devices (IEDs), which are widely deployed in the whole area. It is a two-way communication technology developed that give information about the control system for smart grids. Compared to WAN, the data rate is not high, and the transmission power is low for short-range transmission. WLAN, PLC and ZigBee are some of the techniques on which the NAN network can be implemented [23].

4. Proposed protection system simulation and modelling

In some cases, the generator starts to behave like a motor when the prime mover does not provide enough torque to keep the generator rotor rotating at the same frequency as the line of the parallel power source, and instead of giving power; it draws power from the parallel power source. Also, if the synchronisation ranges process rotates slowly, also both the loss of the alternator excitation. The governor is the fault of the original sender. Similarly, the generator will also extract the current from the source line [24]. When the rotating part of the generator fails, the generator stops generating electricity and starts drawing electricity from the parallel power source [25]. This situation may damage the drive unit and is not desirable. It should be detected as soon as a possible problem, and quickly disconnect the equipment from the parallel power supply, thereby protecting the generator from damage. In exceptional turbine cases, the power supply direction is changed from line to generator. It usually uses a directional protection relay to monitor the current flow and take appropriate action to prevent all outage case. The directional protection relay is working when the reverse power exceeds a certain percentage of the rated power output; it will trip the circuit breaker of the generator, disconnect the generator from the line under not normal circumstances, the relay setting is about 5% of the power generator [26]. The directional protection relay is located on the generator latch cabinet and is an integral part of the circuit breaker. The structure of the relay is designed to limit the reverse current flow depending on the amount of current and voltage between the two phase angles. If the line power is inverted, the current through the relay current coil will be inverted concerning the polarisation voltage and provide directional torque [27]. This technique compares the relative phase angle between the (current and voltage), as shown in **Figure 2**.

Typically, the phase angle is used to define the fault compares to the reference value. The voltage is usually applied as a reference amount. By comparing the operating voltage and current phase angle, can be inferred the fault occurs. Therefore, the fault current can be described with the phase relationship with the voltage line −90 for the forward fault, 90 for reverse fault. The relay wills response to the phase angle difference between the two quantities to come out trip signal [28]. In cases where optimal protection is required, Rogowski coil current sensors are used as CT and PT to avoid faults in conventional AC Transformers and must set a certain amount of delay during operation, to prevent power fluctuations, the transient effect during synchronisation. If the angle between the current vector and the voltage is Δ, the power flow is $-900 < \Delta < 900$ [29]. Under normal conditions, the voltage overlaps with the current range is more significant than their non-overlapping interval. However, in the case of reversing energy flow, this overlap is reduced to a lower level. **Figure 3** shows this assembly and implementation. The low signal of the current and voltage of RC sensors changes to form a square wave having a value of "±1" and then multiplying these level signals to produce a positive number in the overlap interval, in the negative numbers are generated in the non-overlap interval [30].

The integration limit of the scheme is set to zero, therefore the integration of the load is perpetually <0 under normal conditions. However, in the opposite trend, the production condition system as a whole tends to decline until the threshold constant

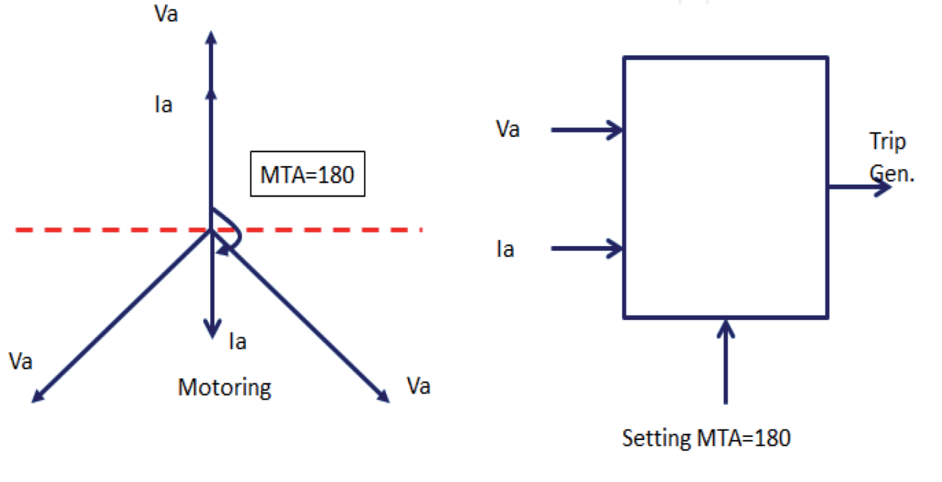


Figure 2.
According to the reverse power relay current with a voltage vector diagram.

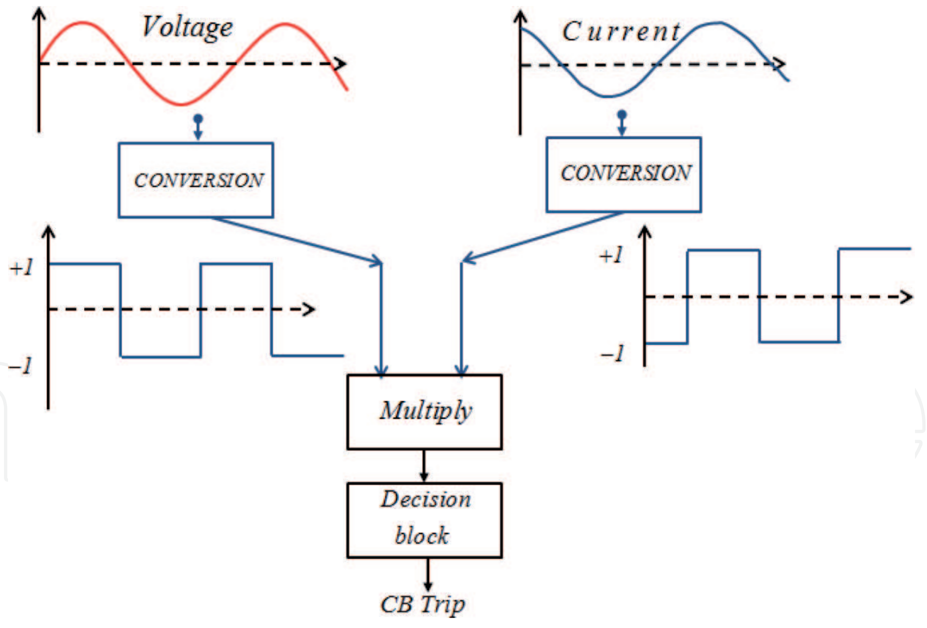


Figure 3.
Diagram of implementing a directional component.

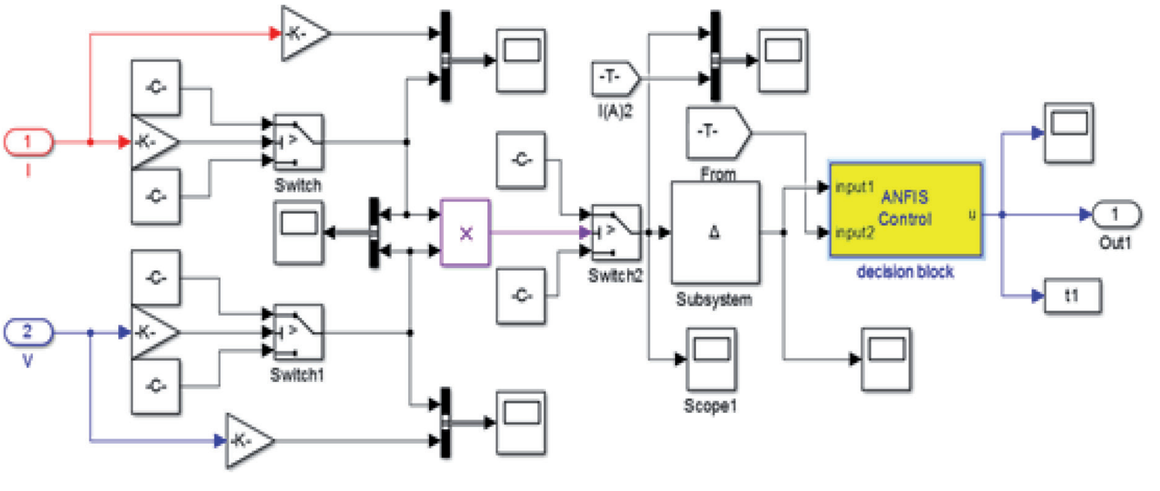


Figure 4.
Modelling of a directional relay component.

is reached. In this situation, the constant is set to 0.01 and the select value based on the amount of reverse power [23]. The output of the reverse power relay (RPR) is transferred to a decision where the production is one for normal operation, zero for abnormal conditions, as displayed in **Figure 4**.

Figure 5(a) presents the 3ø current directions, cos ø, and power factor, and **Figure 5(b)** the same ideas of the P and Q expansion.

4.1 The adaptive neuro-fuzzy approach

The selection of the membership function dramatically affects the quality of the fuzzy controller. Therefore, the method requires a more fuzzy logic controller. In this paper, a new method of neural networks is used to solve the adjustment problem of a fuzzy logic controller. We consider a dynamic system of multiple entrances, a single exit. The system is exported to the desired state of the control action can be described by the concept of the well-known "if-then" rule, where the input variables are first converted to their respective linguistic

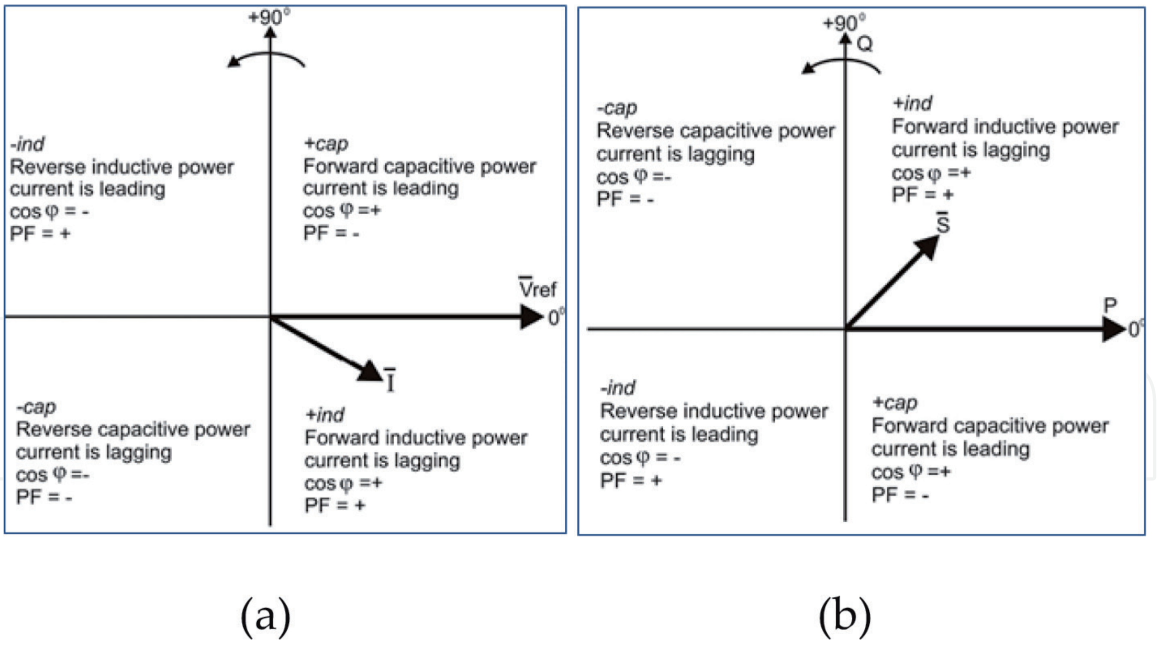


Figure 5.
(a) Quadrants of current/voltage. (b) Quadrants of a power.

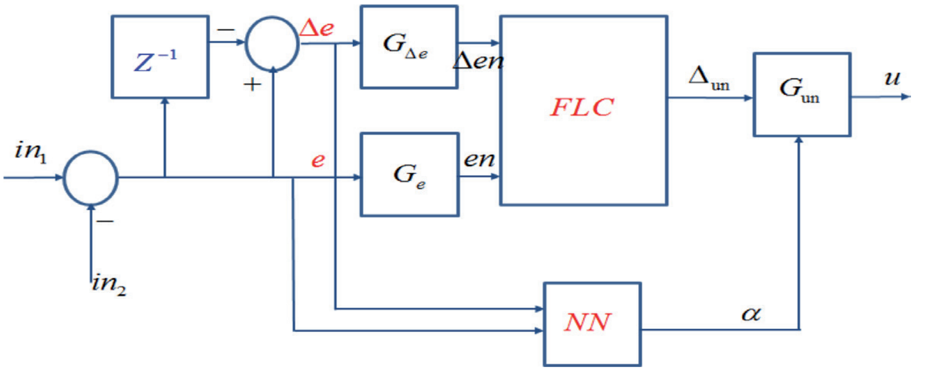


Figure 6.
Control method using adaptive neuro-fuzzy.

variables, also known as fuzzification. The value of these rules certainly output. Then use defuzzification to convert the output to a precise value. For simplicity, we used a modified centre of area method, and the Triangle fuzzy set will be used for input and output.

The linguistic form of the control rules is the basis of the designed fuzzy unit. It depends on the accuracy of the choice of parameters, which is the translation of the linguistic rules of the fuzzy set theory. The neural network (NN) is used to improve the selection of these parameters. In this scenario, the neural network is combined with the fuzzy logic unit. As shown in **Figure 6**, it uses the first fuzzy logic rule and then uses the neural network to generate the automatic adjustment output. References input [in (1)] related to the existing input [in (2)], product e(t), and incremental changes Δe(t) [31, 32]:

$$\Delta e(t) = e(t) - e(t-1) \tag{1}$$

The proposed unit has two input factor gain measures of control, Ge and GΔe, and one scaling gain GΔu. The output-input scale factors are expressed as follows:

$$\Delta_{eN}(t) = \Delta e(t).G_{\Delta e}, \tag{2}$$

$$e_N(\mathrm{t}) = e(t).G_e \tag{3}$$

In the same eN and ΔeN scaling factor system to identify the fuzzy logic controller input signal product [33, 34]. Fuzzy logic controller output signal is ΔuN, it is the scale factor input. The neural network has two inputs, e(t) and Δe(t), and the neural network signal output α, which is used to fine-tune the product control of the operator. The output signal of the scale factor can be expressed by the formula:

$$\Delta u(t) = \Delta u_N(t)\alpha.G_{\Delta u} \tag{4}$$

The output signal can be written as follows:

$$u(t) = \Delta u(t) + u(t-1) \tag{5}$$

The results are displayed in **Figure 7**, which illustrates the specified fuzzy rules. We have selected fuzzy set and membership functions, **Table 1** summarizes the development of the rules used in this study [1].

Forming a neural network composed of three layers (two input layers, three hidden layers and one output layer). Neural network input (NN) is including the same number of output of fuzzy logic. The activated function has a value from −1 to +1 for the output signal, as shown in **Figure 8** [35–37].

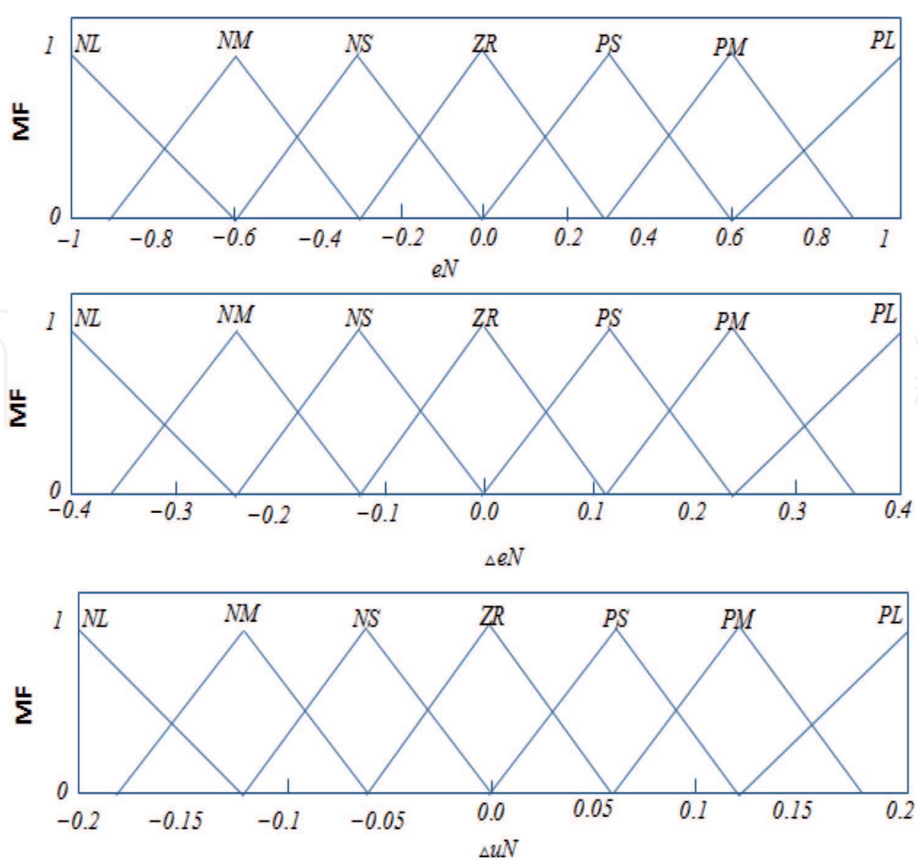


Figure 7.
Fuzzy logic membership functions.

Δe_N \ e_N	NL	NM	NS	ZR	PS	PM	PL
NL	PL	PL	PM	PM	PS	PS	ZR
NM	PL	PM	PM	PS	PS	ZR	NS
NS	PM	PM	PS	PS	ZR	NS	NS
ZR	PM	PS	PS	ZR	NS	NS	NM
PS	PS	PS	ZR	NS	NS	NM	NM
PM	PS	ZR	NS	NS	NM	NM	NL
PL	ZR	NS	NS	NM	NM	NL	NL

Table 1.
Rules of FL.

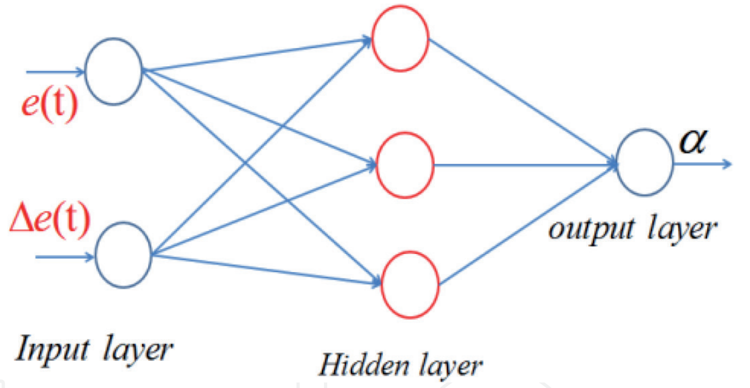


Figure 8.
The description of the neural network compositions.

$$f(x) = \frac{1 - e^{-x}}{1 + e^{-x}} \tag{6}$$

The activation function neuron in the output layer is:

$$h(x) = \frac{1}{1 + e^{-x}} \tag{7}$$

Control Unit based on the measured output signal $u(t)$ from neuro-fuzzy circuit to adjust the trip circuit:

$$\theta_{new} = \theta_{initial} - k.u \tag{8}$$

where the θ initial is the initial switching output and k is a constant.

4.2 Simulation results

As shown in **Figure 9**, the simulation design uses 200 MVA /11 kV, with a synchronous generator connected to a transmission line 25 kV through an 11/25 transformer, 60 Hz, Load10 MW, and 3 Mvar. Relays are tested in a variety of situations. The conditions and results of the discussion are as follows.

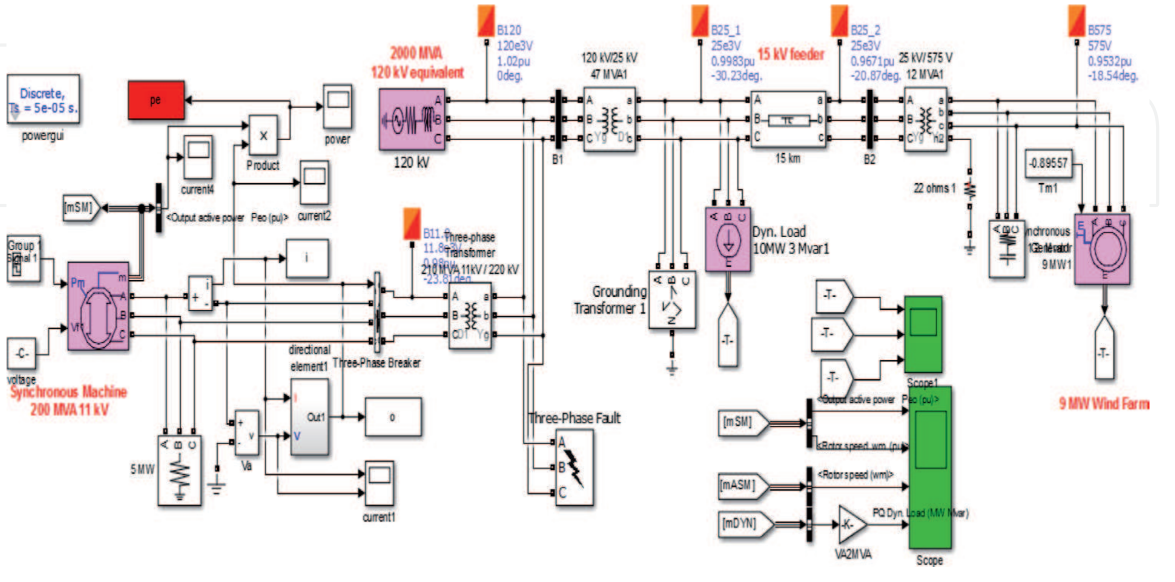
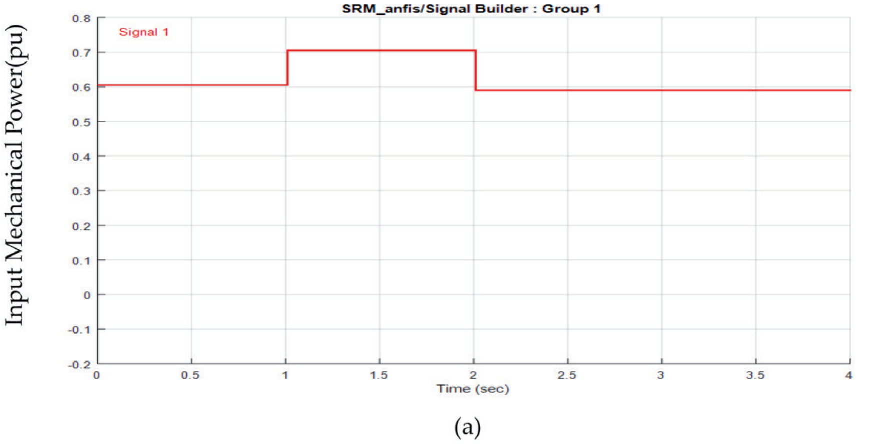
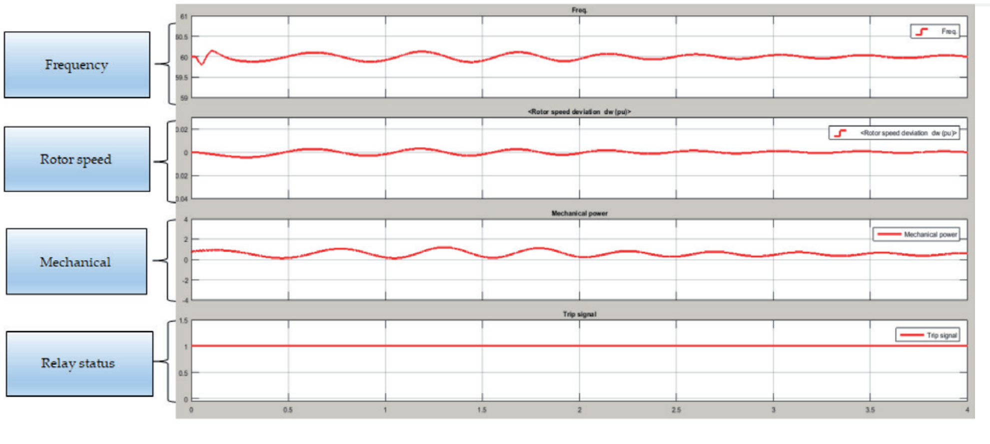


Figure 9.
Model of a reverse power relay in an electrical power system.

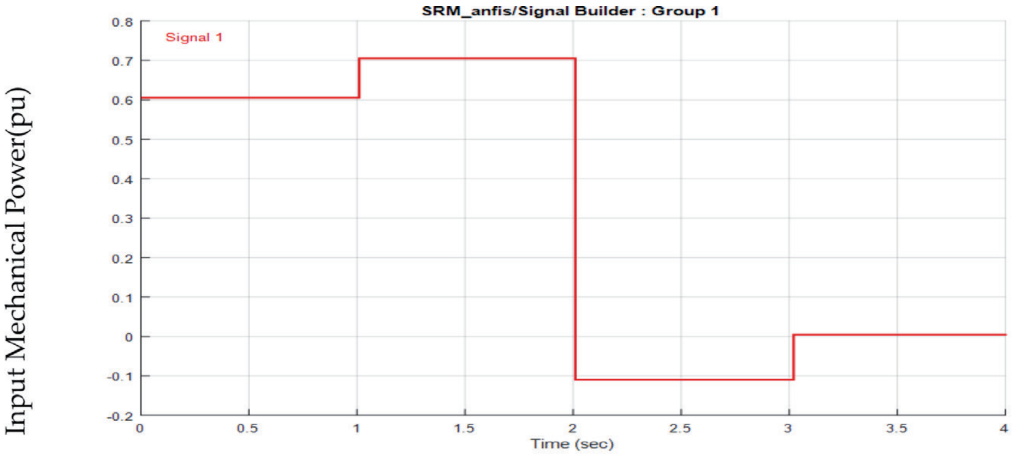


(a)

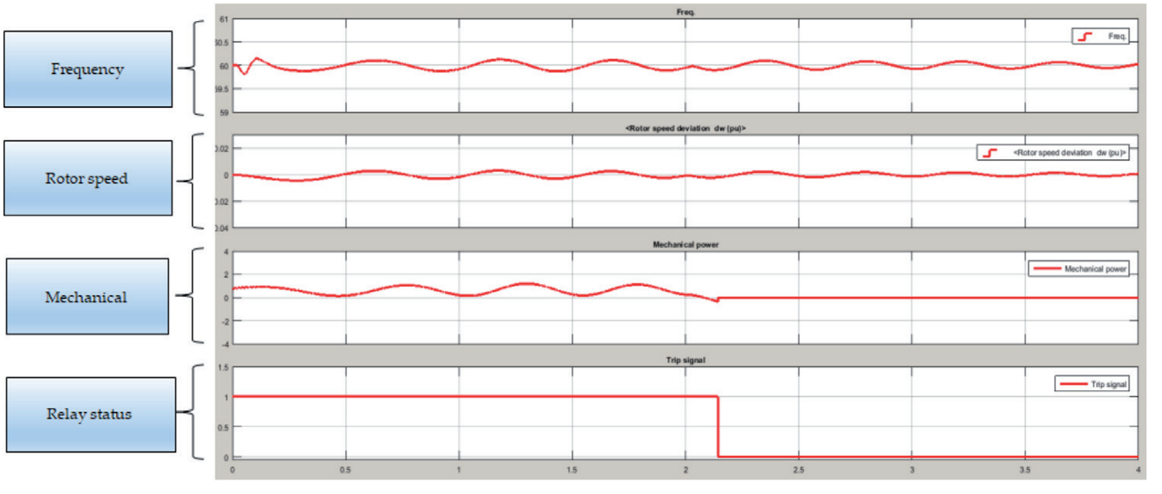


(b)

Figure 10.
(a) Performance of input-output power; and (b) relay status.



(a)



(b)

Figure 11.
(a) Performance of the input-output power; and (b) relay status.

The structure of propose protection is shown in **Figure 4**. The nodes of in_1 and in_2 represent the input variables and pass their values to the blocks that contain the respective membership functions in Neuro-Fuzzy controller. The relays are tested under a variety of conditions. We have provided the details of the system in **Table A1** [1].

4.2.1 Simulation results under the normal condition

In this case, the mechanical power input of the generator within 1–2 seconds differs from 0.6 to 0.7 pu, at the under normal circumstances the observed state is shown in **Figure 10**, and the relay does not trip.

4.2.2 Simulation results under the faulty condition

In this case, the mechanical power input in 2–3 seconds from 0.7 to −0.1 pu. Relay responds to this change after 0.15 second for safe, and the relay is triggered, where the fault occurred at 2 seconds as shown in **Figure 11**. Input Mechanical Power (pu).

The reverse current adjustment knob and the delay time are shown in **Table A2** of the Appendix, and then the trip is confirmed with the minimum reverse current in the range of 2–20%. The trip time delay setting range is 0–20 seconds.

5. Wireless sensor network using OPNET simulator

5.1 Zigbee network method

The OPNET modeller is one of the most important simulation tools for communication network inspection. ZigBee networks are known for their low power consumption, low cost, low data rate, and high battery life.

The current work as shown in **Figure 12**, consists of the workstation featuring a coordinated connection to six routers, with eight nodes installed at a range (200 meters) from each other. To participate in the calculation of system variables, the OPNET collected a large number of variables. The indicators relate to two types of statistical data for the agreement: local and global statistics. However, in terms of network performance, this study is more occupied in collecting quantitative information for the system. As a result, current research is based on data obtained from global statistics [1].

The values of the design parameters are shown in **Figure 13**, and the values of the parameters on the router are shown in **Figure 14**. Transmission power is estimated to be 0.1 w.

The ZigBee coordinator parameter is illustrated in **Figure 15**.

5.2 Simulation results

The simulation results are simulated under different topologies of the wireless sensor network, and the effects of different topologies on network efficiency are discussed.

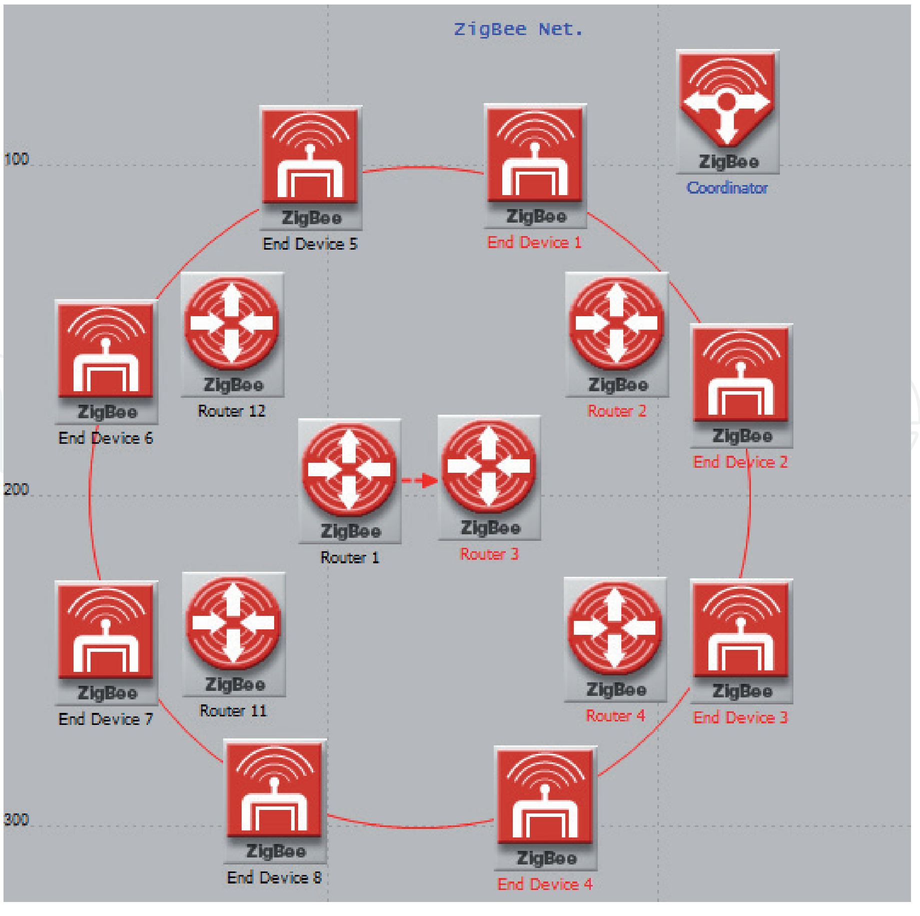


Figure 12.
Basic scenario consisting of one coordinator, (6) routers and (8) end devices.

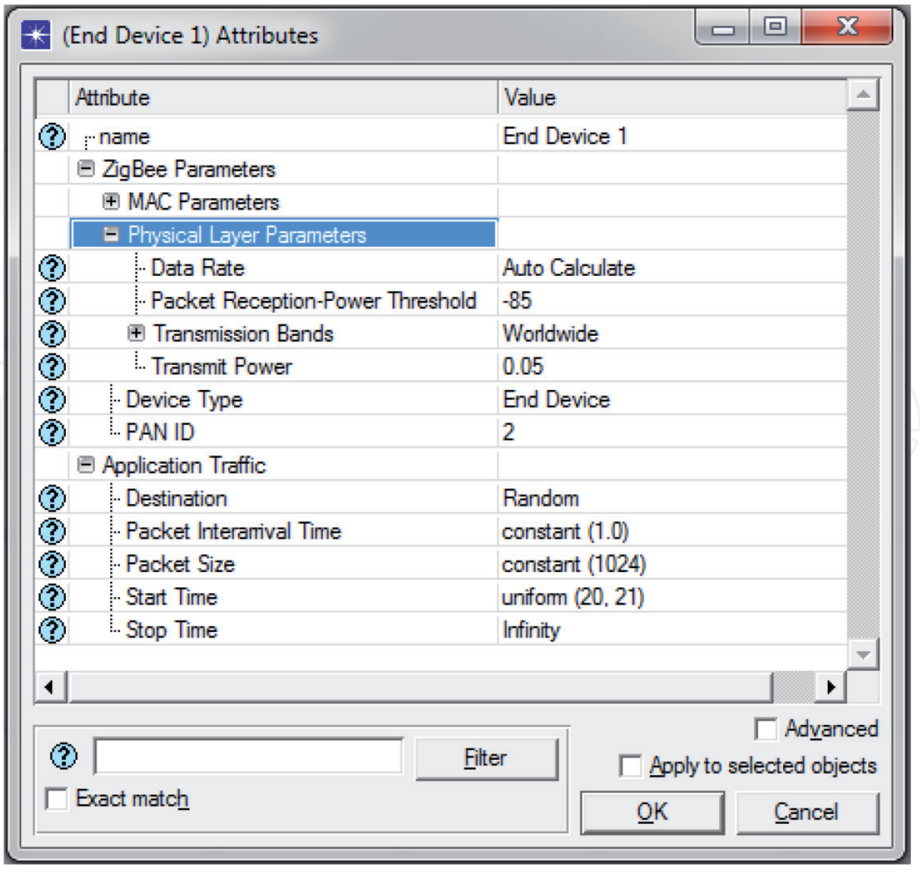


Figure 13.
End-device parameters.

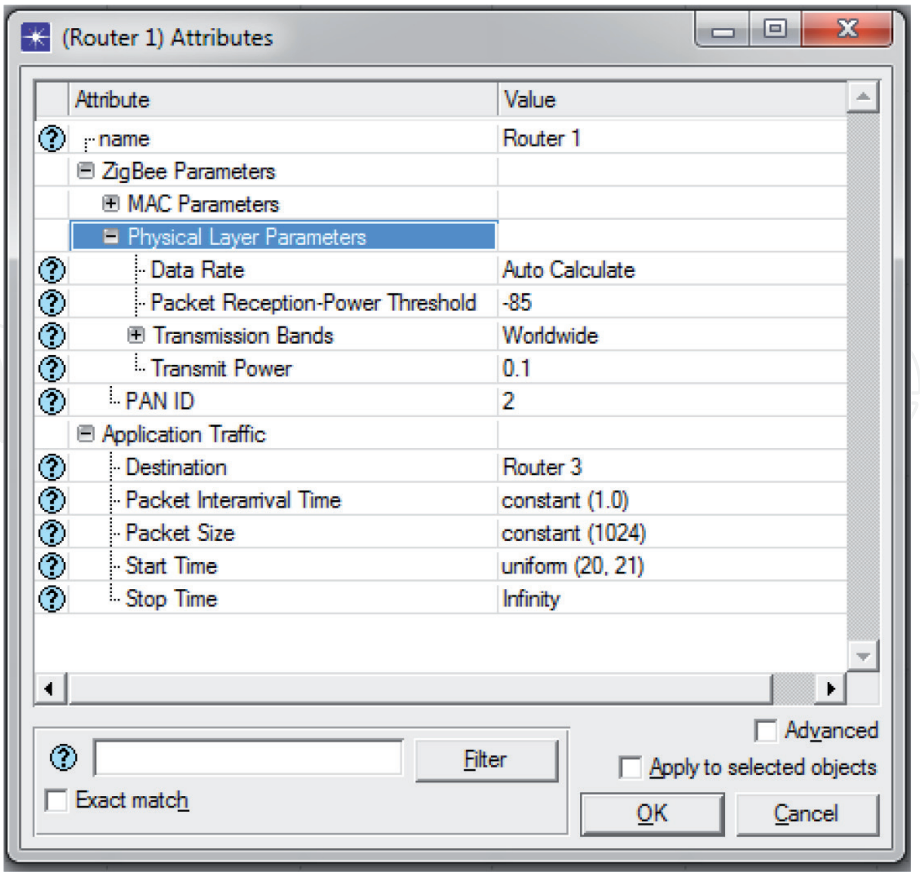


Figure 14.
Router parameters.

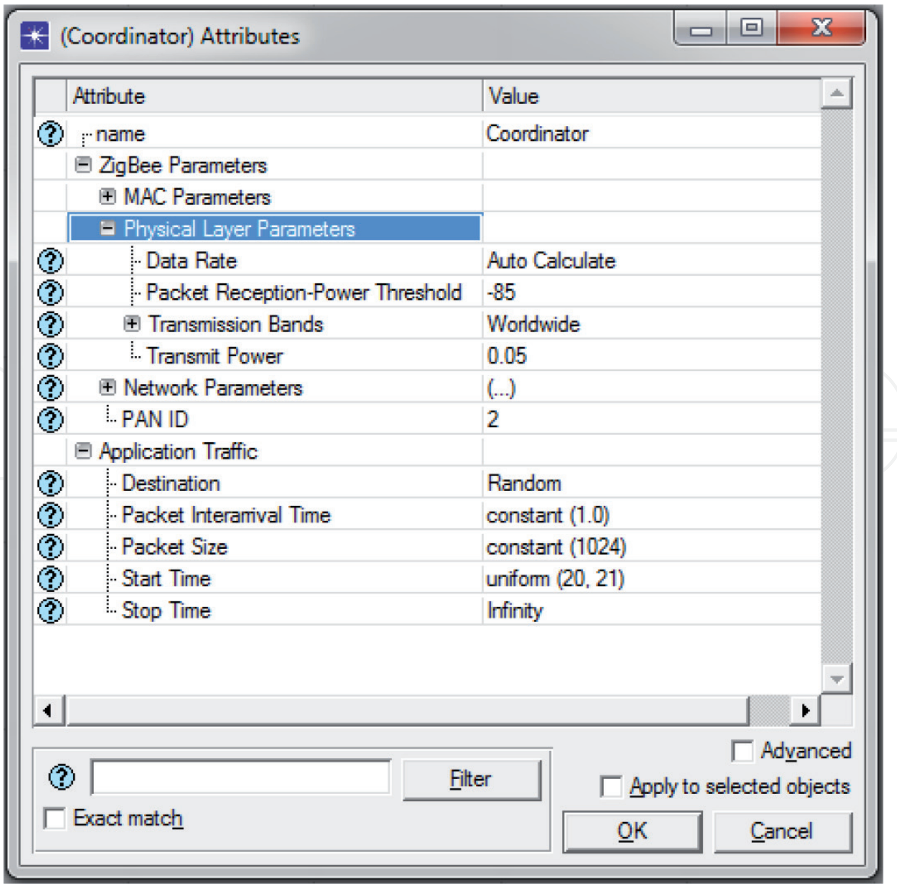


Figure 15.
ZigBee coordinator parameter.

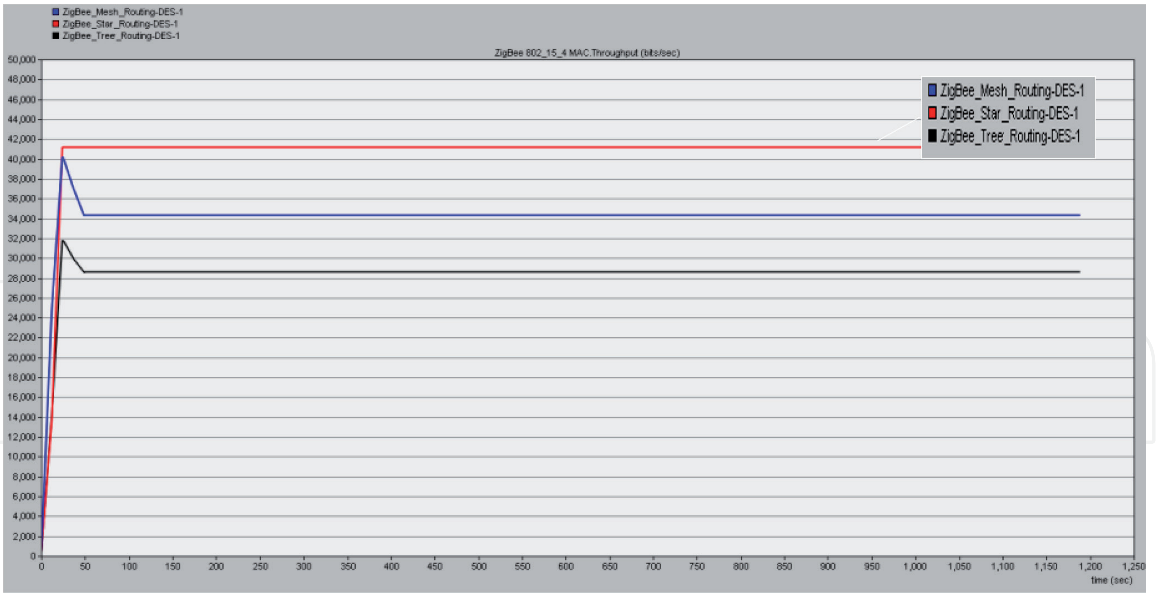


Figure 16.
Throughput case.

5.2.1 Throughput

Defined as the average number of bits or packets that are successfully transferred from source to destination. The steady-state results for the star, mesh and tree topology are 0.041, 0.034, and 0.028 Mbit/s, In the star topology, can achieve maximum throughput, this finding is that the star topology interacts with the personal area network (PAN) coordinator, (**Figure 16**).

5.2.2 Data traffic sent

As shown in **Figure 17**, and finding indicates that the maximum data traffic is in a star topology because this topology type allows communication with the coordinator. The data traffic sent was 0.1465, 0.0385, and 0.0325 Mbit/s, for a star, mesh and tree topology [1].

5.2.3 Data traffic received

Data traffic is defined as the number of data bits received per unit of time. **Figure 18** shows that the received data traffic for (star, mesh, and tree) topology is 0.650, 0.650, and 0.3805 Mbit/s.

This discovery means that the traffic received in the star topology is the largest because all devices communicate via the PAN coordinator and are responsible for generating traffic and routing [1].

Figure 17.
The total number of data bits transmitted.

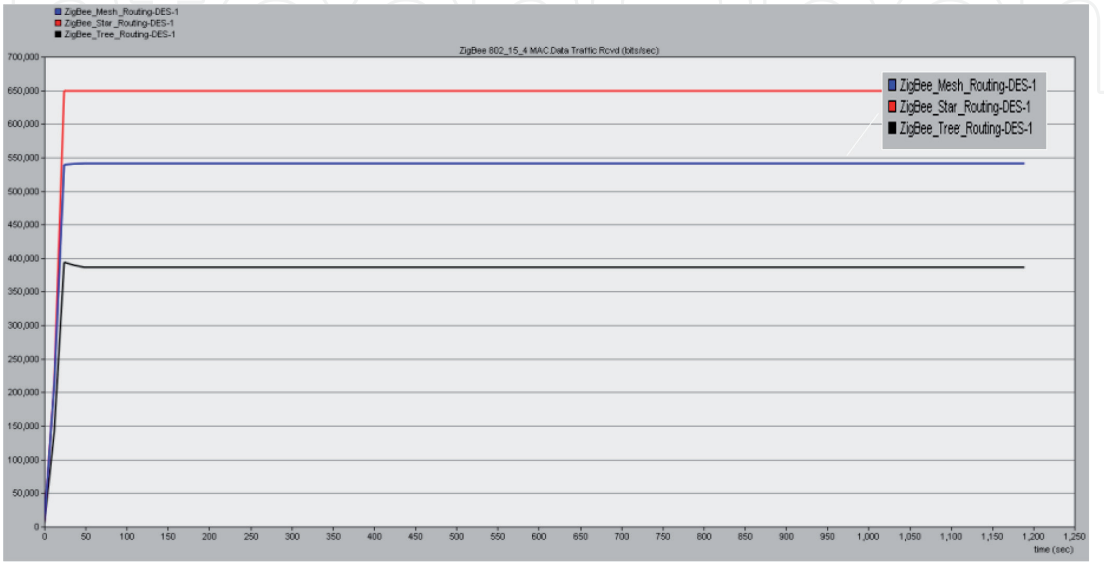


Figure 18.
Data traffic received.

5.2.4 End-to-end delay

It is the time it takes for a home target application to get the package generated by the source application. The results show the mesh/tree, and star topology delays are 9.6 and 7.9 ms. And the delay time of the mesh/tree topology is longer than that of the star topology, as shown in **Figure 19**. In a star topology, only one parent object is represented by a ZigBee coordinator. Therefore, the final mobility of the device may cause some delay.

5.2.5 Medium access control (MAC) load

As shown in **Figure 20**, MACload is used for forwarding the load for each PAN in the transmission of packets in the IEEE 802.15.4 MAC, that is, the physical layer, in the upper layers. The performance of the MACload presents similar results to the throughput performance. In other words, this result confirms the conclusion that

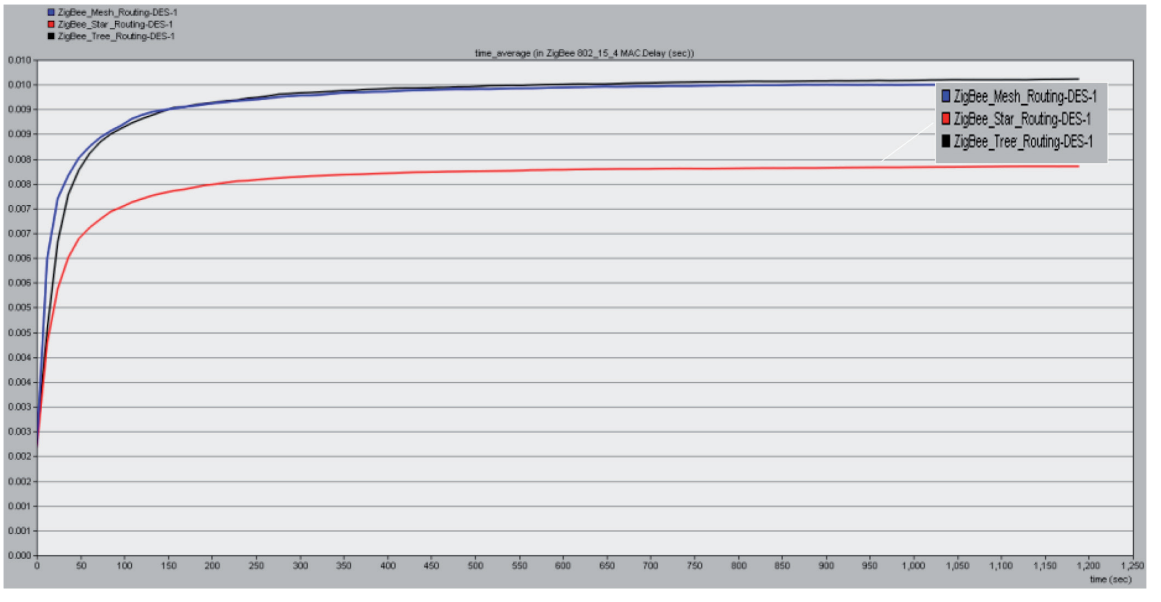


Figure 19.
Data arrival rate against delay.

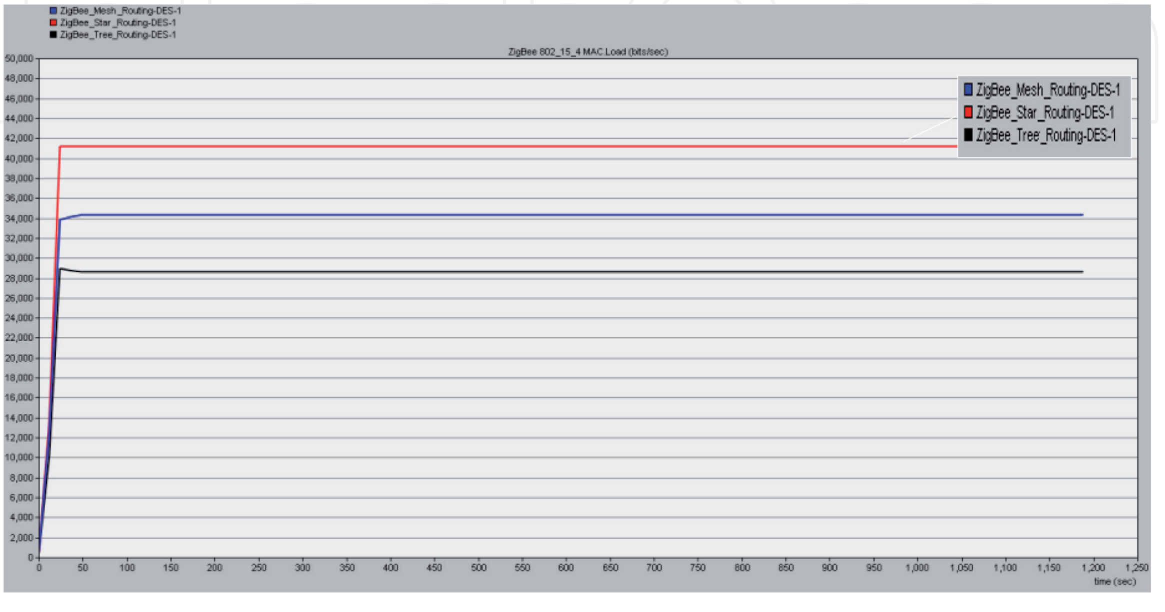


Figure 20.
Simulation scenario against a MAC load.

Definition	Value
Test zone (radius)	~100 meters
Number of end devices	8
Number of routers	6
Number of coordinators	1
Mobility model	Random
Simulation duration	1200 s

Table 2.
Summary of the simulation parameters.

the faster the load transfer to the upper layers from the physical level is, the more efficient the network. As shown in **Table 2** the local routing information covers only a small area (the diameter of the test distance is about 250 meters) [1].

6. Conclusions

The difference between the ZigBee and the WiMAX mobile networks is the distinction in their technology standard. The WiMAX mobile networks used in the simulation employ the IEEE 802.16 standard technology, whereas ZigBee follows the 802.15.4 standard. Mobile WiMAX seems to have better functionality than ZigBee, but taking into account the scalability of the latter, the former can install additional ZigBee devices because of its low-cost features and the possibility of reducing the battery size and operation hours. However, ZigBee may be more effective in certain areas because if its low energy consumption rate. The advantages of proposed protection are as follows:

(1) To prevent the flow in the opposite direction, and damage to the generator or the main engine. (2) To avoid the occurrence of explosion or fire, this is mostly caused by unburned fuel in the generator.

The existing power system is undergoing significant changes. Smart grid technology is the method used in the future power system framework, the integration of energy and communications infrastructure is inevitable. Intelligent network technology is characterised by the realisation of a complete dual communications infrastructure, automatic measurement, renewable energy integration, distribution automation and network monitoring. Wireless network to achieve the collection and transmission of real-time data. With flexibility in a wireless sensor network, high detection accuracy, low cost and excellent performance. Therefore, it can be used to develop interesting remote sensing applications. Implementation of sensor networks must meet the flexibility, scalability, cost, equipment, changes in the topology of the environment and energy consumption and other factors and limitations. Wireless sensor network has the flexibility, with high precision sensing, low cost and other excellent characteristics. Therefore, the sensor network must meet the flexibility, scalability, cost, environmental topology changes and energy consumption and other factors. The performance analysis of the topology of the ZigBee wireless network was carried out by using OPNET 14.5 simulators. The network topology of the star, tree and mesh is compared according to the end-to-end delay, throughput, Mac traffic load, and the four parameters of the transmit and receive traffic parameters. In terms of star topology throughput, the MacLoad is higher than the resulting value of the mesh topology, so the use of star topology is considered to be very important. The network types of the star, tree, and grid are compared according to the end-to-end delay, throughput, MAC traffic load, and the four parameters of the transmit and receive traffic parameters. The star topology is the best in terms of performance and has a MAC load that is similar to the mesh topology. Since the ZigBee network has a large number of nodes, so the use of star topology is considered to be very important.

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A. Appendix

Set point	Value
Range	~2–20% reverse current
Time delay	Adjustable 0–20 seconds

Table A1.
Technical data for reverse power monitoring.

Microgrid	Parameters	Value
Generator	Voltage	11 k V L-L, S = 200 MVA
Transformer	Voltage	V_P/V_S (L-L) = 11 kV/220 kV
	Frequency	60 Hz
Feeders	Line impedance	R = 0.02 X, L = 0.64 mH
	15 km feeder	R/km = 0.4 Ω, X/km = 0.3 Ω
Load	Dyn load	10 MW, 3 Mvar

Table A2.
Microgrid simulator parameters [1].

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