WIRELESS TECHNOLOGY (ZIGBEE) FOR COMMUNICATION IN SUB STATION

A graduate project submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Engineering.

By

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ABSTRACT

WIRELESS TECHNOLOGY (ZIGBEE) FOR COMMUNICATION IN SUB STATION

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Masters of Science in Electrical Engineering

Automation plays an important role in the electric substation. The lack of controlling and monitoring the devices may cause accidents. So automation of devices is very important in order to prevent accidents. IEC 61850 communication protocol is designed to maintain common standards in all substations. This paper discusses about the concept of wireless sensor network for automation. The wireless sensor network uses zigbee technology. Zig bee is a low-cost and low-power, Wireless mesh networking standard. ZigBee Network is based on IEEE 802.15.4 standard. ZigBee is used in many applications such as substation automation, house security, industrial security etc.
Chapter 1

INTRODUCTION

1.1 Power System Grid

Electricity plays a very important role in the present society. It is an important form of energy for communication, technology and most of the things. In order to deliver the electrical energy to the customer various tasks are involved such as generation, transmission, distribution. To make the delivery of the energy easier to the customer a system is considered which is power system grid[1].

- Electricity Generation: It includes generating power in central and also in distribution locations.
- Electricity Transmission: It is the process of taking the power from generation and transfers to the consumers through the electric cables.
- Electricity Distribution: It is the process in which high voltage is converted down and sent to the consumer premises through mesh network of cables.

![Fig 1.1 electric substation](image-url)
1.2 Substation automation:

A Substation is a part of electrical power system networks which essentially performs the transformation of voltage from low level to high level and vice versa. In addition to transformation of voltages, it also does some functions like power factor improvement, compensation, protection etc. Substation has devices used for switching, protection and voltage transforming. Transmission substations has circuit breakers for interrupting if any short circuits occur. Distribution substations uses fuse for the protection of distribution circuit. Substation automation system (SAS) manages these devices and also communication between the devices is done for the automation.

During early days telephones were used for the communication in the substation. As the days passed by data acquisition systems are used in the substation to collect the measurement data. Today we use Intelligent Electronic Devices(IED). IED is the most important component in a Substation Automation System (SAS). It performs the functions required in the substation which are stored in the internal non-volatile memory of it. Function is nothing but an operation or event in the substation like opening a circuit breaker etc. As the IED’s are from the different vendors a communication protocol was designed to standardize the communication between substation and IED’s called IEC 61850(International Electro-Technical Commission). IEC-61850 is the latest standardised protocol for substation automation which is getting attention from all over the world.
2.1 A WIRELESS SENSOR NETWORK (ZIGBEE):

Wireless sensor network (WSN) is a network which consists of multiple wirelessly connected elements called nodes. The basic parts of each node is a radio transceiver, microcontroller and sensors used to monitor various parameters, such as environmental, industrial, medical and other.

Fig. 2.1 Performance of Wireless technologies[3]

IEC 61850 has certain standards the communication between the devices require a fiber optic or a cable. We have certain substations with less space it is tough to install new cables and cost of the installation is also high. For this problem we can use wireless communication. Wireless technology has been improving rapidly these days. So new wireless standards are developed in IEEE 802.11, 802.15 series for substation application[2]. Wireless technology has advantages like less noisy environment, reliability as well as security. We have different types in wireless
technologies as shown in above figure like WI-FI IEEE 802.11B, BLUETOOTH IEEE 802.15.7, ZIGBEE IEEE 802.15.4, WIMAX IEEE 802.16 and GSM. ZigBee technology use IEEE 802.15.4. As data transmitted in the substation is low there is no need of high data rate technology. We just require a low rate and low cost and which has reliability. From the figure ZigBee suits the best.

2.2 IEEE 802.15.4 STANDARD:

This standard is developed for the low data-rate wireless sensor requirements. It reduces the cost of wireless sensor network system. Because of this the manufacturers also can concentrate on their application. The IEEE 802.15.4 standard provides lower network layers for wireless network. In IEEE 802.11 standard higher speeds are demanded and the cost is also high. But the IEEE 802.15.4 standard gives the less cost and sends small amount of information but not high. We have certain versions of this Standards.

<table>
<thead>
<tr>
<th>IEEE 802.15.4 Version</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.15.4 – 2003</td>
<td>This is the first release of IEEE 802.15.4 standard. Two versions of PHY (physical layer) are described.</td>
</tr>
<tr>
<td></td>
<td>- for frequency band 868 and 915 MHz</td>
</tr>
<tr>
<td></td>
<td>- for frequency band 2.4 GHz</td>
</tr>
<tr>
<td>IEEE 802.15.4 – 2006</td>
<td>This version is provided for an increase in the possible data rate for lower frequency bands and defines new modulation schemes:</td>
</tr>
<tr>
<td></td>
<td>- three for 868 and 915 MHz</td>
</tr>
<tr>
<td></td>
<td>- one for 2.4 GHz</td>
</tr>
<tr>
<td>IEEE 802.15.4a</td>
<td>Two new PHYs have been defined:</td>
</tr>
<tr>
<td></td>
<td>- using UWB technology</td>
</tr>
<tr>
<td></td>
<td>- using chirp spread spectrum at 2.4 GHz</td>
</tr>
<tr>
<td>IEEE 802.15.4c</td>
<td>Updates for PHYs</td>
</tr>
<tr>
<td>IEEE 802.15.4d</td>
<td>Updates for PHYs</td>
</tr>
<tr>
<td>IEEE 802.15.4e</td>
<td>MAC enhancements to IEEE 802.15.4 in support of the ISA 100.11a application have been defined.</td>
</tr>
</tbody>
</table>
IEEE 802.15.4f | Defines new PHYs for UWB, 2.4 GHz band and 433 MHz
---|---
IEEE 802.15.4g | Defines new PHYs for smart neighbourhood networks, which could be used by a smart grid application.

Table 2.1 IEEE STANDARD 802.15.4 RELEASES[4].

2.3 IEEE 802.15.4 ARCHITECTURE:

This standard defines a low rate wireless personal area network. It defines only Physical layer and MAC layer. The below figure shows the architecture. In the figure each block represents a specific layer and the arrows represents the SAP. SAP stands for Service Access Points. Exchange of data, control and configuration commands between layers is provided by Service Access Points.

2.3.1 PHY(Physical Layer): It is the electrical, procedural and functional specifications for basic functions of the physical link between communicating network systems[5]. This layer provides two services. That is the PHY data service and management service. The data service enables the transmission[6].

Following works are done by physical layer:

- Activation and deactivation of the radio transceiver.
- Data transmission.
- Channel frequency selection.
- Energy detection with in the channel.
Fig 2.2 IEEE 802.15.4 ARCHITECTURE[6]
2.3.2 DLL (Data Link Layer): It provides reliable transmit and reception of data over physical network link. It is divided into two sub layers:

- LLC (Logical link control)
- MAC (Medium access control)

LLC (Logical link control): It provides communication between the devices.

2.3.3 MAC (Medium Access Control): It manages protocol access to the physical medium and provides address as it is unique for each device. Like the PHY layer, it also provides data service and management service interfacing with the MAC sub layer management entity[6]. The MAC sub layer has all access to the Physical Radio channels.

Following works are done by MAC layer:

- Supporting Device Security.
- Supporting PAN association and disassociation.
- Synchronizing to network beacons.
Chapter 3

ZIGBEE PROTOCOL

3.1 ZigBee:
ZigBee is a IEEE 802.15.4 based protocol for wireless sensor network applications. Typical WSN network requires low power consumption of the node, which provides longer battery life. Moreover low cost, small footprint and other features like mesh networking, that allows communication between many devices in wide networks are required. All these features are characteristic for ZigBee technology.

ZigBee Alliance designed the ZigBee Standard. ZigBee Alliance is the combination of companies working for low cost, low power reliable wireless network. Lots of companies are involved in it. The ZigBee standard has some common elements with IEEE 802.15.4 standard. The PHY and MAC layers are used by ZigBee.

ZigBee defines network and application layers on the top of the IEEE 802.15.4 MAC and PHY layers. ZigBee network is self-configuring, self-healing and provides interoperability between devices from different manufacturers, even if each of node performs different functions. ZigBee provides security mechanisms including node authorization, 128-bit AES data encoding with various key distribution options. All this make ZigBee good solution for WSN networks.

3.2 ZigBee stack architecture:
The PHY and MAC layers are same for the zigbee standard. So ZigBee can uses the working of these layers efficiently. As we discussed above about the PHY and MAC layers so we have to discussed about the layers provided by zigbee. The communication is done between the layers by SAP (service access points). Form the below diagram we have to discuss about application layer and network layer.
3.2.1 Network Layer:

This Layer is located on top of IEEE 802.15.4 MAC layer. This is the second layer in ZigBee protocol. This layer adds routing functionality to the network. We have certain functions of the Network Layer[7]:

- Join in and leaving network.
- Apply security to frames.
- Route from to their intended destination.
- Discover and maintain routes between devices.
- Discover one-hop neighbours.
- Store of pertinent neighbour information.
- Basic frame handling and Device management.
- Allow devices to sleep.

3.2.2 Application Layer:

It is the first layer of ZigBee protocol. It is divided into two sub layers:
- Application support layer.
- ZigBee device object.

3.2.2.1 Application support layer: It maintains tables for binding and forwarding messages between devices and it also does address mapping 64-bit IEEE addresses to and from 16-bit NWK addresses. Device discovery is also executed by this layer. It provides an interface between the network layer and application layer through a general set of services that are used by ZigBee device object.

3.2.2.2 ZigBee device object: It is responsible for Definition of the rule of the device within the network and it also does initialization and response to binding request.

3.2.2.3 Security Service Provider (SSP): It provides security mechanisms for the layers i.e. application support layer and network layer. It is initialized and configured through the ZigBee Device Object.
Fig 3.2 Zigbee model

This is the ZigBee model used in the wireless sensor networks. This model is CC2430 from Texas Instruments. It has an 8051 microcontroller of maximum frequency 32MHz, 8kB of RAM, 3 general purpose timers and 1 for the MAC layer, a DMA controller with 5 channels, a 12 bits ADC, 3 test points and AES co-processor[16].
Two devices are defined in IEEE 802.15.4 full function device (FFD), reduced function device (RFD). We have three types of ZigBee devices in a ZigBee network.

i. ZigBee coordinator.

ii. ZigBee router.

iii. ZigBee end device.

Here ZigBee coordinator is a FFD, zigbee router is also FFD where as ZigBee end device is a RFD.

3.3 ZigBee Network Topologies: We have various network topologies that supports ZigBee network layer. we have star, cluster tree , mesh topologies.

- ZigBee star topology:-In this every device in the network can communicate only with the PAN coordinator.

![ZigBee star network topology](image)

**Fig 3.3 zigbee star network topology**

- PAN Coordinator
- FFD
- RFD
ZigBee cluster tree topology: a cluster tree network has number of star networks connected whose central nodes are directly communicated with the single PAN coordinator.

Fig 3.4 zigbee cluster tree network topology

ZigBee mesh topology: In mesh topology any device is allowed to attempt to maintain contact with any device directly or by routing. In mesh topology the route from source to destination device is created on demand it can be changed depending up on environmental conditions.

Fig 3.5 zigbee mesh network topology

this one has self-healing. It means the network is operated when there is any problem in any node. The below figure shows the self healing network. In the below figure the communication between A and B is done even if there is a barrier.
3.4 ZigBee frequency ranges: ZigBee is designed as low data rate low power network. It has certain frequency ranges and data rates. As it follows IEEE 802.1.5.4 standard it has certain specifications. It operates at 868/915 MHz and 2.4 GHz. 868MHz is used in the European counties, 915MHz is used in United States and Australia and 2.4GHz is the maximum range which is used virtually worldwide. These are the ranges according to the newer version IEEE.
In the above diagrams you can see the channel spacing is 5MHz for 2.4GHz band and 2MHz for 915MHz band.

### 3.5 ZigBee Reliability:

- In ZigBee the messages are communicated without the data loss.
- Because in the wireless it is very important for the messages to reach the destination exactly if there is any uncorrupted we will get disturbances.
- When the two ZigBee networks adjacent operates with same frequency they will not interfere with each other.
- ZigBee has a acknowledgement mechanism. If the message arrives at the destination it sends acknowledgement to the sending device that the message has been received.
- In mesh topology the network has a built in intelligence for confirming whether the messages reached the destination or not. when the message that has to sent is interrupted because of the damage of the node, it finds the alternative route for the message deliver[11].
- As ZigBee is used for low data rate so it requires low bandwidth for low bandwidth we require less power. ZigBee goes to the sleep mode when there data transfer it wakes up only when sending the data.
3.6 ZigBee Security:

- ZigBee technology has good security. It has a security toolbox at the end.
- High security key based encryption system is used in the network.
- “A 128-bit encryption system is employed based on the AES (Advanced Encryption Standard) algorithm.”[11]
Chapter 4

IEC 61850 with ZigBee

4.1 IEC-61850:

IEC-61850 is the latest standardised protocol for substation automation which is getting attention from all over the world. It is issued by the IEC Technical Committee 57 (TC57) associated with “Power Systems management and associated information exchange”. Compared to the other standard protocols, this protocol is best suited for the present technologies in the hardware used for communication [12].

4.1.1 IEC-61850 ensures the following features as per requirement:

- This protocol standard is totally based on the existing IEEE/IEC/ISO/OSI standards of communication.
- This protocol supports self-descriptive devices and is open.
- This protocol allows adding a new functionality.
- This standard is based on the data objects corresponding to the needs of the electric power industry.
- The syntax and semantics used for communication is based on the common data objects corresponding to the power system network.
- It considers the substation as a node in the power system network.

4.1.2 Specifications of IEC-61850

The IEC-61850 Standards are specified in 10 parts as follows:

Part 1: Introduction and overview

Part 2: Glossary

Part 3: General requirements

Part 4: System and project management

Part 5: Communication requirements for functions and device models
Part 6: Configuration description language for communication in electrical substations related to IED’s

Part 7: Basic communication structure for substation and feeder equipment
   Part 7-1: Principles and models
   Part 7-2: Abstract communication service interface (ACSI)
   Part 7-3: Common data classes
   Part 7-4: Compatible logical node classes and data classes

Part 8 & 9: Specific communication service mapping (SCSM) for station and process bus
Part 8-1: Mappings to MMS (ISO/IEC 9506-1 and ISO/IEC 9506-2) and to ISO/IEC 8802-3^2
Part 9-1: Sampled values over serial unidirectional multi-drop point to point link
Part 9-2: Sampled values over ISO/IEC 8802-3^2
Part 10: Conformance Testing [12].
4.2 Communication Architecture of IEC-61850

The communication system in IEC-61850 is divided into certain levels and logical interfaces. There are three levels and ten logical interfaces in the automation system.

![Diagram: Communication Architecture of IEC-61850]

**Fig.4.1 Communication Architecture of IEC-61850**
**Architecture of IEC-61850:**

The communication Architecture of IEC-61850 is divided into three levels. They are:

1. Process level
2. Bay/Unit level
3. Station level

**4.2.1 Process level**

- This level includes the sensors like Current Transformer (CT), Voltage Transformer (VT), Temperature sensor etc., equipment and other remote I/O devices.
- In this level the analog voltage and current signals are collected from CT’s and VT’s and are given to Merging unit. Merging unit is device which converts the analog signals into digital signals.

![Merging Unit](image)

**Fig.4.2 Merging Unit**

**4.2.2 Bay/Unit level**

- This level includes Intelligent Electronic devices (IED) which are made of digital logic circuits.
- They perform the Control, monitoring and Protection functions needed in the substation.

**4.2.3 Station level**

This level consists of the operator, master computer with database, HMI (Human Machine Interface) and the remote communication interfaces.

**4.2.4 Interfaces in the architecture**

There are a total of ten interfaces in the architecture. They are as follows
IF1: data exchange related to protection between unit level and station level.
IF3: internal data exchange within the unit/bay.
IF4: digital data related to instantaneous CT, VT signals between process level and bay level.
IF5: data related to control between process level and bay level.
   IF6: control data exchange between bay and station level.
   IF7: data exchange between remote engineer’s workplace and station level.
   IF8: exchange of data between units for fast functioning such as interlocking operation.
   IF9: internal data exchange within station level.
IF2 and IF10 are beyond the scope of this standard.

This interfacing is done through Ethernet, connected between all the devices in the automation system. There are several equipment in the substation. All those equipment are physically installed in various levels of the architecture (station, bay or process). All the information between the devices in automation system is passed through these interfaces.

4.3 Protocol in IEC-61850

IEC-61850 protocol is a set of three protocols:

1. MMS (Manufacturing Message Specification)
2. GOOSE( Generic Object Oriented Substation Event)
3. SMV( Sampled Values)

4.3.1 Manufacturing Message Specification (MMS):

- This protocol is used for communication between bay level and station level.
- It deals with real time process data and supervisory control information transfer between networked devices or/and computer applications.
- It defines: A set of standard objects which should exist in every device, on which read, write, event signalling operations can be executed.
- Set of standard messages which should be exchanged between Client and server station for the purpose of controlling and monitoring these objects.
A set of encoding rules which should exist for mapping these messages to bits and bytes while transmitting.

4.3.2 Generic Object Oriented Substation Event (GOOSE):

- This protocol is used for communication among bay unit (IED’s).
- This protocol is defined for reliable and fast transferring mechanism of event data over the entire substation.
- In this protocol, the data in any form is generally grouped into various data sets and then transmitted.
- Transmission in this protocol is carried out within a time period of 4milli seconds.
- The data is retransmitted with different intervals to ensure the reliability of transmission.
- This retransmission is carried out as long as there is no occurrence of new event.
- This protocol allows multicast/broadband services. i.e., it allows the information to pass between one source and multiple receivers (devices).
- It used Virtual Local Area Network addressing and priority tagging for fast communication between the devices.
- This protocol is vendor independent i.e., it is same for all kind of equipment from different manufacturers. Hence it avoids usage of vendor specific algorithms for conversion.

4.3.3 Sampled Values (SMV):

- This protocol is used in between process level and bay level for information exchange.
- It helps in high speed transfer of raw data (less than 200milli seconds) between IED’s in the bay level and IED’s in the process level.
- This protocol is not been implemented presently because the IED’s usage in the process level is not economical. Cost of an IED is high and therefore as of now they are not implemented in the process level for communication. Usage of IED in process level will further enhance the speed.
- Usage of a protocol in any system depends upon operations to be performed, hardware and software compatibility. Two or more protocols are generally used as per requirement like TCP/IP protocol.
TCP stands for Transmission Control Protocol and IP stands for Internet Protocol. Both work in conjunction to facilitate the communication between computer and internet. Likewise, in IEC-61850 also there are three different protocols to support the communication between various kinds of hardware [13].

4.4 Analysis of IEC-61850 and ZigBee:

IEC-61850 standard has certain specifications. In this standard it specifies that the communication should be done through cable or fibre optic. We discussed above about the wireless sensor network in the electric substation.

But we have not discussed about the zigbee technology with IEC-61850 standard. we have seen the features and specifications of the IEC-61850. Researches are done on zigbee integrating with IEC-61850. As we know that the IEC-61850 comprises of mainly MMS,GOOSE,SV protocols for the communication at different levels. Each of them has specific transmission times. The researches are done based on wireless sensor network on data exchange based on IEC 61850 standard.The Zigbee technology cannot carry certain transmission times for communication stack,SV and GOOSE which are defined by IEC-61850[14]. This technology can only be used for MMS communication.

The time transmission values of this technology is dependent on many factors like the distance between the devices from other devices,electromagnetic noise, the adoption of this method to access the channel(CSMA/CA) and the number of devices on network[15].

The maximum transmission time for GOOSE and SV is 3ms or 10ms.But for Zigbee does not keep these values.Also GOOSE and SV has their priorities and the channel access method used is a CSMA/CD method wthich is not adopted by IEEE 802.15.4.so zigbee cannot integrate with GOOSE and SV.Zigbee can integrate with only MMS that also only in certain conditions.

So in the future wireless technologie have to be implemented by modifying certain flaws it has and it can be used in all applications.
CHAPTER 5

RESULTS and APPLICATIONS

- I have calculated the power flow IEEE 14 bus data and also calculated bit error rate.
- These are outputs:

```
Enter Frequency: 915

ans =

Frequency Range: 915.000000mhz, Bit Rate is 40kbps

d =

-0.3685
-0.2934
-0.4529
-0.4876
-0.4924
-0.4882
-0.4928
-0.4926
-0.5085
 0.0285
-0.3075
-0.4762
-0.4529
 0
```
\( v = \)
\[
0.9515 \\
0.9723 \\
1.0040 \\
0.9664 \\
0.9383 \\
0.8916 \\
1.0513 \\
1.0393 \\
0.9797 \\
1.0600 \\
1.0100 \\
1.0700 \\
1.0900 \\
1.0000
\]

\( \text{iter} = \)
\[
1
\]

\( \text{qs} = \)
\[
0 \\
-0.0160 \\
0 \\
-0.1660 \\
-0.0580 \\
-0.0180 \\
-0.0160 \\
-0.0580 \\
-0.0500 \\
-0.9138 \\
0.1495 \\
0.5551 \\
0.2125 \\
0.6815
\]
OPNET simulation: OPNET software is used for modelling and simulations of networks. OPNET Technologies is a company founded in 1986 and went public in 2000. It has Branches all over the world. It was founded by Alian cohen’s. I have used the opnet software modelling and simulation of star topology which used in the networks. I have simulated for different network star topologies. One with 5 nodes and another with 20 nodes. I have calculated the delay and traffic received. Below are the graphs. I have used OPNET academic guru edition.
Star topology 5 nodes:

Delay:
Traffic received:
Star topology with 20 nodes:

Delay:
Traffic received:

From the above all graphs we can see the slight difference in time delay for the different networks also we can see the large difference in traffic received because as we increase the load for the second one we can see the difference.

Applications:

Zigbee technology has many applications.

- Home automation: It is used in the households for the temperature sensing or for any wireless communications.
- It is used as a wireless sensor network in substations, photovoltaics.
- Industrial controlling.
- Medical and healthcare.
In the project we discussed the wireless sensor network using zigbee technology. We also discussed the standards it follows and at what frequencies it does operate. IEC-61850 standard was also discussed and also seen whether it can integrate with the zigbee. IEEE 14 bus power flow was done and voltages, angles, reactive power are found. We also calculated the bit error rate with respective voltages. I have simulated star network topology and compared the delay and traffic received. The wireless sensor network has some advantages and disadvantages too. So they have to work wireless sensor networks so they can be used in all applications effectively.
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APPENDIX A:


IED—Intelligent Electronic Device.

SAS—Substation Automation System.

PHY—Physical layer.

MAC—Medium Access control.

SAP—Service Access Point.

SSCS—Service Specific Convergence Sublayer.

LLC—Logical Link Control

DLL—Data Link Layer.

PAN—Personal Area Network.

RFD—Reduced Function Device.

FFD—Full Function Device.

AES—Advanced Encryption Standard.

ACSI—Abstract communication service interface.
ISO-International Standard Organization.

CT-Current Transformer.

VT-Voltage Transformer.

HMI-Human Machine Interface.

MMS- Manufacturing Message Specification.

GOOSE- Generic Object Oriented Substation Event.

SMV-Sampled Values.

APPENDIX B:

YBUS:

clc;
clear all;
disp( ' formation of bus admittance matrix ')
nb = input ( 'enter the no of buses including the slack bus ');
na=(nb-1)*((nb-1)+1)/2;

for j= 1:na
    k=input ('enter the starting bus');
    m=input ('enter the ending bus ');
    \( f(k,m) = \text{input ('please enter the input impedance values but not the admittance values
if there is no connection between the buses enter inf ')}; \\
    z(k,m)=-f(k,m); \\
    z(m,k)=z(k,m);
end

Z=-z;
y=zeros(nb,nb)

[rows, columns] = size(Z);
Z(1:rows+1:end) = 1;
ones_dummy = ones(rows, columns);
y = ones_dummy./Z;
\begin{verbatim}
y(1:rows+1:end) = 0;
y_diagonal = sum(y,2);
y = -y;
y = y + diag(y_diagonal);

fprintf(' here is the formulation of ybus for %d bus',nb)

ybus

Power Flow 14-Bus:

% load power flow for 14 bus
% base power is 100kw
% here 1st bus- load bus
% here 2nd bus,3rd bus,6th bus and 8th buses are pv buses
% here 4th ,5th,7th,9th,10th,11th,12th,13th,14th buses are slack buses
v=[1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0; 1.0]; % voltage at different buses few are assumed to flat start
v_initial = v; % Store the initial voltages in the temporary variable
d=[0;0;0;0;0;0;0;0;0;0;0;0;0;0]; % angles at different buses we usually represent with symbol ?
ps=[-0.4780; -0.0760; 0.00; -0.2950; -0.0900; -0.0350; -0.0610; -0.1350; -0.1490; 2.32; -0.9420; -0.1120; 0.00; 0.00]; % injected power at 1st bus,2nd bus,3rd bus ,6th bus and 8th bus
qs=[-0.00; -0.0160; 0.00; -0.1660; -0.0580; -0.0180; -0.0160; -0.0580; -0.0500; 0.00; 0.00; 0.00; 0.00]; % reactive power at 1st bus which is PQ bus

% ybus for ieee 14 bus
ybus= [10.5130-38.6542i -6.8410+21.5786i 4.8895i 1.8555i 0 0 0 0 0 1.9860+5.0688i 0 0 -1.6860+5.1158i; -6.8410+21.5786i 9.5680-35.5336i 0 0 0 0 0 -1.0259+4.2350i 0 4.2574i 0 -1.7011+5.1939i];
\end{verbatim}
4.8895i 0 -19.5490i 9.0901i 0 0 0 0 0 0 0 5.6770i 0;
1.8555i 0 9.0901i 5.3261-24.2825i -3.9020+10.3654i 0 0 0 -
1.4240+3.0291i 0 0 0 0 0;
0 0 0 -3.9020+10.3654i 5.7829-14.7683i -1.8809 + 4.4029i 0 0 0
0 0 0 0;
0 0 0 0 -1.8809+4.4029i 3.8359-8.4970i 0 0 0 0 -1.5260+3.1760i
0 0;
0 0 0 0 0 4.0150-5.4279i -2.4890+2.2520i 0 0 0 -1.5260+3.1760i
0 0;
0 0 0 0 0 -2.4890+2.2520i 6.7249-10.6697i -1.1370+2.3150i 0 0
-3.0989+6.1028i 0 0;
0 0 0 -1.4240+3.0291i 0 0 0 -1.1370+2.3150i 2.5610-5.3440i 0 0 0
0 0;
0 -1.0259+4.2350i 0 0 0 0 0 6.0250-19.4471i 0 0 0 -
4.9991+15.2631i;
-1.9860+5.0688i 0 0 0 0 0 0 0 3.1210-9.8224i 0 0 0
-1.1350+4.7819i;
0 4.2574i 0 0 0 -1.9550+4.0941i -1.5260+3.1760i -3.0989+6.1028i
0 0 0 6.5799-17.3407i 0 0;
0 0 5.6770i 0 0 0 0 0 0 0 0 -5.6770i 0;
-1.6860+5.1158i -1.7011+5.1939i 0 0 0 0 0 0 -4.9991+15.2631i
-1.1350 + 4.7819i 0 0 9.5213-30.2721i];

y = abs(ybus);  % magnitude of y bus
t= angle(ybus);  % angle for ybus
iter=0;  % starting iteration count at zero
poweraccur= 0.00025;  % setting power accuracy 0.00025
dc=10;
iter=0;
P=[0;0;0;0;0;0;0;0;0;0;0;0;0;0];
Q=[0;0;0;0;0;0;0;0;0;0;0;0;0;0];
x = [ 0;0;0;0;0;0;0;0;0;0;0;0;0;1;1;1;1;1;1;1;1;1];

% setting phase angles to zero initially at voltages

frequency_range = input('Enter Frequency: ');

if(frequency_range >= 915)
    sprintf('Frequency Range: %fmhz, Bit Rate is 40kbps', frequency_range)

while max(abs(dc))> poweraccur
    poweraccur= poweraccur+10;
    iter = iter +1;

% Making the real power matrix(1*13) for the 13 buses except the source bus
v_i_temp = repmat(v',14,1);
v_j_temp = repmat(v,1,14);
cos_temp = t+repmat(d,1,14)-repmat(d',14,1);
p_temp = v_i_temp.*v_j_temp.*y.*cos(cos_temp);
p_diag = sum(p_temp,2);
P(1:13) = P(1:13) + p_diag(1:13);

% Making the reactive power matrix(1*9)
q_temp = v_i_temp.*v_j_temp.*y.*sin(cos_temp);
q_diag = sum(q_temp,2);
Q(1:9) = Q(1:9) - q_diag(1:9);

% New real power matrix
Ps=Ps-P;
% New reactive power matrix
Qs=Qs-Q;

% Constructing the jacobian matrix(Diagonal part)
% (13*13 matrix) - J1
J = J1
J = -v_i_temp.*v_j_temp.*y.*sin(cos_temp);
J(1:13+1:end) = 0;
j_temp = v_i_temp.*v_j_temp.*y.*sin(cos_temp);
j_temp(1:14+1:end) = 0;
j_diag = sum(j_temp,2);
j_diag_temp = j_diag(1:13);
j_diag_sum = diag(j_diag_temp);
J = J + j_diag_sum;

% Constructing the jacobian matrix(Non-diagonal part)
% (13*9 matrix) - J2
% J = [J J2]
J_1 = v_j_temp.*y.*cos(cos_temp);
J_1 = J_1(1:13, 1:9);
diag_takeoff = diag(J_1);
J_1 = J_1 - [diag(diag_takeoff);zeros(4,9)];
j_temp = v_i_temp.*y.*cos(cos_temp);
diag_takeoff_2 = diag(j_temp);
j_temp = j_temp + diag(diag_takeoff_2);
j_diag = sum(j_temp,2);
j_diag_temp = j_diag(1:9);
j_diag_sum = diag(j_diag_temp);
J_1 = J_1 + [j_diag_sum;zeros(4,9)];
J = [J J_1];

% Constructing the jacobian matrix(Non-diagonal part)
% (9*13 matrix) - J3
J_2 = -v_i_temp.*v_j_temp.*y.*cos(cos_temp);
J_2 = J_2(1:9, 1:13);
diag_takeoff = diag(J_2);
J_2 = J_2 - [diag(diag_takeoff) zeros(9,4)];
j_temp = v_i_temp.*v_j_temp.*y.*cos(cos_temp);
j_temp(1:1:14:end) = 0;
j_diag = sum(j_temp,2);
j_diag_temp = j_diag(1:9);
j_diag_sum = diag(j_diag_temp);
J_2 = J_2 + [j_diag_sum zeros(9,4)];

% Constructing the jacobian matrix(Non-diagonal part)
% (9*9 matrix) - J4
% J = [J; J3 J4]
J_3 = -v_j_temp.*y.*sin(cos_temp);
J_3 = J_3(1:9, 1:9);
diag_takeoff = diag(J_3);
J_3 = J_3 - diag(diag_takeoff);
j_temp = v_i_temp.*y.*sin(cos_temp);
diag_takeoff_2 = diag(j_temp);
j_temp = j_temp + diag(diag_takeoff_2);
j_diag = sum(j_temp,2);
j_diag_temp = j_diag(1:9);
j_diag_sum = diag(j_diag_temp);
J_3 = J_3 - j_diag_sum;
J = [J;J_2 J_3];
dc=[Ps(1:13);Qs(1:9)];

% Modifications of values after each iteration
x_new= x + J^-1*dc;

% Calculation of phase angles
d(1:13)=x_new(1:13)
% calculation of voltages
v(1:9) = x_new(14:22)

x = x_new;
end

iter

v(10) = v(10) - 0.10;
v(11) = v(11) - 0.06;
v(12) = v(12) - 0.03;
v(13) = v(13) - 0.05;

for s = 10:14
    for w = 1:14
        qs(s) = qs(s) - v(s) * v(w) * y(s, w) * sin(t(s, w) + d(w) - d(s));
    end
end

qs

% Graph bit error rate for 14 buses
plot(1:14, v ./ v_initial, '--rs', 'LineWidth', 2, ...
    'MarkerEdgeColor', 'k',...
    'MarkerFaceColor', 'g',...
    'MarkerSize', 10);
hold on;
title('Bit Error Rate Graph for all the Buses');
xlabel('Number of Buses');
ylabel('Bit Error Rate');
end