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Wireless Sensor Network Based Smart Grid Converter Control Using Hybrid Energy Source

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Absract : A smart grid (SG) has attracted great attention due to recent environmental problems. SG technologies enable users, such as energy system operators and consumers, to reduce energy consumption and the emission of greenhouse gases, by changing energy infrastructure more efficiently. As a part of the SG, home energy management system (HEMS) has become increasingly important, because energy consumption of a residential sector accounts for a significant amount of total energy consumption. This project presents a hardware design of smart grid home gateway that integrates smart home network to be compatible for smart grid integration with hybrid energy system: photovoltaic arrays, wind turbine etc. This project also presents the control strategy and power management for an integrated three-port converter, which interfaces one solar input port, one bidirectional battery port, and an isolated output port. Multimode operations and multiloop designs are vital for such multiport converters. In this network, a Smart Grid Home Gateway can control the electrical appliances based on the programming schedule or data received from control center Wireless sensor networks (WSNs) are small micro electrical mechanical systems that are deployed to collect and communicate the data from surroundings. WSNs can be used for monitoring and control of smart grid assets.

Keywords:- Smart grid (SG), Home energy management system (HEMS), Home Area Network (HAN), Neighborhood Area Network (NAN), Wireless sensor networks (WSNs)

I. Introduction

The electrical grid is being revolutionarily transformed as Smart grid. Smart Grid is an automated and broadly distributed energy generation, transmission and distribution network. It is characterized by full duplex network with bidirectional flow of electricity and information. It is a close loop system for monitoring and response. Smart Grid is being conceptualized and developed by various organizations around the world such as National Institute of Standards and Technology (NIST), Institute of Electrical and Electronics Engineers (IEEE), European Technology Platform (ETP), International Electro technical Commission (IEC), Electric Power Research Institute (EPRI), etc. Diverse set of standards and harmonization between various standards are also being rigorously researched by these organizations. It can be defined in various ways as per its functional, technological or beneficial aspects. As per the definition given by U.S. department of energy, "A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources".

Smart Grid is an integration of electrical as well as information and communication technologies to make the power grid more reliable, flexible, efficient and robust. It is an intelligent power grid with assimilation of various alternative and renewable energy resources. Automated monitoring, data acquisition, control and emerging communication technologies are the most prominent features of smart grid deployment. Use of diverse set of communication standards requires analysis and optimization depending upon constraints and requirements. These requirements can be decided on the basis of area of coverage, type of application, bandwidth requirement, etc. Smart grid hierarchical communication network can be categorized as Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN) as per the applications of communication technologies at various levels of deployment of smart grid.

1.1. Home Area Network

HAN is applicable for home automation. It is used for the consumer domain and consists of electronics appliances and wireless sensor networks. These consumer electronics appliances communicate their energy consumption statistics to central home monitor and regulator or smart meter. Central regulator or smart meter sends it to the central electricity grid for monitoring, control, fault

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detection and billing purposes. Smart meters and intelligent electronic devices receive the commands from central power grid and they control the home appliances based on the received commands. Home Area Networks (HANs) have the coverage area of few meters. IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 (Zigbee), IEEE 802.11 (WLAN/Wi-Fi), IEEE 802.3 (Ethernet), Narrowband PLC (Power line communication), etc. standards can be used for Home area networks.

1.2. Neighborhood Area Network

The function of Neighborhood Area Network (NAN) is to communicate the information collected by smart meters to central controller. The NANs may contain few hundreds of smart meters deployed in HANs. Smart meters are linked with different gateways through NANs. The coverage region of NANs is around 1–10 square miles. The requirement of data rates for NAN is around 10–1000 Kbps.

1.3. Wide Area Network

The Wide Area Network (WAN) connects various NANs. Data collection points are located at various places and the collected data are forwarded to central controller. The coverage area for WAN is around thousands of square miles. The requirement of data rate is around 10–100 Mbps. Wide area network requires very high bandwidth for itsoperation and management. WAN is suitable for Supervisory Control And Data Acquisition (SCADA) systems for monitoring, data acquisition, control and management of power grid. With the advancement in communication standards and embedded systems, wireless sensor networks have become an inevitable component of smart grid technology. They can be used to bring intelligence in power grid due to their capability to collect, store, process and communicate information. The layered architecture of Smart Grid in terms of national, continental and intercontinental power management is also crucial for design and deployment of interconnected networks.

At present, Smart Grid is the most inventive technology being explored by researchers over the world. Design and testing of communication network for Smart Grid layered architecture using Zigbee technology. Other technologies such as Wi-Fi, Wimax and Bluetooth are considered for Smart Grid communications. Implementation of Internet of Things (IoT) for Smart Grid is explored. Cyber security for Smart Grid infrastructure is an inevitable requirement for reliable operation of utilities. Cyber security threats and solutions for smart grid are analyzed in various studies. A critical case study on overall Smart Grid security aspects and solutions for HAN based on Zigbee technology is described by Saponara et al. The authors have depicted the lessons learnt from implementation of smart micro grid using personal area network based on IEEE 802.15.4 standard in University of Pisa. The relation between intricacy and security has been pointed out by Schumacher et al.: "Complexity is the worst enemy of security".

Smart Grid is an interconnected, hierarchical and heterogeneous network with enormous complexities and dynamics. Thus, gigantic network architecture of Smart Grid creates many security challenges. However, the above-mentioned statement is divergent for WSN as it contains tiny sensor nodes with limited computational and storage capabilities. For WSN, simplicity of design and implementation becomes the worst enemy of its security and makes it more vulnerable to attacks.

1.4 Application of Wireless Sensor Networks in Smart Grid

WSN is a cost effective solution for monitoring, control, measurement and fault diagnosis in various domains of smart grid network. A sensor node mainly contains sensors, memory, processor, power supply, transceiver and actuator. Sensors are used to sense various quantities like humidity, temperature, current, etc. Generally, WSN nodes are battery powered. Fig: 1.1 shows the basic structure of WSN node.

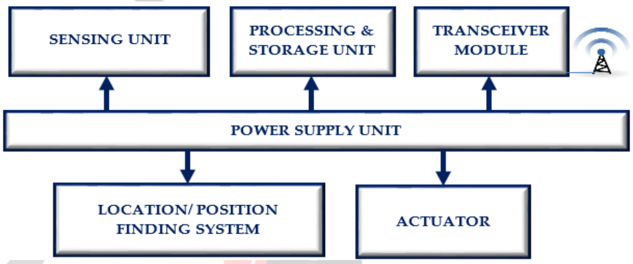

Fig: 1.1Architecture of WSN (Wireless Sensor Network) Node.

WSN facilitates both sensing and communication requirements. Small sensor nodes collectively form a sensor network which is used for remote wireless communication in HAN, NAN and WAN. Large scale deployment of sensor nodes can be used to communicate the conditions of various generation, transmission and distribution units. Wireless sensor nodes can provide economical solution for smart micro grid monitoring which facilitates high penetration of renewable energy sources. WSN is a significant part of advanced metering infrastructure (AMI). Sensing and communication are crucial for Plug in Hybrid Electric Vehicle (PHEV) system which is one of the most ingenious components of smart grid technology. PHEV contains gasoline or diesel engine with an electric motor as well as a large rechargeable battery. PHEV can be recharged from an electrical power outlet. It has the potential to reduce Green House Gases (GHG) emissions and carbon footprint. PHEV facilitates flexibility as well as economy in fuel usage. WSN can be used to communicate PHEV statistics to upstream network layers for operation and control of Smart Grid components. This information will be online available to various stakeholders through a web of sensor nodes. An effective remote monitoring, diagnosis and control can prevent cascaded disastrous events and breakdowns.

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Wireless sensor networks can be used for accurate monitoring of generation, transmission, distribution and consumption of electricity. WSN is the most suitable solution for HAN, NAN, WAN and smart micro grid applications for integration and operation of renewable energy sources.

- Smart power generation

Wireless sensor networks can be used at the generation side for monitoring and management of produced energy. It is a prominent solution for smart micro grid applications using renewable energy resources. WSN can be used in solar farm, wind farm, biogas plant, etc. to monitor and control intermittent energy. One of the objectives of smart grid is to expedite the use of renewable energy sources. Renewable energy resources are situated in harsh environments and hostile locations. Moreover, their unpredictable behavior creates more challenges during their operation and management. WSN nodes are economical solutions for monitoring the behavior of renewable energy resources [55–58]. Various parameters of generating equipment can be effectively measured, communicated and controlled using WSN.

- Smart power transmission and distribution

Transmission and distribution of power contains various components like overhead transmission lines, underground cable network, substations and distribution transformers. WSN is an essential element of SCADA system. Real time remote monitoring of these components is inevitable to prevent power failures due to equipment breakdown or malicious attacks. Wireless sensor networks can be used for power monitoring, fault detection and isolation, location discovery and outage detection.

- Customer applications

Wireless sensor network is an effective and prominent solution for home automation systems. It can be used for complete energy management of customer premises. Consumer plays an active role in smart grid technology. Consumers have the power to decide the time of use and rates of energy usage in smart homes. For these applications, wireless sensor networks are inevitable for communication and processing of information. WSN is the backbone of smart home applications and HAN.

1.5 Radio Frequency Identification (RFID)

The term **RFID** stands for **Radio Frequency Identification**. **Radio** stands for invocation of the wireless transmission and propagation of information or data. For operating RFID devices, **Frequency** defines spectrum, may it be low, high, ultra high and microwave, each with distinguishing characteristics. **Identification** relates to identify the items with the help of various codes present in a data carrier (memory-based) and available via radio frequency reading. The RFID is a term which is used for any device that can be sensed or detected from a distance with few problems of obstruction. The invention of RFID term lies in the origin of tags that reflect or Retransmit a radio-frequency signal. RFID makes use of radio frequencies to communicate between two of its components namely RFID tag and the RFID reader. The RFID system can be broadly categorized according to the physical components of frequency and data.

1.6 RFID System Components

An RFID system is basically an integrated combination of various components which work together for detection and identification of objects or persons. These are the components which are primarily responsible for working of any RFID system whether basic or complex. Although there can always be additional components associated with RFID systems like sensors etc. but the following are amongst the key components of these systems:

• RFID Tag (Attached with an object and possess unique identification)
• Antenna (Tag Detector and creates magnetic field)
• RFID Reader (Manipulator and receiver of RFID Tag information)
•Application Software (User or Database or Application and RFID Reader Interface)
•Communication Infrastructure (Enables the RFID system to work and transfer data amongst various components)

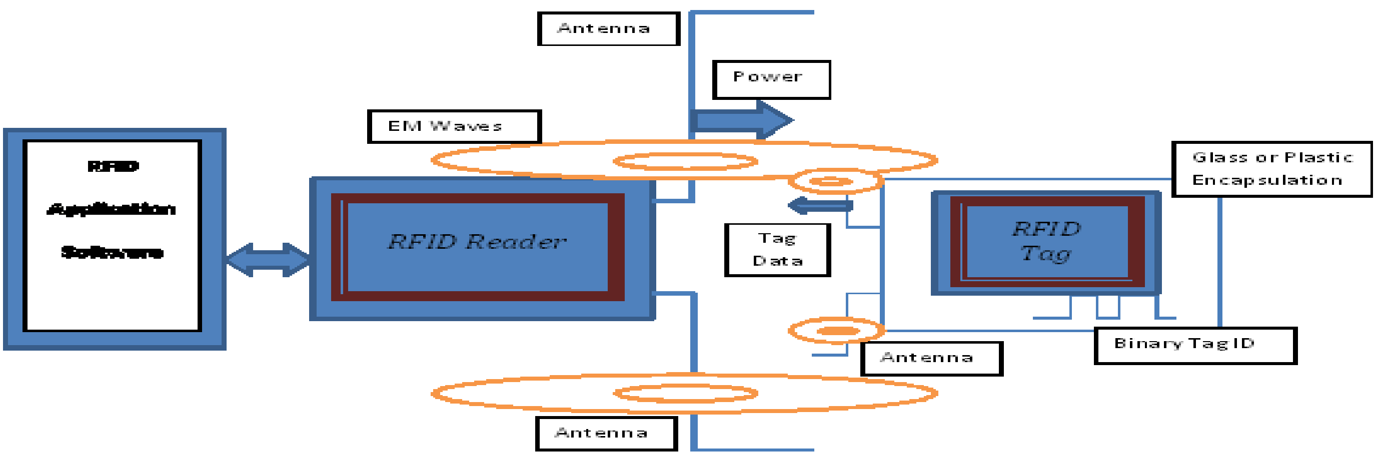

Fig: 1.2 The RFID System

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II. EXISTING SYSTEM

A novel high step-up dc/dc converter is presented for renewable energy applications. The suggested structure consists of a coupled inductor and two voltage multiplier cells, in order to obtain high step-up voltage gain. In addition, two capacitors are charged during the switch-off period, using the energy stored in the coupled inductor which increases the voltage transfer gain. The energy stored in the leakage inductance is recycled with the use of a passive clamp circuit. The voltage stress on the main power switch is also reduced in the proposed topology. Therefore, a main power switch with low resistance RDS (ON) can be used to reduce the conduction losses. The operation principle and the steady-state analyses are discussed thoroughly. To verify the performance of the presented converter, a 300-W laboratory prototype circuit is implemented.

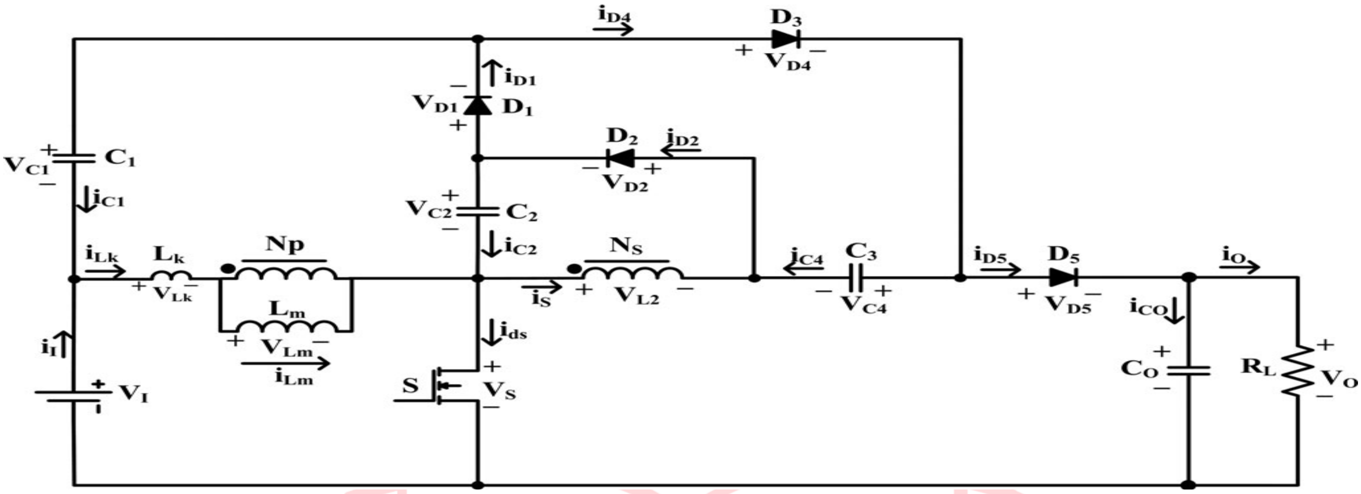

Fig2.1 High-Step-Up Converter

The circuit configuration of the proposed converter is shown in Fig. 1. The proposed converter comprises a dc input voltage (*VI*), active power switch (S), coupled inductor, four diodes, and four capacitors. Capacitor *C*1 and diode *D*1 are employed as clamp circuit respectively. The capacitor *C*3 is employed as the capacitor of the extended voltage multiplier cell. The capacitor *C*2 and diode *D*2 are the circuit elements of the voltage multiplier which increase the voltage of clamping capacitor *C*1 . The coupled inductor is modeled as an ideal transformer with a turn ratio *N* (*N*P/*N*S), a magnetizing inductor *Lm* and leakage inductor *Lk*. In order to simplify the circuit analysis of the converter, some assumptions are considered as follows:

1) All Capacitors are sufficiently large; therefore *VC*1 , *VC*2 , *VC*3 , and *VO* are considered to be constant during one switching period;

2) All components are ideal but the leakage inductance of the coupled inductor is considered.

III. PROPOSED SYSTEM

In this project, we presents the control strategy and power management for an integrated three-port converter, which interfaces one solar input port, one bidirectional battery port, and an isolated output port. Multimode operations and multi loop designs are vital for such multiport converters. However, control design is difficult for a multiport converter to achieve multifunctional power management because of various cross-coupled control loops. Since there are various modes of operation, it is challenging to define different modes and to further implement autonomous mode transition based on the energy state of the three power ports. A competitive method is used to realize smooth and seamless mode transition. Multiport converter has plenty of interacting control loops due to integrated power trains. It is difficult to design close-loop controls without proper decoupling method.

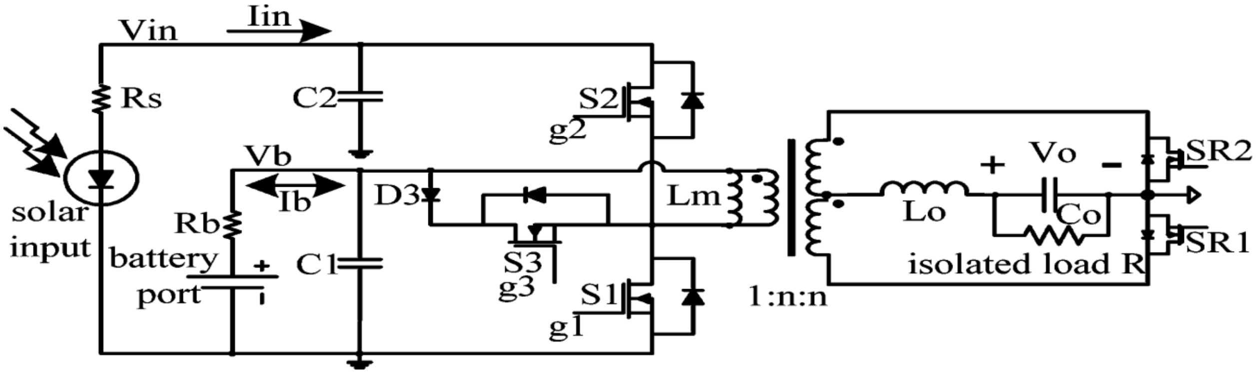

Fig: 3.1Three Port Topology Control Structure

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The three-port topology and control structure. As shown in Fig:4.1, it is a modified version of pulse width-modulated (PWM) half-bridge converter that includes three basic circuit stages within a constant-frequency switching cycle to provide two independent control variables, namely, duty-cycles *d*1 and *d*2 that are used to control S1 and S2, respectively. This allows tight control over two of the converter ports, while the third port provides the power balance in the system. The switching sequence ensures a clamping path for the energy of the leakage inductance of the transformer at all times. This energy is further utilized to achieve ZVS for all primary switches for a wide range of source and load conditions.

Having different operational modes is one of the unique features for three-port converters. An orbital satellite's power platform experiences periods of insolation and eclipse during each orbit cycle, with insolation period being longer. Since MPPT can notably boost solar energy extraction of a photovoltaic (PV) system, the longer insolation period means that MPPT is more often operated to allow a smaller solar array while managing the same amount of load.

Two assumptions are made to simplify the analysis: 1) load power is assumed to be constant and 2) battery over discharge is ignored because PV arrays and batteries are typically oversized in satellites to provide some safety margins. Four stages in satellite's one-orbit cycle yield two basic operational modes as follows.

In battery-balanced mode (mode 1), the load voltage is tightly regulated, and the solar panel operates under MPPT control to provide maximum power. The battery preserves the power balance for the system by storing unconsumed solar power or providing the deficit during high-load intervals. Therefore, the solar array can be scaled to provide average load power, while the battery provides the deficit during peak power of load, which is attracting to reduce solar array mass. In battery-regulation mode (mode 2), the load is regulated and sinks less power than is available, while the battery charge rate is controlled to prevent overcharging. This mode stops to start mode 1 when the load increases beyond available solar power, i.e., battery parameter falls below either maximum voltage setting or maximum current setting.

The converter has three circuit stages to allow two control inputs that are used to regulate two of the three ports. The output voltage is regulated at any given time, but either input port or battery port can be regulated depending on which is most urgently needed according to available solar power and battery state of charge. The control design for multiport converter is challenging and needs to manage power flow under various operating conditions. Therefore, the control strategy must be "powerful" and "intelligent" enough to realize complicated control tasks, and should have different operational mode transition control. A competitive method was utilized to realize autonomous mode transitions. Basically, there are no modes from controller point of view, which simplifies the control algorithm and avoids possible system oscillations due to elimination of instant duty-cycle value change. This project also presented a general modeling procedure specially tailored for three-port converters. Since there are many control inputs and state variables for multiport converter, converter model derivation adopts matrix-based averaged state-space method. Moreover, the small-signal models for different operational modes were obtained separately, while the model derived for each mode includes two ports' dynamic characteristics other than one for two-port converters.

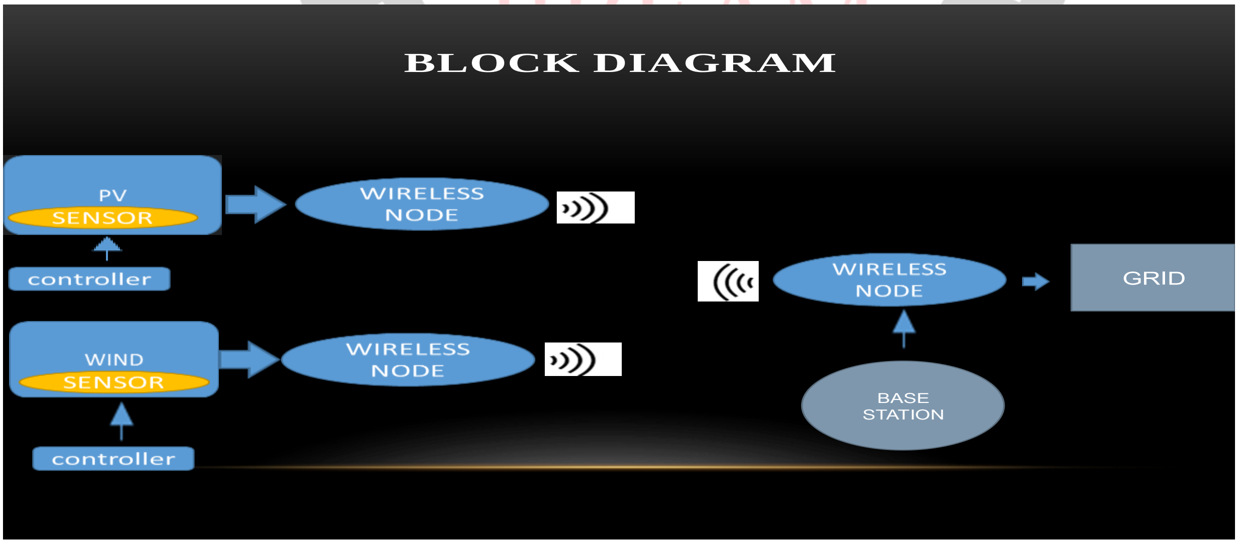

Fig: 3.2 Block Diagram

IV. SIMULATION AND RESULTS

In this section, the simulation results are shown. Where the output schematics are simulated by the MATLAB 2013Ra and network simulator tool.

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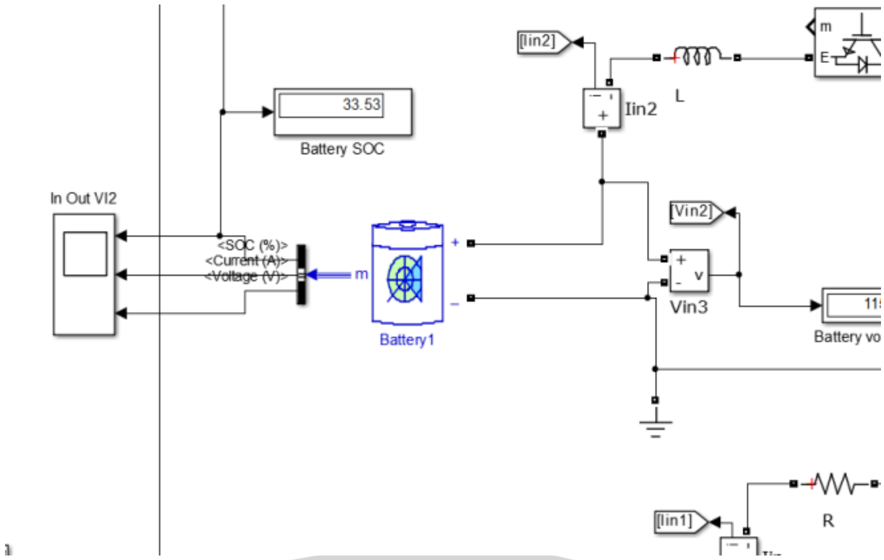

Fig: 4.1 Bs Energy Storage

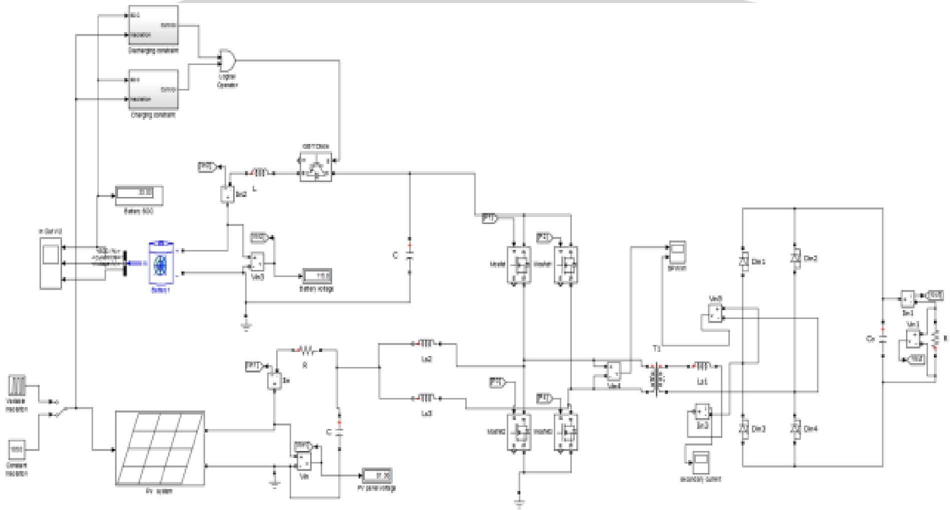

Fig: 4.2 Total Topology

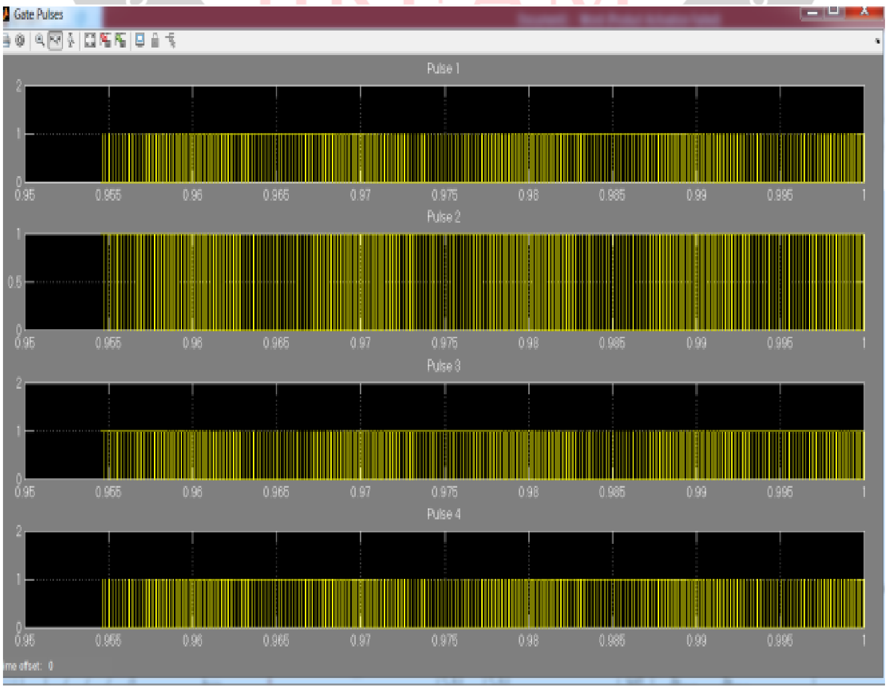

Fig: 4.3 Pwm Waveform

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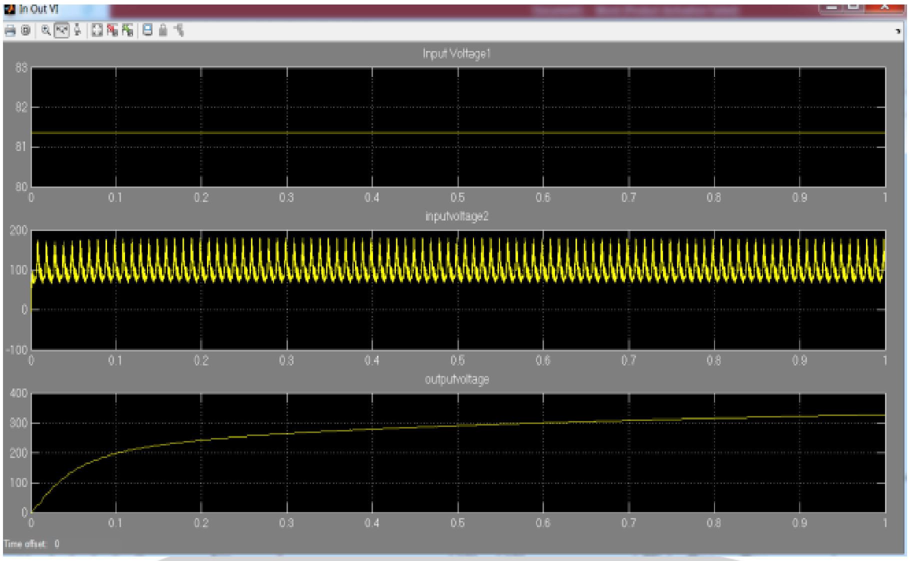

Fig: 4.4 Corresponding Source And Load

Network simulator

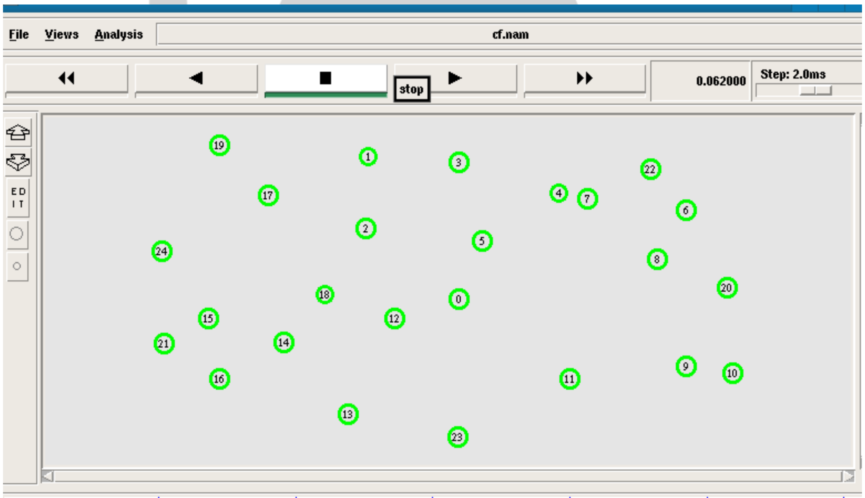

Fig: 4.5 Node Creation

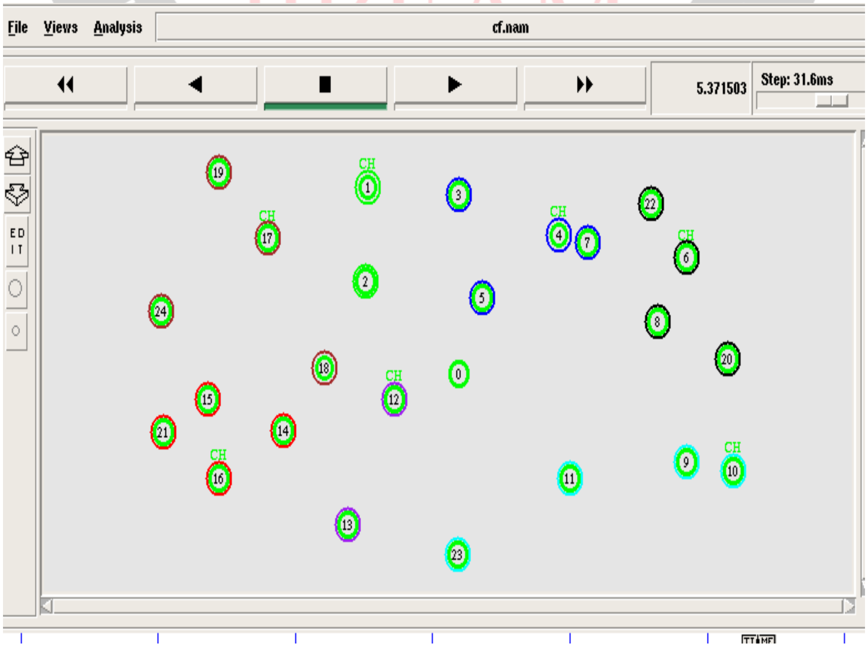

Fig: 4.6 Proposed Topology Communication

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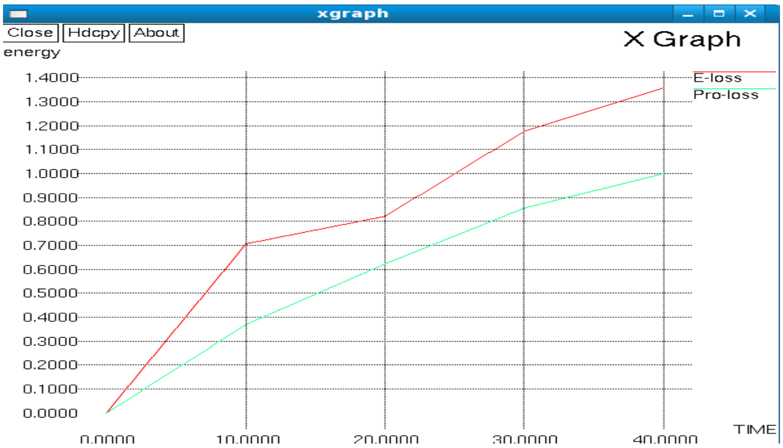

Fig: 4.7 Existing And Proposed Loss Comparison

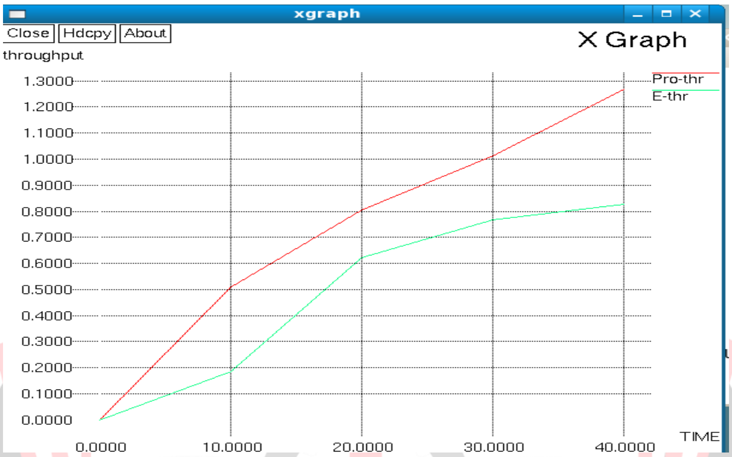

Fig: 4.8 Comparison Chart For Throughput

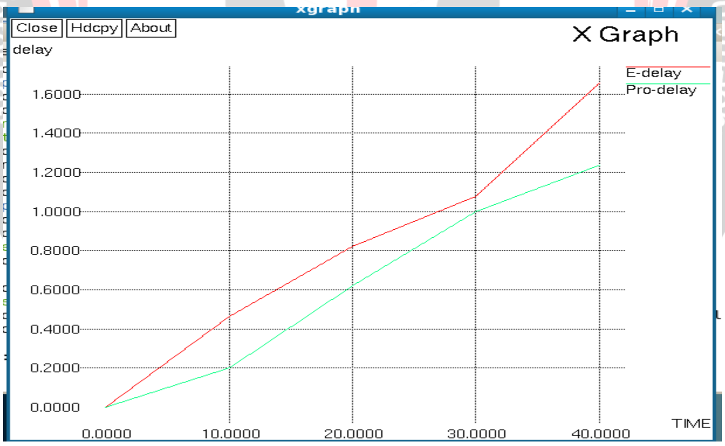

Fig: 4.9 Comparison Chart for Delay

V. CONCLUSION

The present power grid is going through a huge transformation with the deployment of smart grid technology. Smart grid is a complex hierarchical and heterogeneous network. Wireless sensor network is a prominent solution for various applications of smart grid. Wireless sensor networks are distributed collection of sensor nodes situated at various places for measurement and communication of various parameters such as temperature, voltage, current and humidity.

These parameters are required for remote monitoring and control of different components of smart grid. WSNs are effective solutions for energy management system in home, industry and business applications. These small sensor nodes are extensively vulnerable to attacks as they are placed in hostile surroundings. Node capture results into complete control of attacker on the WSN node and tampering of hardware as well as software of the node. The energy exhausted sensor nodes can be easily victimized.

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