AN EFFICIENT MODELING AND SIMULATION PLATFORM TO ASSESS AUTONOMOUS POWER SYSTEMS

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Computer Networking.

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DEDICATION

To the Almighty, my wife, my parents, and my friends for their ultimate encouragement throughout my education and for incomparable advice throughout my life.

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ABSTRACT

Autonomous power system (APS) that exploits local renewable energy sources has potential to provide useful energy at lower costs when compared with conventional energy. Modern APS involves the control of renewable energy systems with intermittent power production; interaction with conventional energy generation; and management of energy storage and consumption. The system configuration of an APS is often complex due to the mix of energy generations and desire to optimize the utilization of the renewable energy. The fact that a large amount of data must be processed within a very short period of time makes the APS very challenging. In this work, we introduce a modeling and simulation methodology to analyze autonomous power systems. We develop a simulation platform using VisualSim software package to create simulation programs. We model an APS for hybrid electrical vehicle (HEV) with solar energy, thermoelectricity, fuel energy, and various buses. Simulation results suggest that controller area network (CAN) bus outperforms FlexRay and Bluetooth; this is because CAN bus optimizes the communication required by the vehicular system to use the renewable energy sources. The proposed modeling and simulation platform is easy, fast, and reliable to assess the components required in any autonomous power systems.

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LIST OF ABBREVIATIONS

ACK	Acknowledge
APS	Autonomous Power System
ASIC	Application Specific Integrated Circuit
BD	Bus Driver
BG	Bus Guardian
CAN	Controller Area Network
CAPPlab	Computer Architecture and Parallel Programming Laboratory
CC	Communication Controller / Catalytic Converter
CRC	Cyclic Redundancy Check
DC	Direct Current
ECU	Electronic Control Unit
EOF	End Of File
EREMS	Effective Renewable Energy Management System
FIFO	First In First Out
FTDMA	Frequency-time Division Multiple Access
HEV	Hybrid Electric Vehicle
IPCC	Intergovernmental Panel of Climate Change
ISM	Industrial, Scientific and Medical
JasPar	Japanese Automotive Software Platform and Architecture
MAC	Media Access Control
MHz	Mega Hertz

LIST OF ABBREVIATIONS (continued)

MUF	Maximum Urgency First
NREL	National Renewable Energy Laboratory
OPENSIG	One Pair Ethernet Special Interest Group
SOF	Start of Frame
SRE	Sustainable and Renewable Energy
TDMA	Time Division Multiple Access
TEG	Thermoelectric Generator

CHAPTER 1

INTRODUCTION

Over the past decades energy has been a growing concern for world's overall economic development and therefore, researchers are being increasingly interested about APS. An APS can be based on different renewable energy sources like solar power, wind power, wind turbines, hydro power, and thermoelectric generator along with fossil fuel generators. But as renewable energy is highly intermittent in nature it is important to have appropriate storage devices to managing the demand and supply ratio when conventional energy generation system is not integrated. It is also very important to have an efficient power management system for best utilization of the generated power even if renewable energy generation sources are integrated to conventional energy sources. Therefore, in this work we have developed a simulation platform to assess an APS for HEV where the APS exploits renewable energy source along with conventional energy generation.

1.1 Energy Management

Energy management systems has four main focus areas namely planning and operation of generation, minimize operating cost, reduce environmental impact and increase profitability. The energy management system also needs to ensure that user has uninterrupted access to their energy requirement despite meeting the above criteria of energy management system. But this is a very complex system as demand varies from day to night and also from season to season. Therefore, it is extremely important to know the demand patterns to optimize the generation and thus reduce energy losses. As energy management system demands to reduce environmental impact on energy generation it is becoming very popular to integrate renewable energy sources with conventional one.

The energy management system becomes more complex when APS uses local renewable energy sources along with conventional energy generation because the renewable energy generation is very dynamic in nature as it depends mostly on the weather condition which is unpredictable. For example there will be no solar energy at night time and no wind energy when there is no flow. Also solar energy will depend on the intensity of the sunlight at any particular period and wind energy will depend on the speed of wind. Thus, to maximize the utilization of the renewable energy source it is extremely important to know the renewable energy generation at any particular period of time along with customer demand at that period. This increases the power management system further as high data transfer rate is required at that particular period of time.

1.2 Evaluation Methods

Performance evaluation of a system is becoming increasingly important issue due to its general pervasiveness. A system behavior can be predicted quantitatively by running a performance evaluation of that system. It is very important to evaluate every system at every stage of their life cycle. For example, it is very important to perform performance evaluation because we must know whether a system is performing up to the desired level. For a new system it is very much essential to know if the system should meet the requirements. Therefore, to know its optimal performance parameters before starting the design and implementation phase, we must need some tool which will help us modify the key control parameters and see how the system behavior changes with the change of control parameters. It is also very important to evaluate even an running system to know whether it is performing as expected or there is still some rooms for improvement. If we look to the system development cycle we see that the requirement of system evaluation never stops as we want every system to perform to its optimal capacity.

There are three basic techniques [1] to evaluate the performance of a system. They are as follows:

1. Measurement
2. Analytical Modeling
3. Computer Based Simulation

All three basic techniques have their own advantages and disadvantages. Analytical modeling is based on mathematical models of a system with considerable amount of details but is always approximate of the real system. They are most inexpensive and fast. But the price must be paid as it is most inaccurate of all three techniques. Measurement on the other hand is the most fundamental techniques but only possible when the system has already been built and is running. They are most expensive and also requires considerable amount of time and engineering efforts before real results can be obtained. However, the results obtained by these techniques are most accurate among all three of them. Finally, computer simulation requires model construction for the system and runs it with the appropriate workload. Simulation also requires adequate amount of time to derive the model and coding the simulator. But it is more accurate as this is very much flexible and major control parameters can be changed to observe system behavior. Table 1 summarizes the advantages and disadvantages of all three techniques of performance evaluation. It very important to be noted that all these three techniques are complement to one another and one can be used to validate others. Different phases of a development process different techniques can also be used which is called hybrid modeling [2,3].

TABLE 1.

Advantages and Disadvantages of Performance Evaluation Techniques

Description	**Advantages**	**Disadvantages**
Analytical Method	1. System may or may not exist 2. Generally less costly 3. Fastest of all three system	1. Less accurate 2. Cannot be validated is the system is not there
Computer Simulation	1. System may or may not exist 2. Less costly 3. Takes less time than measurement 4. Very flexible	1. Less accurate than measurement and accuracy depends on design parameter. 2. Needs validation
Measurement	1. Most accurate results 2. Required for validation of other two techniques.	1. Most time consuming 2. Most expensive 3. System Must exist

Among all three performance evaluation techniques computer based simulation technique is arguably the most effective one because of usefulness in wide variety of areas with relative low cost but accurate results. Productivity, quality and safety are all that can be measured by computer simulation, doesn't matter where the issues takes place in manufacturing floor, warehouse, marketing section, office, climate or in nuclear plant. The history of computer simulation begins as a scientific tool in the period after World War II [4].Since then computer simulation has been used in all areas of scientific research including astrophysics, material science, renewable energy harvesting, engineering, climate science, biology, ecology, economics, business, sociology, medical science, and may more. The most important benefits of looking to a system by building computer simulation rather than real implementation is that the level of details that can be provided by simulation cannot be obtained sometimes by real experiment with our current technology. We can put extreme values of some control parameters and observe the system behavior which might not be possible in case of experimental measurement. Therefore, it has become most powerful tool now-a-days to evaluate performance of a system.

In this work we have developed and described an effective computer simulation tool for management of APS of a HEV. The simulation tool has been designed by using VisualSim software [5].

1.3 Background and Motivation

Energy has been the primary concern for worlds economic development as demand has increased significantly in the past decades. There are mainly two sources of energy. One is fossil fuel like petroleum, coal, natural gas etc. The other one is renewable energy sources like solar power generation, wind power generation, ocean energy, geothermal energy, thermoelectric energy generation etc. The intergovernmental panel on climate change (IPCC) shows that fossil fuel provided 85 % of the total energy [6]. But the supply of fossil fuel is not endless. As per peak oil theory (M. King Hubert's theory) fossil fuel extraction is expected to enter a terminal decline [7]. One alternative to this could be nuclear energy but due to its safety issues nuclear energy generation is being limited day by day throughout the world. Another disadvantage of combusting fossil fuel is that it contributes 56.6 % of all greenhouse gas emission worldwide [8]. Therefore, a sustainable and environmental friendly energy sourced has been of great research interest which is renewable energy sources. Renewable energy sources, having both the property of sustainability and also supportive to global climate system, have become very lucrative as alternative energy generation source. On the global basis it has been estimated that renewable energy has been contributed 12.9 % of the total energy supply [9]. But the capacity of renewable energy is much higher than this as researchers have shown that with proper integration of renewable energy sources with electrochemical storages it is possible to power up the electric grid 99.9 % [10] of time just by using solar and wind energy sources.

If we look to the above scenarios renewable energy sources look like the best alternative energy source for the future. But there are unique challenges to use renewable energy sources successfully as alternative energy generation. First of all energy generation with renewable sources are highly weather dependent and therefore, makes it more complicated to integrate it with conventional energy generation system. As no one can guarantee the amount of production first of all it needs to be integrated with electrochemical energy storage system and then use the energy as per user demand. Secondly the energy conversion rate is significantly lower up to now than the fossil fuel energy sources. Thirdly the capital investment cost for renewable energy generation projects are relatively high in compare to fossil fuel energy generation. Finally communication system is a vital technology for integration of renewable energy system into the grid and therefore, we must find an effective communication medium to integrate all renewable energy generation sources with electrochemical energy storage system and conventional energy generation system to meet up user requirement which is also very dynamic in nature and therefore, tons of information must be processed in certain amount of time for flawless operation of the total system. Figure 1 shows data and energy flow pattern of a typical renewable energy source integration with the main grid.

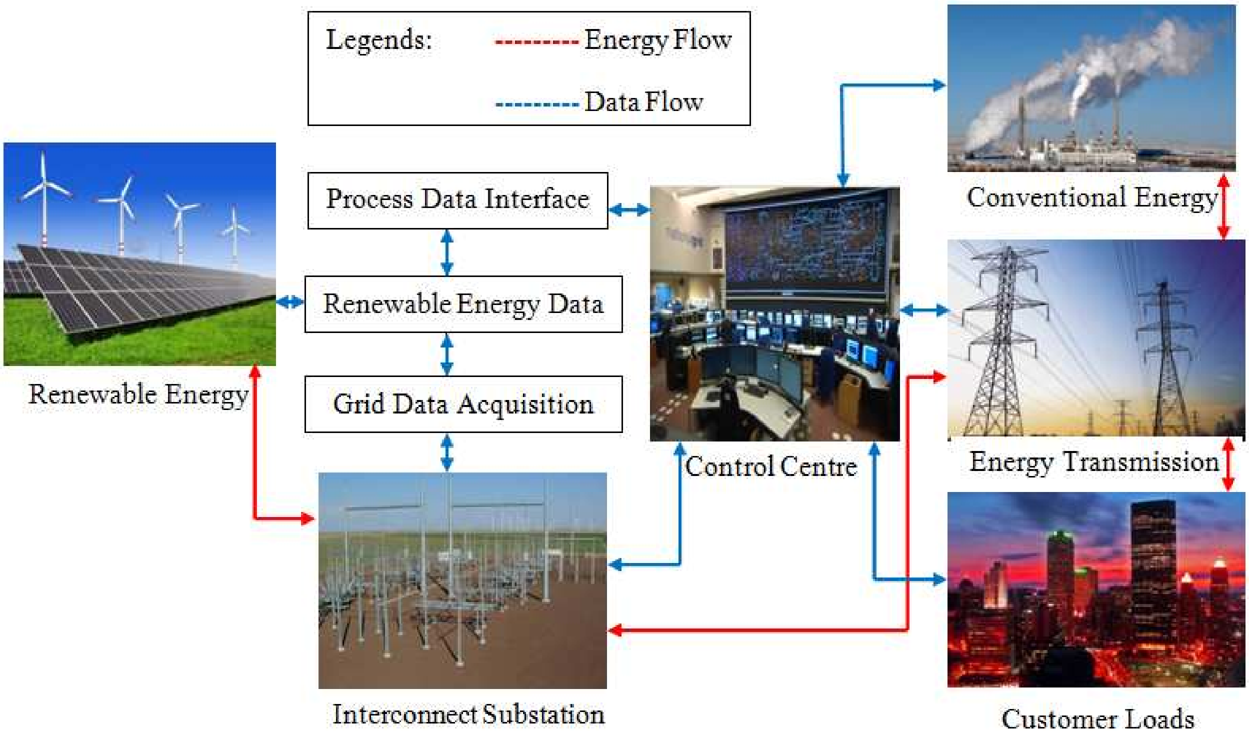

Figure 1. Grid Integration of Renewable Energy Sources With Main Grid [11]

From Figure 1,it is easy to understand that the renewable energy sources integration process is a mammoth task and therefore, it is very important to know all the possible outcomes of such system so that the energy management system can perform at its optimal capacity. In this work we have described an effective renewable energy management system (EREMS) for a regular sedan car which uses both renewable energy sources along with its regular fossil fuel energy generation source. The reason choosing the renewable energy management system for a vehicle is because transportation sector in United States uses 70 % [12] of the total petroleum based fuels and 60 % [13] of the total transportation energy is used by light vehicles. Thus reduction of fossil fuel use in a regular sedan car by producing some renewable energy without significant change in present energy generation system will save a lot of money in the long run and also reduce CO_2 emission significantly.

1.4 Problem Statement and Contributions

Although there are some simulation tools to assess solar energy system [14, 15],they do not allow controlling the solar intensity and not flexible enough to put all other control parameters such as solar panel properties, solar panel dimensions, customer load, etc. They are also not integrated with other renewable energy generation sources such as thermoelectric energy generation, wind energy generation, and so on. They also do not provide any information regarding integration process such as data flow, energy flow and network latency information, which is indeed necessary to have an efficient energy management system.

In this work, we introduce a reliable and flexible simulation platform where anyone can easily evaluate the performance of an integrated renewable energy system along with conventional one. We have developed a simulation platform to evaluate APSs where we have integrated solar energy and thermoelectric energy generation sources with conventional fossil fuel energy for a regular sedan car.We also have simulated various communication mediums including CAN, FlexRay and Bluetooth for a regular sedan car.

1.5 Thesis Organization

The rest of the manuscript is organized as follows:

In Chapter 2, we are going to discuss in details of all the renewable energy generation techniques and the equipment that has been considered in this simulation platform.

In Chapter 3, we introduced the proposed efficient modeling and simulation platform for better understanding and assessment of sustainable and renewable energy management system.

In Chapter 4, we describe some of the system parameters and details of all the modules used for this simulation platform.

In Chapter 5, we present the experimental results for the selected APS and compare them with real implementation results.

In Chapter 6, we conclude our work and present future extension of this work.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

In this chapter, we discuss the theoretical background of the elements that have been used to model the simulation platform. First of all, we describe three different intra-vehicle communication medium to select an optimal one for our proposed APS. Then we discuss the renewable energy sources and the energy storage device that has been considered for our APS of HEV. Finally, we represent some simulation methods that have used these and summarize the chapter.

2.2 Intra-vehicle Communication Mediums

The number of electronic control unit (ECU) of a vehicular system has been increased due to increased requirement of integration of energy sources, safety, comfort and performance. But this leads intra-vehicle communication to be complex and huge in size. The number of signals exchanged by a modern car which is nearly 2500 signals exchanged by up to 70 ECUs [16,17] certainly will increase if we want to integrate renewable energy sources to conventional energy generation. To meet this entire requirement we need an efficient, high speed, low cost and dependable communication medium. This system must contain real time communication properties with strict timing constraints.

There has been plenty of intra-vehicle networking options are present now a days. They can be categorized mainly in two different parts. One is wired communication networks and the other one is wireless communication networks. Wired networks can also be divided into two other major categories namely electrical bus based communication and optical bus based communications. Different Communication networks have been shown in Table 2which can be used for intra-vehicle communication.

All of these networks are used to communicate in between all the ECUs. As intra-vehicle networks are becoming more and more popular it demands new research and innovation in this field. Recently many special interest groups such as One Pair Ethernet Special Interest Group (OPENSIG) [18], the AVnu alliance [19], and the Japanese Automotive Software Platform and Architecture (JasPar) group [20] have been formed to standardize these technologies between car manufacturers and equipment manufacturers.

TABLE 2.

Different Types of Intra-vehicle Communication Network

Network Types for In-vehicle Communication		
Wired Medium		**Wireless Medium**
Electrical Bus Based	***Optical Bus Based***	
CAN	FlexRay	Bluetooth
LIN	Byteflight	UWB
MOST-50	1394 Automotive	Zigbee
TTP	MST-150	RFID

In this work we have described different properties of different types of communication medium. We choose to discuss one in each categories of bus based, optical fiber based and wireless communication network and finally we have shown the results on each group using simulation tool called VisualSim. We have shown the network latency, channel occupancy of each group and observed that different communication network might be suitable for different area based on the application requirement. We also have shown the cost comparison to justify that although some communication medium is faster than others they might not be suitable for their higher cost. Finally we also have shown the failure scenarios by varying the parameters in the simulation platform to find the optimal result and to see at which point the communication network fails for each cases.

2.2.1 Controller Area Network (CAN)

Controller Area Network was developed by Robert Bosch GmbH in the mid-1980s which is a serial broadcast bus and subsequently it becomes the ISO standard in 1994 [16]. Since then CAN is the most widely used intra-vehicle communication network. CAN has the advantage of having comparative low cost, bounded delay which also provides flexible and robust communication in between ECUS. It has variable bandwidth rates up to 1 mbps [21] which also allows up to 40 meter [21] of bus length at this data rate.

Four distinguishable parts are there in CAN message format namely; data, distant, malfunction and overload frames [22]. We only discuss the information frame in this work. An information frame has 7 fields which start with a start of frame (SOF) bit. Then followed by 18 bits header, data from 0-8 bytes, Cyclic Redundancy Check (CRC) 15 bits, 3 bits acknowledgement (ACK), 7 bits of end of frame (EOF) and finally 3 bits for intermission frame space. Moreover there is a twenty nine bit of extended data frame identifier. Whenever a CAN node wants to transmit data first of all it monitors the bus to see whether it is idle or not. Upon finding it idle it starts transmitting data with identifier field of the message. Simultaneously another node can also starts transmitting finding the bus idle, creates chances for collision.

Therefore, CAN has the arbitration process that last for the length of the identifier field and allows thus avoids collision by allowing the least value identifier message to transmit first..

Another distinguishing feature of CAN is its error handling and error detection capabilities. Error detection is done in five stages namely; bit monitoring, bit staffing, frame check, ACK check and CRC. A node transmitting data will send the reverse bits after transmitting five distinguishable bits. In the concept frame all the receivers are presumed to send a dominant bus during ACK. Whenever the transmitter fails to detect this dominant bus level there is an error. This mechanism leads CAN to be a high integrity and low error recovery time protocol in compare to others.

As CAN protocol works based on fixed priority scheduling the scheduling policy plays a very important role for message transmission. This is done by having lower identification (ID) for higher priority CAN messages. The priority designation is performed before the system starts. But situation might occur in this case that due to limitation of bandwidth lower priority message will not get a chance for transmission. Therefore, there will be incredible delay effect. To avoid that CAN also uses immediate feedback scheduling algorithm called maximum urgency first (MUF). According to this upon invocation the scheduler produces new precedence as per urgency value and then message is transmitted in accordance to new precedence [23].

High malfunction management capacity gives CAN significant advantage to enhance system dependability. CAN provides flexibility with efficient utilization of bandwidth and provides efficient response time. Atypical CAN bus communication simplified block diagram is shown in Figure 2 which has two main different parts namely electronic communication unit (ECU) node and monitor node. Monitor node sends information to PC for display the information and doing further analysis on them. The host processor in this part decides which message has to be broadcasted and what is the significance of the received message. The other part which is called ECU nodes are consists of host microcontroller, CAN controller and CAN transceiver is actually the part which is normally connected to sensors, actuators and other control apparatus. Each node is connected to can-bus line. CAN controller receives the transmitted message bit by bit until the whole message is completed and sent to CAN transceiver where CAN transceiver converts the transmit-bit sign into a signal which can be sent to can-bus eventually [24]. The CAN transceiver is actually an interconnecting interface between protocol control and the real can-bus.

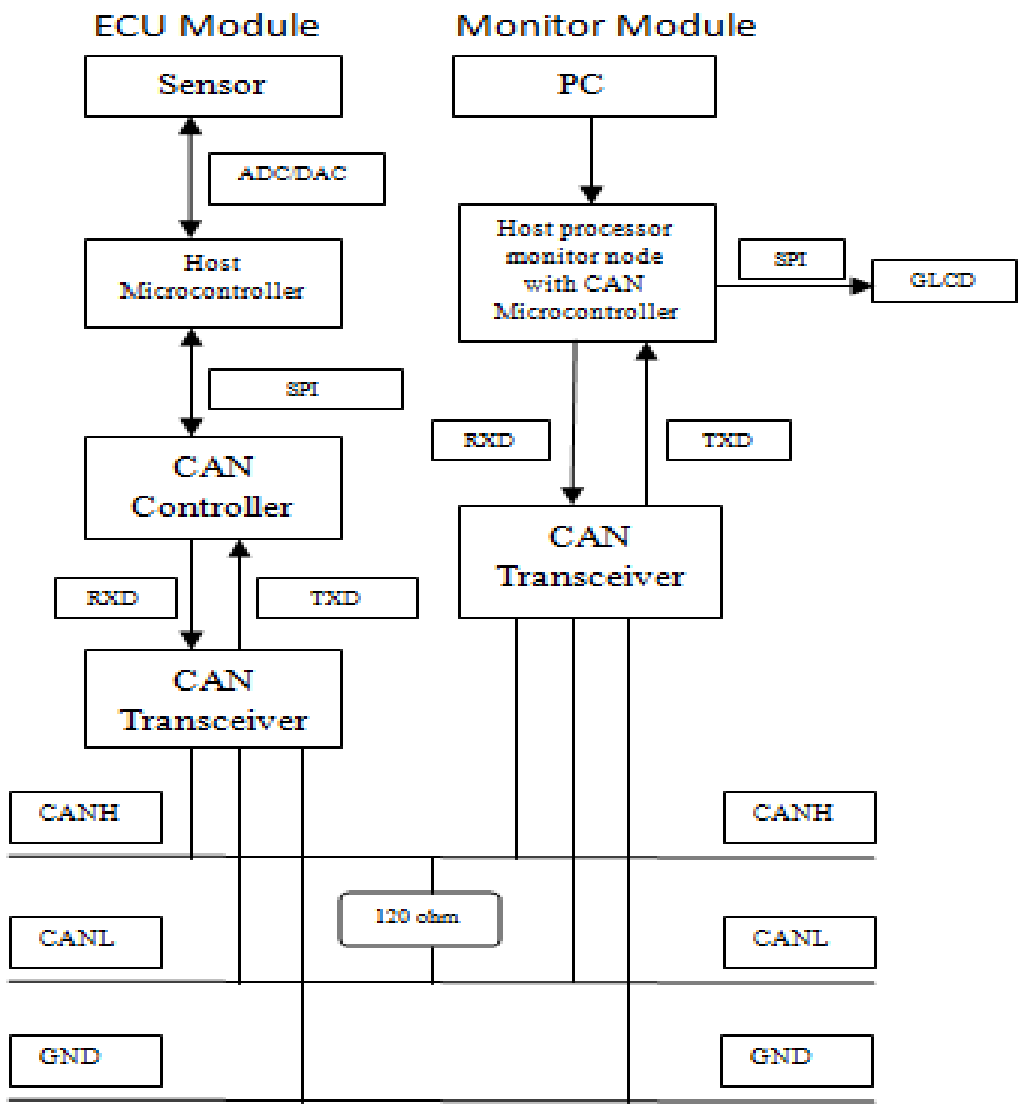

Figure 2. Block Diagram of CAN Network [22]

2.2.2 FlexRay

FlexRay was developed by a consortium of big automobile companies like BMW, Daimler-Chrysler, Philips and Motorola aiming high speed intra-vehicular communication network at around 2000 [25]. The FlexRay standard is now a set of ISO standards of ISO 17458-1 to 17458-5 [26]. It is also dependable and flexible intra-vehicular communication network. The protocol is based on time division multiple access (TDMA) and frequency-time division multiple access (FTDMA) and therefore, can work with both time-triggered and event-triggered communication system. FlexRay supports high data rate as 10 mbps. This can be of different network topologies like bus, star with multiple channels. Exchanged message in FlexRay contains 254 bytes of data with five bytes of header. A static scheduler called elementary cycle which has two windows (static for time-triggered traffic and dynamic for event-triggered traffic) controls the network communication of FlexRay. During the system run this elementary cycle row repeats itself cyclically. For the static window equal length slots and assigned to different nodes in the network and for the dynamic window have minislots which are assigned to nodes based on the message identifiers. Similar to other bus based protocol the bus is accessed based on the message identifier. Each node keeps its own time information, slot number and elementary cycle time to make sure when they are allowed to start transmission or to receive information. Recent research on FlexRay are aiming to improve the real time performance by assigning slots to node and defining duration of slot assignment in the elementary cycle [27].

One other advantage of FlexRay is that I can use dual channel where both of them provides redundancy and higher bandwidth meaning both provide CRC, bus guardian and clock synchronization. This protocol can also be implemented at higher layer than since they don’t provide acknowledgement, membership and service for mode management. Although due to static scheduling time-triggered communication makes FlexRay more predictable it is seen as the standard of the future intra-vehicle communication network where high speed is mandatory.

A typical FlexRay working principle block diagram is shown in Figure 3 where ECU consists of a host processor, the FlexRay Communication Controller (CC) and the Bus Guardian (BG). The host processor supplies and processes the data, which are transmitted via the FlexRay controller. The BG monitors access to the bus. The host processor informs the BG which time slots the FlexRay CC has allocated. The BG then allows the FlexRay CC to transmit data only in these time slots and enables the Bus Driver (BD). Data can be received at any time.

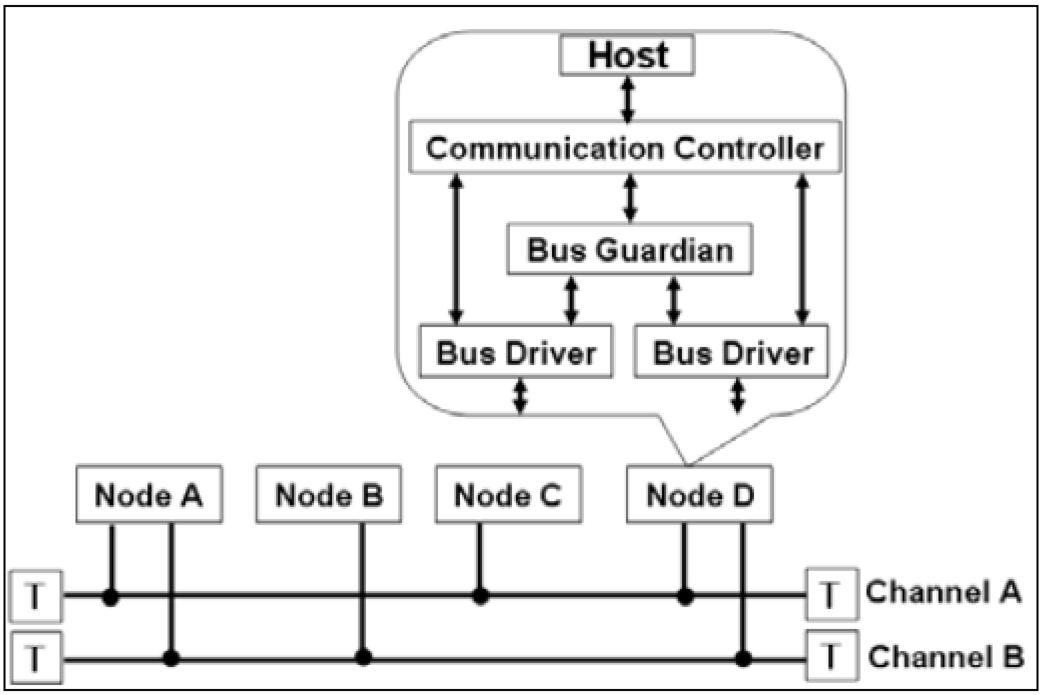

Figure 3.FlexRay Node Architecture with Dual Bus Topology[28]

2.2.3 Bluetooth(IEEE 802.15.1)

Bluetooth was first developed and developed by Ericson which is now most widely used wireless personal area network (WPAN) protocol. The primary idea to develop Bluetooth was to replace short cables connectivity of small devices that are battery operated, cheap and having power saving modes.

Bluetooth is a low power consumption communication protocol adopting master-slave and peer-to-peer communication technique. But with the increasing demand for networking support requirement it adopts one master and multiple slave approach which is called piconet. This approach has only one master and up to seven slave devices. However up to 255 slaves can be in the piconet being in sleep mode. Technically when the master and slave devices comes within the range they form a adhoc network using the Bluetooth technology while a three bit media access control (MAC) address restrict the active nodes in the piconet. Frequency hopping spread spectrum (FHSS) technique is used in Bluetooth to protect against noise and interference resulting frequency hopping sequence is unique for all slave nodes as it is generated on the address of master node. As a result piconet slaves cannot communicate with each other and to resolve this issue scatternet concept has been introduced where a master of one piconet can be a slave of other piconet and one slave of a piconet can be the slave of other three piconets. Bluetooth also supports both broadcast and unicast transmission.

Bluetooth operates in 2.4 GHz band which is also referred to as industrial, scientific and medical (ISM) unlicensed frequency band. As Bluetooth devices communicate to each other by frequency hopping, throughout the transmission it uses 79 channels, from 2.402 to 2.408, spaced 1 MHz from each other. Although Bluetooth is capable to support many intra-vehicle communication network requirement due to its delays in scatternet, mode switching and master slave topology its bandwidth requirement is very high and therefore, uses in intra-vehicular communication network is still limited [29].

A typical block diagram of Bluetooth is shown in Figure 4 which consists of four main different parts. They are Bluetooth microprocessor, a radio frequency for receiving and transmitting data, an interface to the host device and some memory. The baseband protocol processes the signals which are received and transmitted through the radio. The link manager then controls and setup the link to the host device.

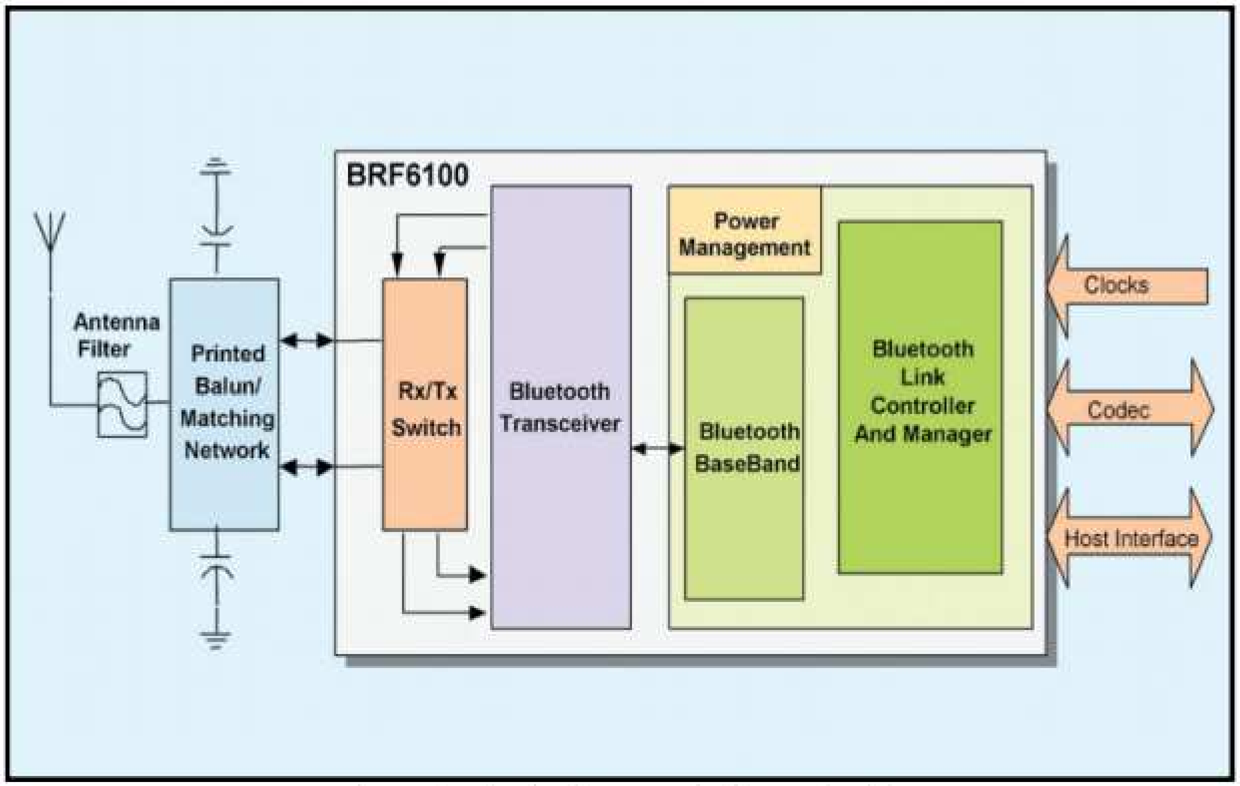

Figure 4. Block Diagram of a Bluetooth Device [30]

2.3 Renewable Energy Sources Used in EREMS

There are many renewable energy sources available; such as wind energy, solar energy, geothermal energy, ocean wave energy, thermoelectric energy generator etc. But in our EREMS for vehicular system we consider solar cell and thermoelectric energy generator as renewable energy source cause several reasons. First of all solar cells has been used to produce electricity cause a regular sedan car has wasted spaces on roof, hood and tank which can be easily covered by solar panels to produce electricity. Secondly we have used thermoelectric generator (TEG) in exhaust gas system cause researchers [31] have shown that approximately 60 to 70 % of combustion energy is lost as waste heat through exhaust (30% as engine cooling and 30 to 40 % as environment through exhaust gas) and the temperature of the exhaust system is very much in favor of installing thermoelectric energy generator module without disturbing the functionality of the whole exhaust system..

2.3.1 Solar Power

Nowadays solar electricity has many applications starting from household use to space vehicles. According to the U.S. Department of Energy, more than 30 states have the capacity to add excess electricity to national grid produced by PV systems after fulfilling the normal household requirements [32].

A solar panel is made of photovoltaic cells and sunlight is directly converted to electricity due photovoltaic effect. The generation of a voltage difference at the junction of two different materials in response to visible or other radiation by the following three steps:

(a) Absorption of Light – Generation of charge Carrier

(b)Separation of charge carrier

(c)Collection of the carriers at the electrode

The total system consists of mainly three different module which are module that convert sunlight to electricity, inverter module that converts DC current to AC current, and support module which consists of circuit breaker, wiring, battery for storage and support structure. Figure 5 shows a typical block diagram for solar energy generation of a solar panel. PV cells which are made of P-type and N-type silicon absorbs photons which heats the electrons loose in a silicon when sunlight impacts the PV cells. The electrons that make up the difference in P-type and N-type silicon on both sides coming into contact with each other and therefore, the electric field will occur between them and finally will result in the separation of two sides. Electrons are pushed from the P-type to the N-type with the electric field. Therefore, they restrict them to flow in reverse direction and thus produce DC current. Anti-reflective coating is used to prevent total reflection of sunlight from the glossy surface of silicon. Finally back electrode and front electrode is used to connect the required load to a solar panel.

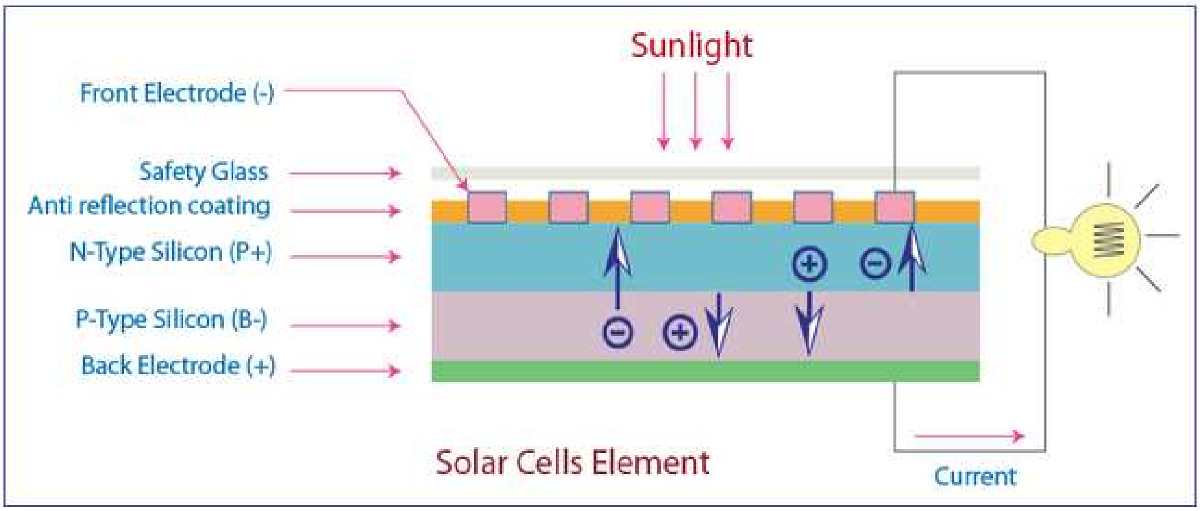

Figure 5.Principles of Solar Electricity Generation [33]

There are many factors that affect solar energy generation. First of all solar energy generation is highly dependent on the weather condition and therefore, geographical location is very important for solar energy generation. Also factors like fog, smoke, snow etc. also affects the solar energy generation. Solar energy generation is directly proportional to the light intensity of solar power. The standard to measure intensity is in clear weather without cloud and smoke and also measured in sea level and the sun is perpendicular to earth's surface. The power (P) generated by the solar cell depends on the solar irradiance (S) which is measured in watt per square meter and the area of the solar cell (A) as shown in equation (1).

$$P = S / A \quad \text{--} (1)$$

Another important factor that affects solar energy generation is the angle between the solar module and the sun. The power density of the sunlight is at maximum when the absorbing surface of solar energy module is perpendicular to it. Therefore, to get the maximum power output it is also very important to know the geographical location where it will be implemented. The radiation incident of a tilted surface (S_{module}) is calculated either by solar radiation measured on horizontal surface ($S_{horizontal}$) or by measured radiation on perpendicular to the sun ($S_{incident}$) as shown in Figure 6.

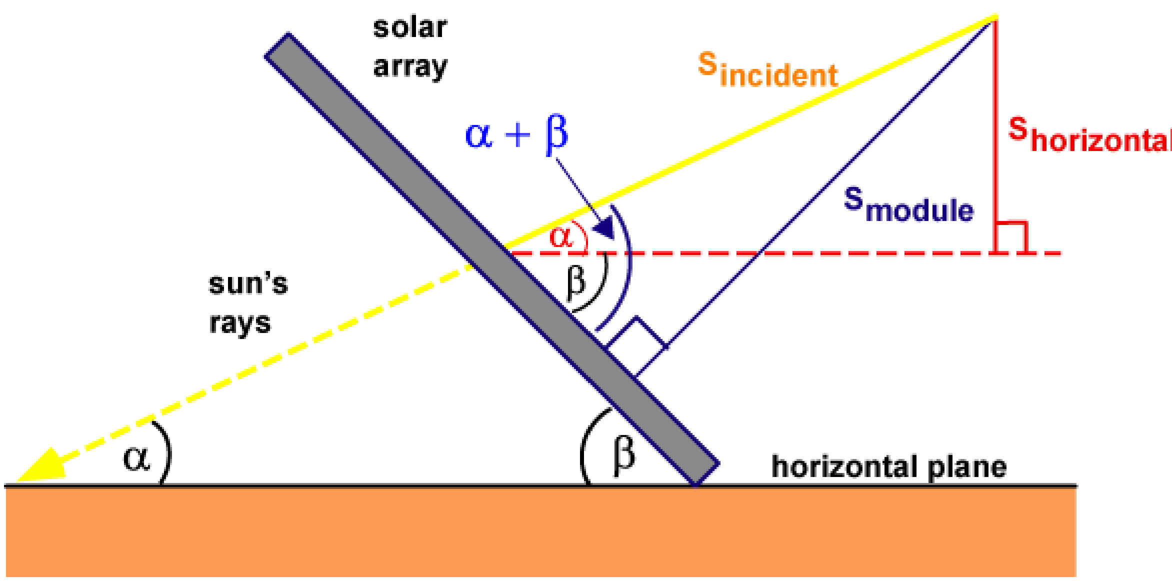

Figure 6. Solar Energy Dependency on Array Tilting [34]

The equation relating to S_{module}, $S_{horizontal}$ and $S_{incident}$ are given in following equation no (2) and (3).

$$S_{module} = S_{incident} \, \text{Sin} \, (\alpha + \beta) \quad \text{--} (2)$$

$$S_{horizontal} = S_{incident} \, Sin\alpha \quad \text{--} \quad (3)$$

where,

α = The elevation angle

β = The tilting angle of the solar module measured from the horizontal plane

Finally the solar energy generation also depends on the temperature. The DC current produced doesn't change with temperature but the voltage generation is reduced with the higher temperature. The standard of the effectiveness of a solar cell is given at 25° C and on an average voltage drops 0.5 % with the increase of 1° C. Solar energy generation is also affected if there is any dart or snow covering the surface of the solar panels but it can be easily eliminated by time to time inspection.

2.3.2 Thermoelectric Energy Generation (Peltier Cell)

Thermoelectric generators are solid state heat devices capable of converting heat to electricity and other way round. These devices work based on thermoelectric effect known as Seebeck effect. The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. If the two conductors or semiconductors are connected together through an electrical circuit, direct current (DC) flows through that circuit. The total system is built by connecting the n-type and p-type semiconductors in series. Free charge carriers known as electrons or holes are carried from hot side to cold side as heat flows from hot to cold side. The temperature differences between hot and cold side determines the voltage generation of the system. Figure 7 shows the a typical thermoelectric energy generator working principle.

The voltage (V) and current (I) generated by thermoelectric generator is dependent on the temperature difference of hot side (T_2) and cold side (T_1), load resistance (R_L), Seebeck coefficient (S) and the internal resistance (R_C) as expressed in equation (4) and (5).

$V = S * (T_2 - T_1)$ -- (4)

$I = S (T_2 - T_1) / (R_L + R_C)$ -- (5)

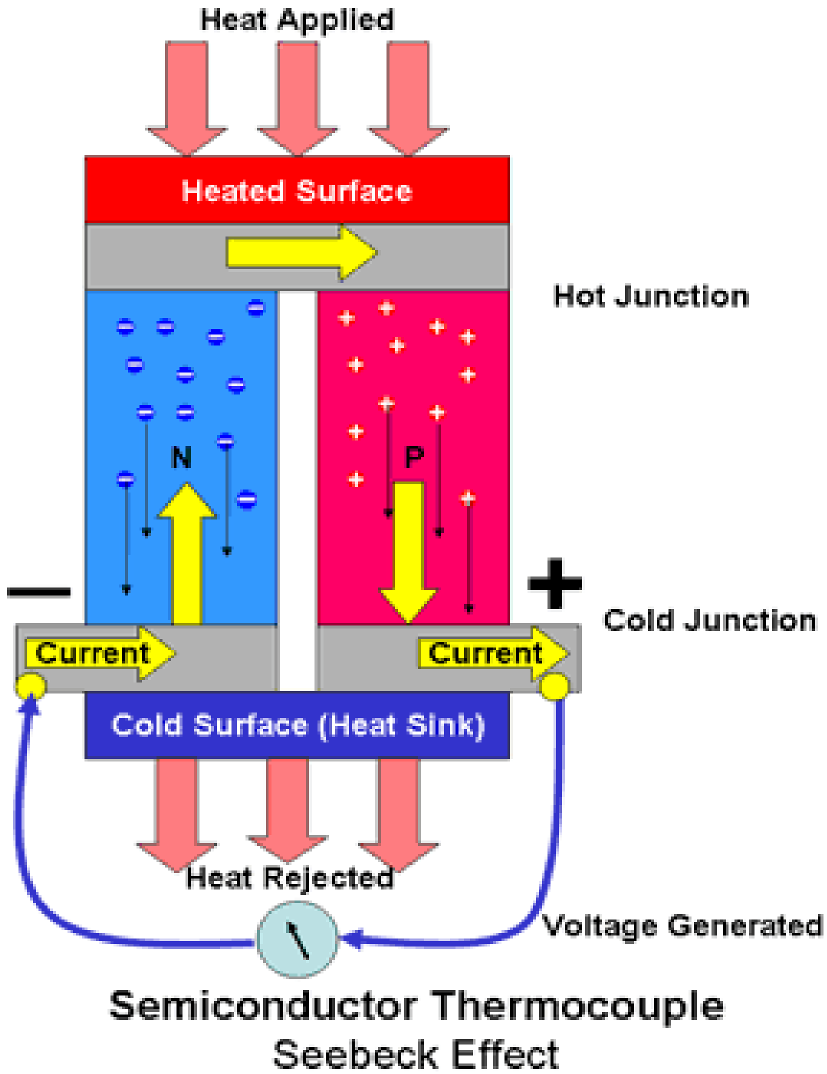

Figure 7. Working Principle of Thermoelectric Generator [35]

In our APS for HEV we have decided to use TEGs in exhaust system because approximately 40 % [31] of combustion energy is lost through this system. But placing the TEGs in proper area of an exhaust system is very critical. Three places can be chosen to place TEGs. One is right in the beginning of the exhaust system after combustion. One is in between catalytic converter (CC) and muffler and finally the other place is to put them after muffler which is the end of an exhaust system for a car. But due to environmental regulations and to prevent backpressure the CC must be working without any interrupt and to work CC flawlessly it requires certain temperature. Therefore, we cannot put TEGs right at the beginning of the exhaust system. Again to generate significant amount of electricity by TEGs we also need certain temperature difference otherwise we will not be able to get desired amount of voltage and electricity which can be usable in car. That's why we also cannot put TEGs at the end of the exhaust system as well. Therefore, the best place to put TEGs is in-between CC and muffler to provide best working environment for both CC and TEGs. Also Liu *et.al.* [36] shows that the average temperature in-between CC and muffler is around 250° C and therefore, we use TEGs which has maximum hot side temperature tolerance limit of 300° C. To produce 14 Volts we need to connect two TEGs in series and therefore, we used four sets of TEGs (each contains two TEGs) in the exhaust system.

2.4 Renewable Energy Storage Module (Supercapacitors)

Supercapacitors are also known as electric double layer capacitors, ultracapacitor or electrochemical double layer capacitors. Supercapacitors are electrochemical devices which are capable of high charge release and deliver high power density within very short period of time. Their ability of store and release quick energy makes them very useful for devices with critical peak power requirement. But now-a-days they are becoming very important for green energy technology because of being capable to store energy very quickly in compare to regular lead-acid batteries. Supercapacitors are consists of two electrodes separated by an electrolyte like conventional parallel plate capacitor. With the increase of the surface are increases the capacitance and also increases with the decrease of distance between two electrodes. When a voltage is applied to the electrodes a double layer is generated in the electrolyte and charge separation occurs and therefore, produces extremely large capacitance.

For our APS we have replaced the lead-acid battery of a car by two supercapacitor banks each contains six supercapacitors to produce required 14 volts to start a car. As supercapacitors discharges very quickly two sets has been used and the properties of a single supercapacitor are given in table-3. By using the supercapacitor banks we also reduce the weight of the car because a regular sedan car lead-acid battery normally weights between 13 to 18 kilograms. But each supercapacitor banks weights maximum of 1.5 kilograms including their mount and other connections. Therefore, just by replacing lead-acid battery we are able to eliminate approximately 15 kilograms of weight and therefore, reduce the fuel consumption of a regular sedan car. The properties of Supercapacitor that have been used in our experiment is shown in Table 3.

TABLE 3

Properties of Supercapacitors

Description	**Value**
Capacitance	350 Farads
Rated Voltage	2.7 Volts
Size (Diameter)	1.3 "
Height	2.3 "
Operating temperature range	-40° C to 65° C
Absolute maximum current	170 amps
Absolute maximum voltage	2.85 Volts

2.5 Simulation Methods

There are eight major steps in simulation methods [37]. they are namely: Define-the problem; Design the study; Design the conceptual model; Formulate inputs, assumption and process definition; Build, verify and validate the simulation model; Experiment with the model and look for improvement; Document and present the result; Define the model of the life cycle. Normally these steps are applied in sequence but it is not mandatory as one can go back to any previous phase to change the scopes, objectives etc. All these stapes are also subdivided into many other steps which help to accomplish the task. A lot of upfront work is necessary to build computer simulation of a given system to make it very successful. Therefore, it is very much necessary to follow the steps and thus minimize the risk of major mistakes.

2.6 Summary

In this chapter we have studied some published articles to know the details of every element that we are going to use for our APS for an HEV. Based on the knowledge we choose the equipment that optimizes our APS. For intra-vehicle communication we find CAN will give us best performance in terms of network latency and cost. We also choose to use solar cell and thermoelectric energy generator as renewable energy sources and supercapacitors for energy storage.

CHAPTER 3

PROPOSED SIMULATION PLATFORM

In this chapter, In this section, we describe our proposed modeling and simulation platform. In order to illustrate the methodology, we consider a system that produces renewable energy and manages an automotive. We use a popular simulation tool, named VisualSim, to model the system and run the simulation programs.

3.1 Target System

The target system has the following major subsystems: (i) Renewable Energy Modules, (ii) Gasoline Energy Module, (iii) Communication Module, and (iv) Management Module. As shown in Figure 8, solar panels and Peltier cells are used to generate renewable energy; CAN, FlexRay, and Bluetooth technologies are considered as the communication module but finally looking to all advantages and disadvantages of the thee communication system CAN has been chosen for our EREMS system; microcontrollers are used to monitor the renewable energy system and manage the whole vehicular system; and energy splitter is used to effectively consume the energy from alternative and traditional resources. The renewable energy generated by solar panels and Peltier cells will be stored in a super-capacitor bank which has a very high charging and discharging rate. Information throughout the system is carried by CAN communication system. The management module is basically a microcontroller that processes the information and makes decisions in real-time. The emergency disconnect controller may automatically disconnect the renewable energy modules (such as solar panels and/or Peltier cells) from the rest of system as fast as needed.

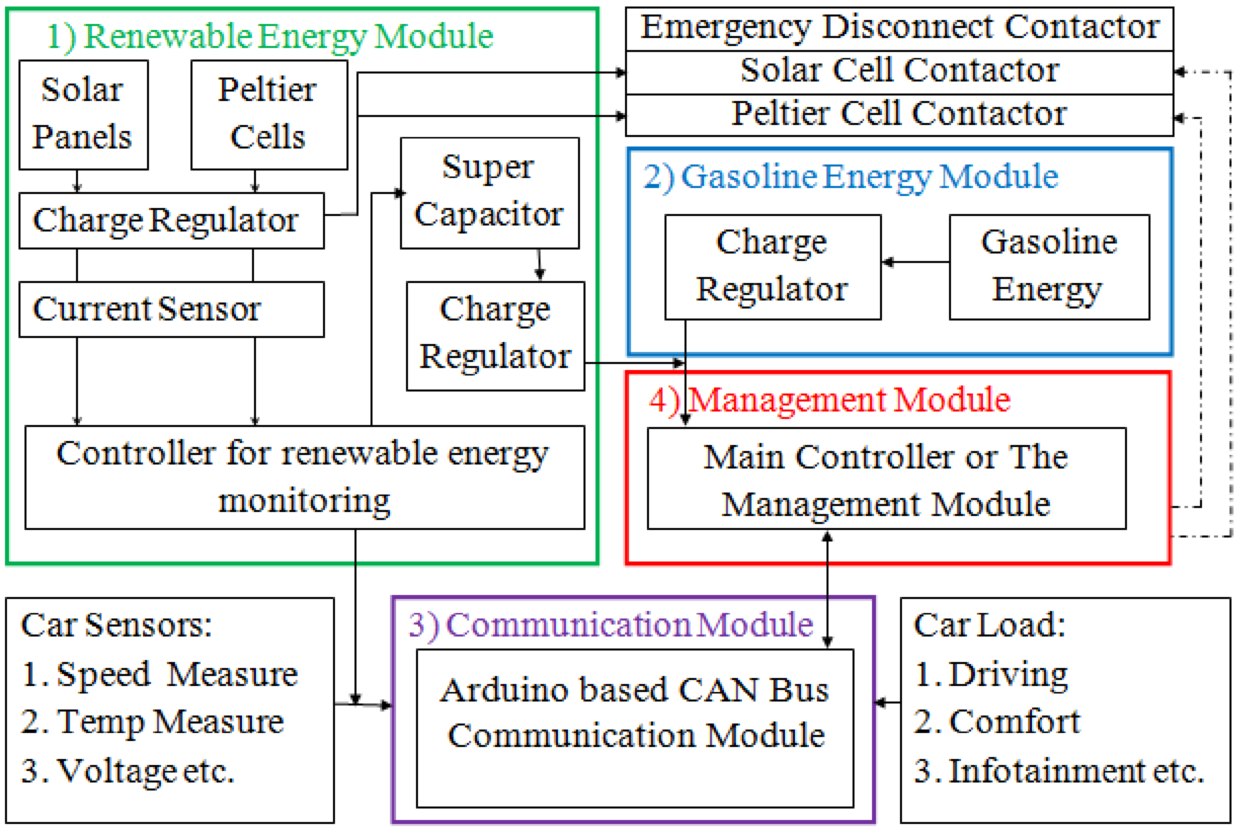

Figure 8. Block Diagram of Proposed EREMS

3.2 Workflow of the Management System

In terms of computation (processing information and making decision) and complexity, the management module is very crucial to design and implement. The workflow of the management system is briefly discussed in this subsection. Flowchart in Figure 9 shows the control logic of the management module of the proposed HEV system. Car status is constantly checked periodically and messages (fuel level, engine speed, etc.) are displayed as appropriate. At each time period, driving load and comfort requests (such as air conditioning, entertainment, etc.) are considered to determine how much total energy is required by the system at that point of time. Then the amount of sustainable and renewable energy (SRE) produced (if any) is considered to determine how much SRE should be used. This process continues until the car is turned off.

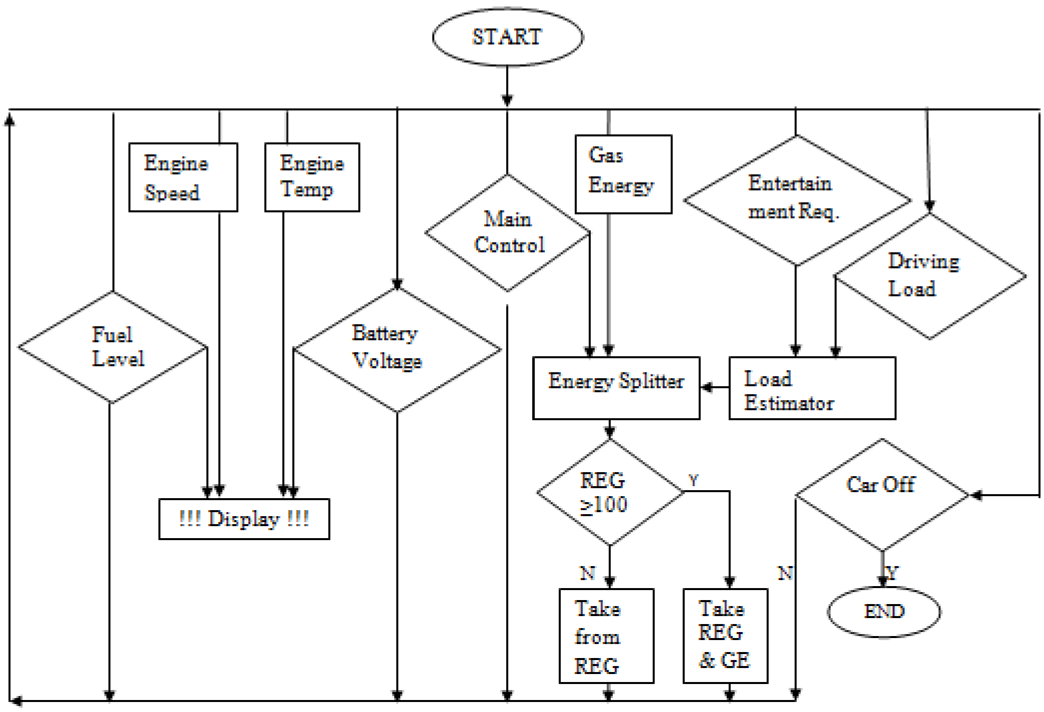

Figure 9. Flowchart of the management module

3.3 Simulation Tools Used

Simulation tool used is VisualSim from Mirabilis Design [5]. The system to be evaluated using VisualSim can be described in three parts – Architecture, Behavior, and Workload. Architecture includes elements such as microcontrollers and CAN bus are specified here. Behavior describes the actions performed on the system. Examples include network traffic shaping. Workload is the transactions that traverse the system such as network traffic. Mapping between behavior and architecture is performed using virtual execution. Connection can be made using dedicated and/or virtual connections. The virtual execution capability makes re-mapping from hardware to software to application specific integrated circuit (ASIC) by just changing a parameter. The output of a block can be displayed or plotted. One of the major advantage of VisualSim is that in every module the simulation platform can be viewed as simulation cockpit. In simulation cockpit every parameters that needs to be changed can be viewed and changed. It is also possible to run and terminate the simulation from the same simulation cockpit view and further results can be seen in both text and graphical form. This makes the simulation platform very flexible to play around with it. Another advantage of VisualSim provides lots of parameterized predefined and precompiled buildings blocks which can be used directly. For example in our for our intra-vehicle communication selection we have used the inbuilt simulation module for FlexRay and Bluetooth to compare them with CAN (Built by us with the help of building blocks). This tool also provide web server (VisualSim Explorer) that enables viewing and analyzing the simulation models within the web browser without any software installation locally.

3.4 Modeling Target System

The components and activities of the target system are grouped into various subsystems (as shown in Figure 8). This is done carefully to simplifying the system without compromising the system properties and scalability. In this work, the target system is modeled using VisualSim development blocks and libraries. The high-level VisualSim model consists mainly of the subsystems and the connections among them. As shown in Figure 10, high-level VisualSim model includes renewable energy, gasoline energy, communication, management, and other subsystems. Each subsystem is represented by a VisualSim block and each connection is represented by a solid line. Each subsystem-block in Figure 9, shown in green color, is a hierarchical block and consists of many components and related activities.

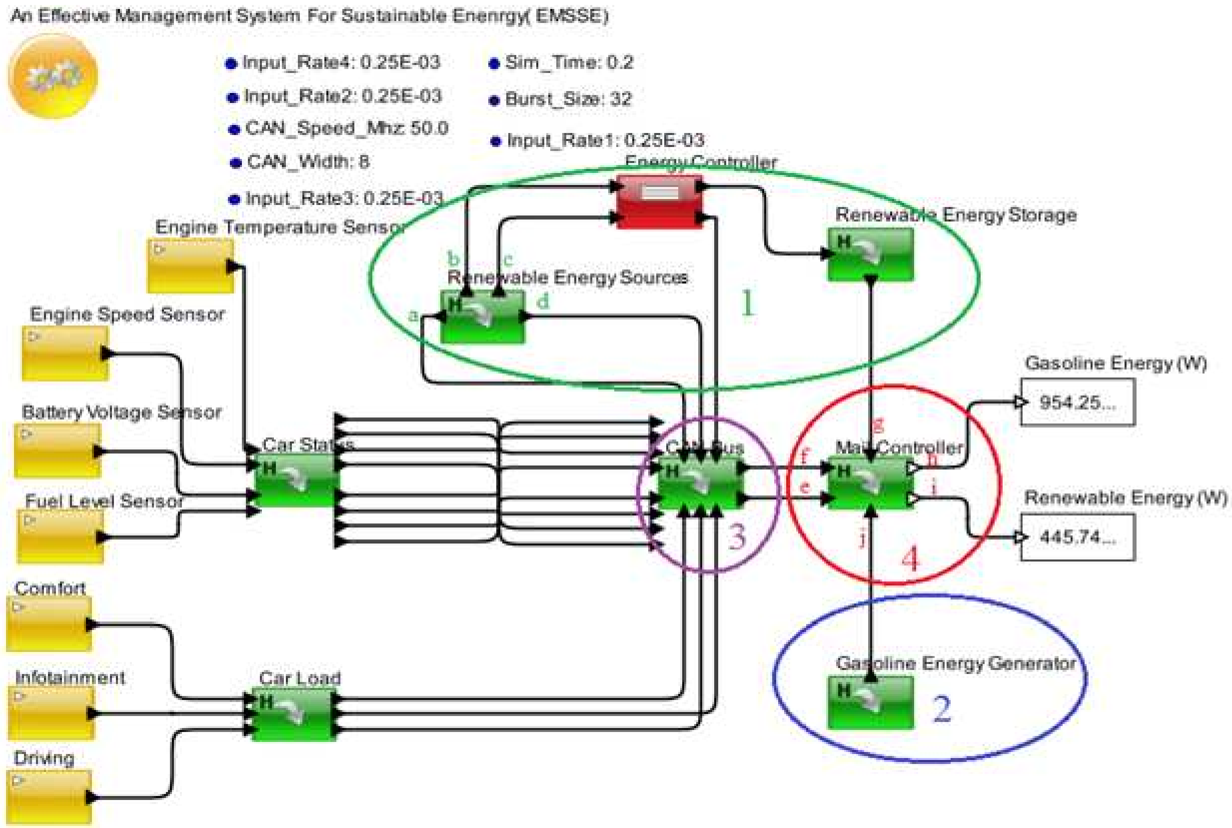

Figure 10. Main Simulation Platform of the Proposed EREMS

3.5 Simulating the Model

VisualSim models are used to develop simulation programs. Additional VisualSim development blocks such as Digital Simulation and Traffic Generator are added to run the programs. First, each VisualSim model represents a subsystem (as shown in Figures 8) is debugged and tested individually. Then the high-level VisualSim model represents the whole system (as shown in Figure 10) is debugged and tested. Similar to block diagram four major sections is shown in simulation platform which are renewable energy module, gasoline energy module, communication module and management module. Each module here is shown by a hierarchical block (Figure 10). If we dig down each hierarchical block we will find further details of different modules which could consists of few more hierarchical blocks as shown in Figure

11. For example, if the hierarchical block in renewable energy generation module block is being opened we will see two other hierarchical blocks named Peltier cell power generation and solar cell power generation. Further digging deeper into solar cell power generation we will find the module that is shown in Figure 12. In Figure 13 we see two output lines comes out as 'a' and 'c' which are power generation information fed to CAN and renewable energy controller respectively are exactly same as shown in Figure 10 in renewable energy sources module.

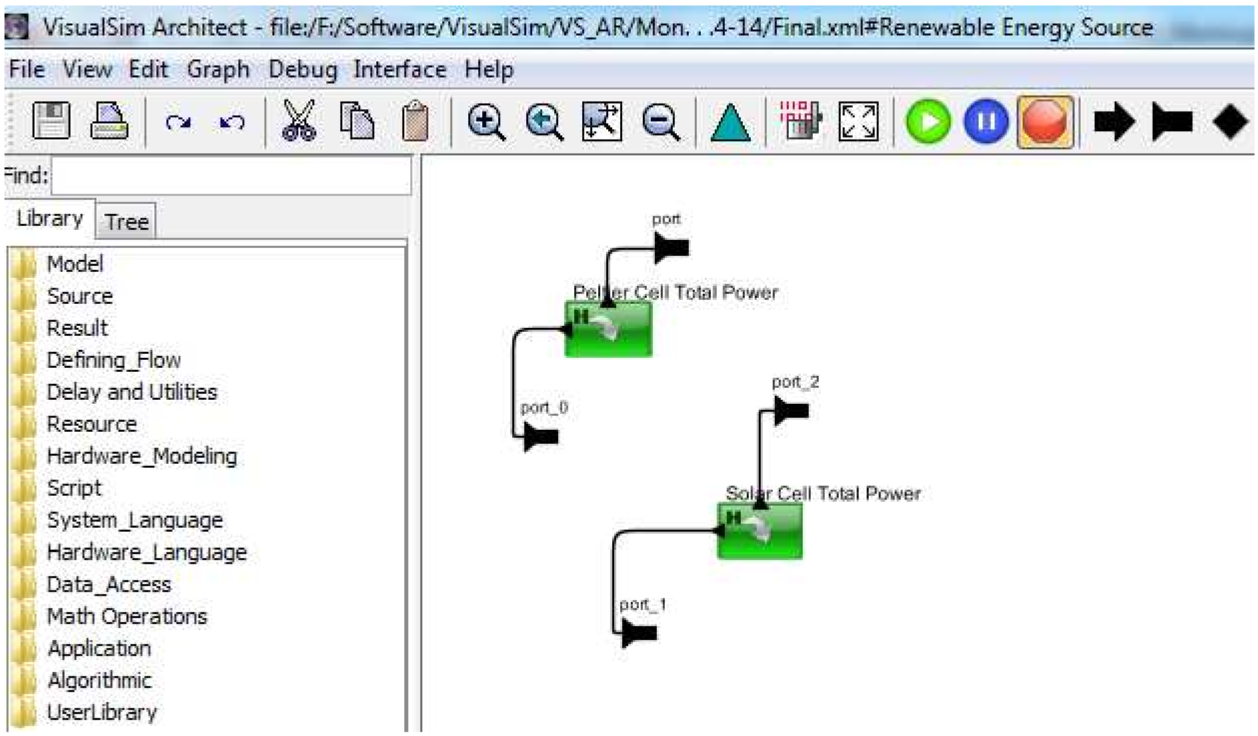

Figure 11.Multiple Hierarchical Blocks under Single Hierarchical Block

Likewise if other hierarchical block like car status, car load, CAN bus hierarchical blocks are opened we can see the detailed simulation design for those. In this work, we use four traffic generators to represent car status and three traffic generators to represent car load information. CAN, FlexRay, and Bluetooth technologies are considered to implement the communication module. Finally we see the for our renewable energy management module CAN gives the optimized solution as it is faster enough for the required communication time and is also cheap in comparison to FlexRay or Bluetooth. Detailed description of each module has been discussed in the following subsections.

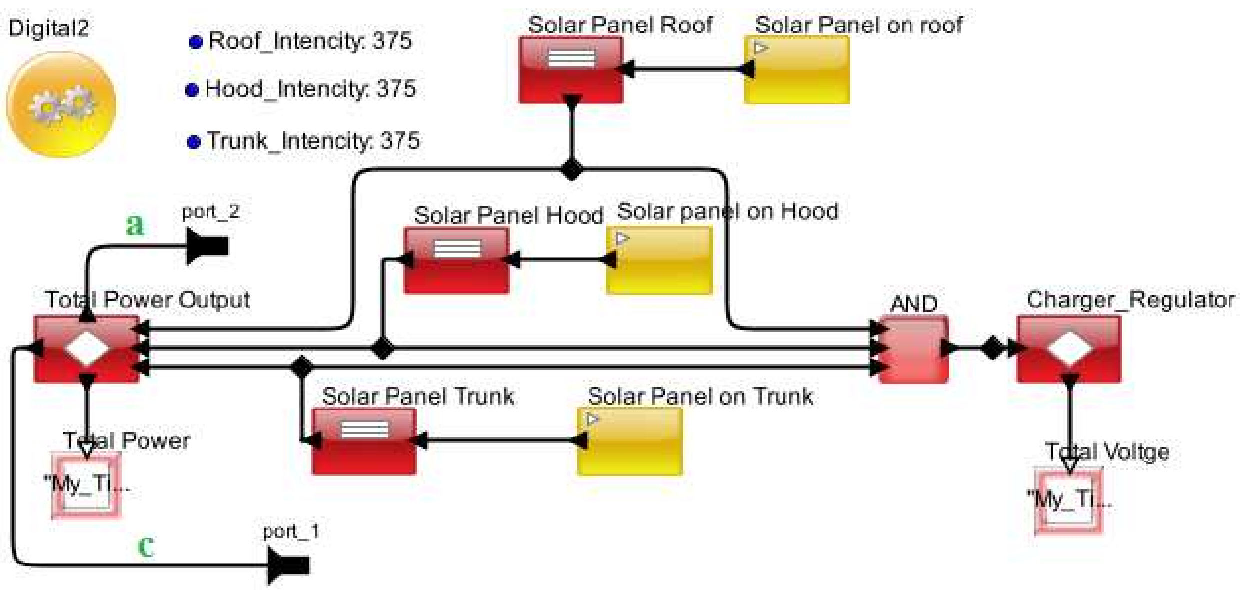

Figure 12. Detailed Simulation Platform of Solar Energy Module

3.5.1 Solar Energy Module

Solar energy generation module has three different energy generation part on hood, roof and tank as those are the areas where solar energy generation has been considered in our EREMS system. All the solar energy generation parts are also connected to charger regulator to control the required voltage output to charge supercapacitors. They are also connected with three different transaction sources to produce continuous energy generation information and feed to the final processing unit which is the total output power block. Finally the total output power block sums up all three generation sources and then total power, total voltage and total current information is send to CAN and renewable energy controller module by using port_1 (C) and by port_2 (a) respectively. Figure 11 shows the detailed simulation platform for solar energy generation module.

3.5.2 Thermoelectric Energy Module (Peltier Cell)

The voltage and current generation of Peltier cells depends on the temperature difference on hot side and the cold side of the system. But for current generation only it also depends on internal resistance and load resistance. Therefore, in Peltier cell energy generation module we see the transaction source of hot side temperature, cold side temperature and internal resistance to calculate the amount of energy generated throughout the simulation process. Finally the output is given to output power block from. From the output power block the information is sent to renewable energy controller and CAN by output port namely port (b) and port_0 (d) respectively. Figure 13 shows the detailed building block of Peltier cell energy generation module.

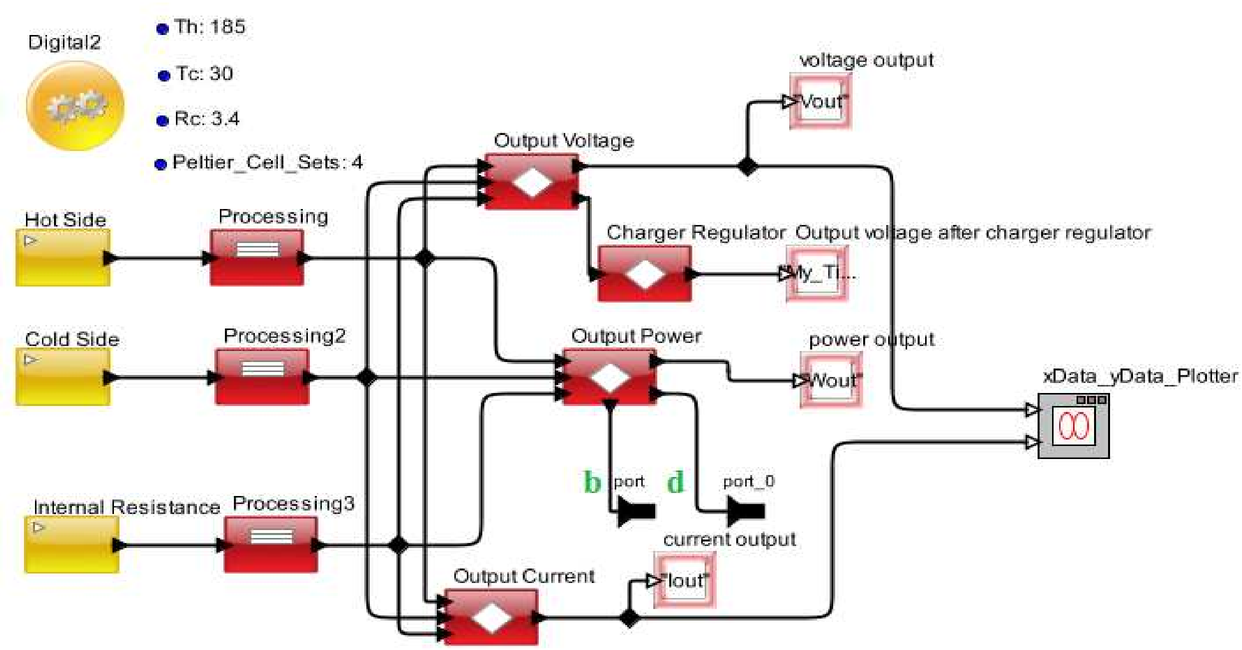

Figure 13. Detailed Simulation Platform of Peltier Cell Energy Generation Module

3.5.3 CAN Module

CAN is the most complex looking simulation platform of all modules in our EREMS because all the information transmission between renewable energy generation module, gasoline energy generation module, controller module and also car parameter measurement is sent through CAN. From CAN we also have a data display block from where anyone can see the actual data or energy generation, car load information, car status information etc. To transfer all the message generated in the car single CAN_Bus area network has been designed. CAN also has two other component namely mapper and smart timed resource to prioritize and control FIFO of all the messages generated by the whole system. Figure 14 shows the details of building blocks for CAN for intra-vehicle communication.

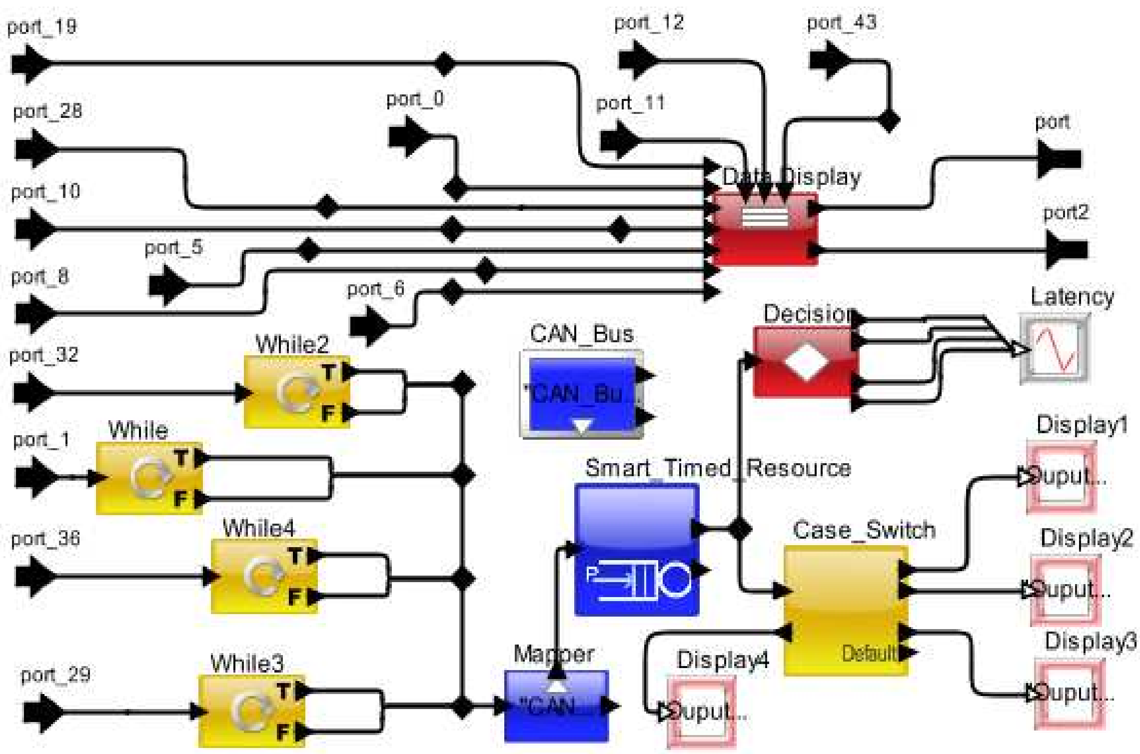

Figure 14. Detailed Simulation Platform of CAN Module

3.5.4 Main Control Module

Main Control module is solely responsible for controlling the total EREMS. This consists of four main processing units shown in figure 15. One unit processes all the information coming from renewable energy generation module through port_7. Through port_1 and port_2 comes the information of car status and car load information to the main controller. Looking at all the information that the main controller tries to maximize the utilization of renewable energy and takes rest of the energy from gasoline energy generation module through port_5 and finally energy splitter gives out required energy from both the sources through port_0 and port_8.

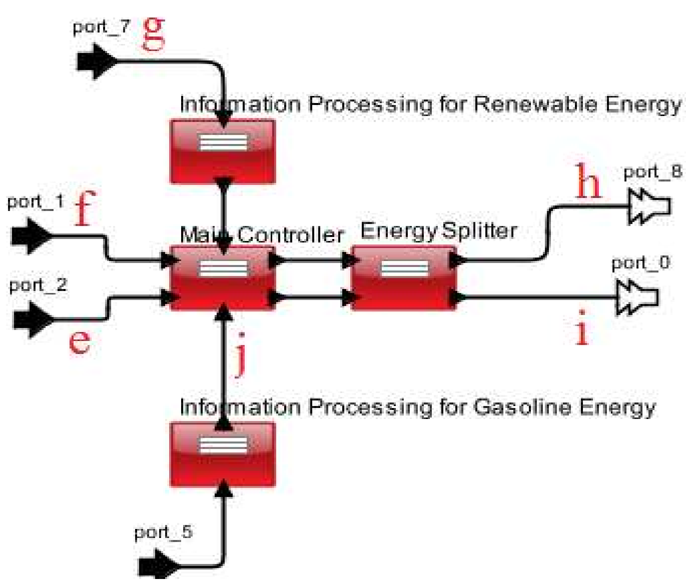

Figure 15. Details of Main Control Module

CHAPTER 4

EVALUATION

We evaluate the target vehicle system with alternative energy sources (shown in Figure 1) by using our proposed modeling and simulation platform. Important assumptions, parameters, and VisualSim simulation cockpit are briefly described in the following subsections.

4.1 Assumptions

The following assumptions are made for evaluating the proposed modeling and simulation platform.

- Two non-traditional alternative energy sources (solar panels and Peltier cells) are considered as a proof of concept. Other alternative energy sources (such as wind and biomass) may be added as needed.
- Non-traditional alternative energy sources may be completely deactivated and/or provide no energy at all.
- Monitoring microcontroller in the renewable energy module is dedicated to determine how much renewable energy is generated and send that information to the main controller in the management module.
- The only responsibility of the emergency disconnect controller is to inactivate any alternative energy module as needed. Therefore, it is not considered in this work.
- The vehicle is assumed to have enough gas all the time to provide 100% energy, if required, to operate the vehicle.
- Only management module can make any crucial decision such as how much renewable energy should be used.

4.2 Input and Output Parameters

It is important to provide the appropriate input(s) to each module/subsystem in order to effectively use the autonomous energy system. Table 4 summarizes some important measurable system parameters.

TABLE 4.

System Parameters Measured in Different Simulation Module

Module	Input(s)	Output(s)
Solar Panels	Solar intensity	Current, Voltage
Peltier Cells	Hot-side temp., cold-side temp.	Current, Voltage
Communication Module	CAN speed, buffer size	Network latency
Management Module	Available renewable energy, total energy required	Energy needed from gas module

4.3 VisualSim Simulation Cockpit

The Simulation Cockpit provides functionalities (left window) to run the model (simulation program) and to collect simulation results (right window). Input parameters can be changed before running the simulation without modifying the block diagram. The final results can be saved into a file and/or printed for further analysis. As shown in Figure 16, the simulation program can be run for different values of solar intensity due to weather conditions for different solar panels to assess how much renewable energy should be generated and how much gas can be saved. Simulation results can be displayed, saved, and printed as texts and/ bar graph/ Line diagram as needed. Simulation Start time and End time may also be changed as needed. The VisualSim simulation cockpit also provides flexibility to assess the whole system as well as the subsystems.

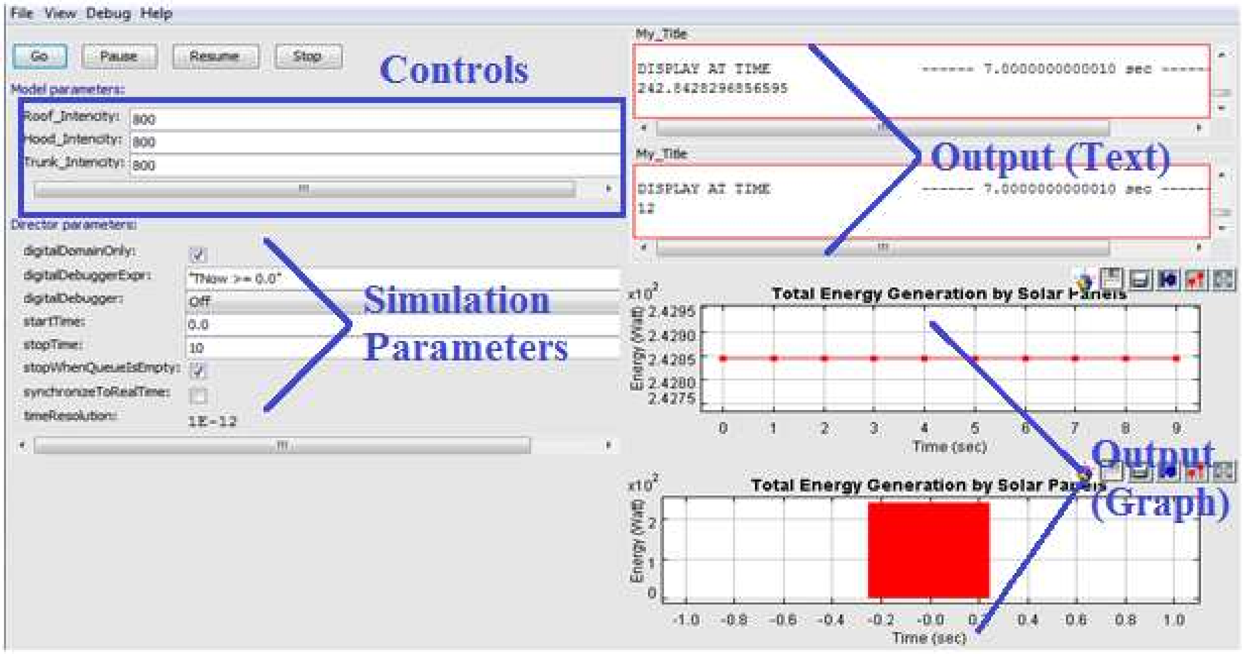

Figure 16. Simulation Cockpit to Run Solar Energy Module

The simulation platform can be failed to execute the whole system for several reasons. For example depending upon the traffic data generation and number of ECU nodes communicating with each other at any point of time, the system may fail. Figure 17 shows that the system failed as the associated queue was full because the transfer because of increasing the data rate from 1600 data/second to 3200 data/second with a payload size of the data is 128 bytes. This is because the data generated by the traffic generators are more than the queue length (buffer size). This experiment helps determine the optimal traffic data generation and queuing buffer size. Likewise other simulation modules can also be failed if parameters are not set properly. Therefore, Visualsim gives very good indication where the system has been failed and why it is failed and therefore, becomes easier for us to rectify the problem.

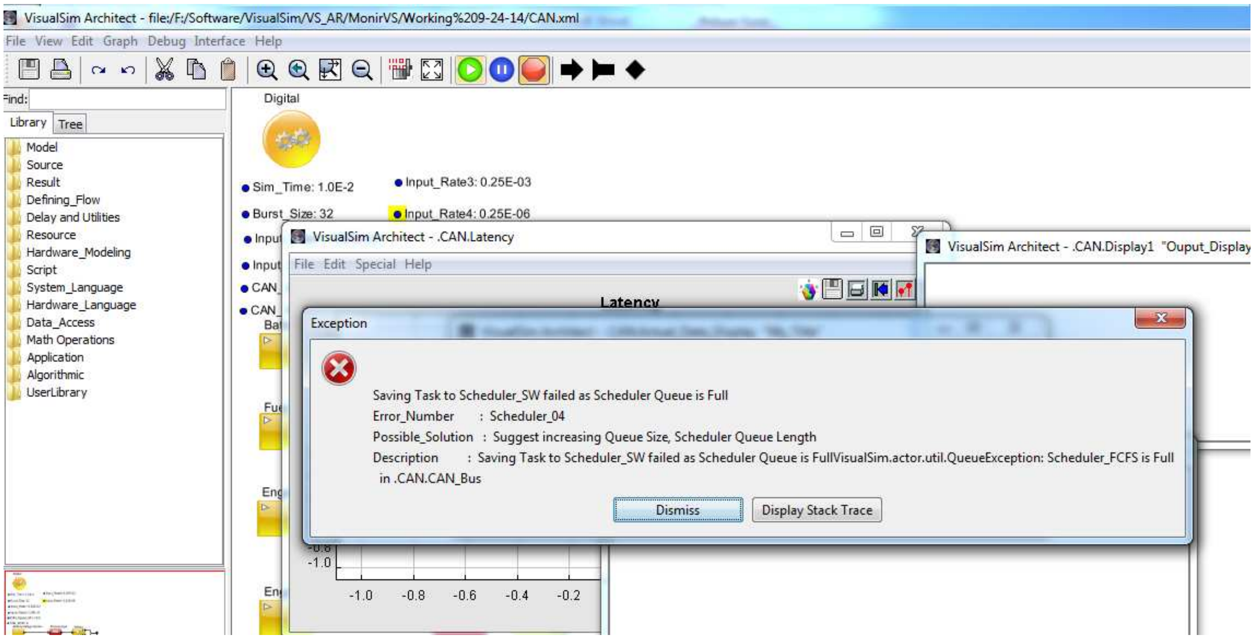

Figure 17.Simulation Failure Message

4.4 Simulation of Intra-vehicle Network Medium

To simulate the intra-vehicle netowrk parameters we uses four different transaction sources as shown in figure 18. The transaction sourcekeeps sending data through all three newtork medium at a consistent rate. It can be observed from the figuer 18 that there are hierarchical blocks named FlexRay, Bluetooth and CAN which was first built individually and tested separately with all transaction sources for their full funtionality. If we dig deeper to that hierarchical block we will see the individual buliding block for all the communicaiton network. After individual test all three newtwork has been combined in one simulation paltform to test them with same data rate generated by the four transation sources. First of all we transfer same data through CAN, flexray and bluetooth to measure their network latency and observe their network network latency and then vary the payload size of the data to observe the failure scenarios for all the communicaiton network.

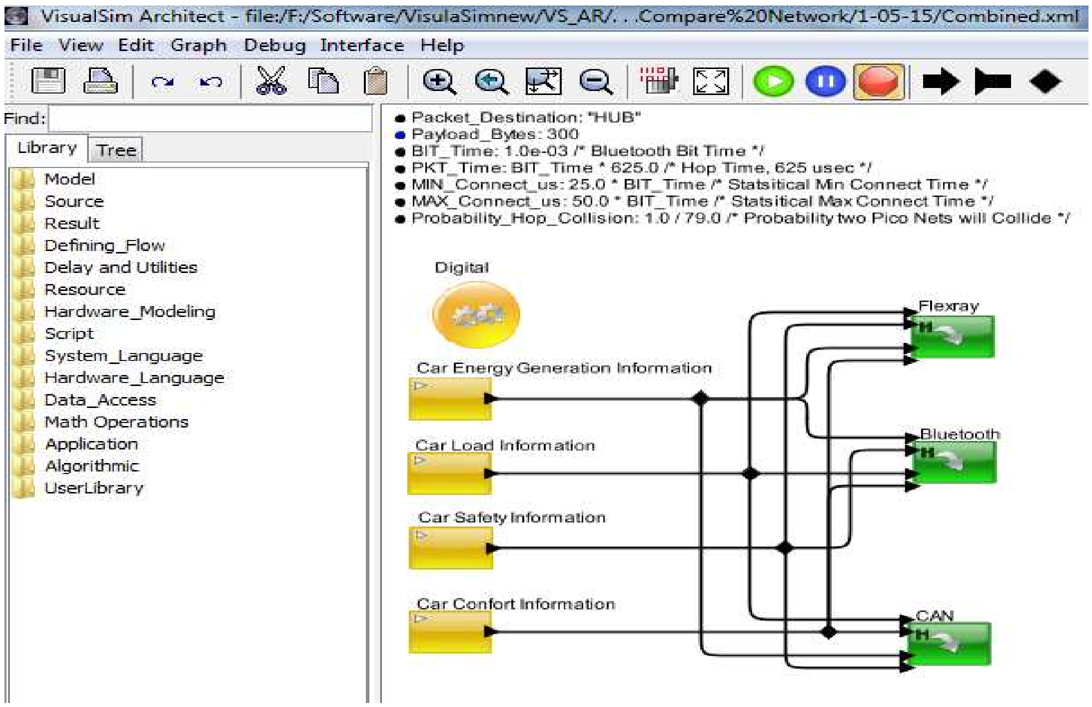

Figure 18. Simulation Arrangement to Compare Intra-vehicle network performance

4.5 CAPPlab EREMS

We have validated our simulation tolls by doing some experiments in CAPPlab. The equipment that we have used for the implemnetaiton of EREMS is whon in figure 19. To do the implementation in CAPPlab we used solar panel and Peltier cell as renewable enrgy sources and supercapacitors as energy storage. We also have used raspberry pi 2 (Model B, starter kit) [38] for main controller and funduinoUNO R3 [39] for the renewable energy module controller. For CAN we used can bus shield [40] along with funduino UNO R3 development board. Based on the enrgy generation from the solar module and Peltier cell we were able to start a regular sedan car and was als able to charge lapto, mobile phone etc.

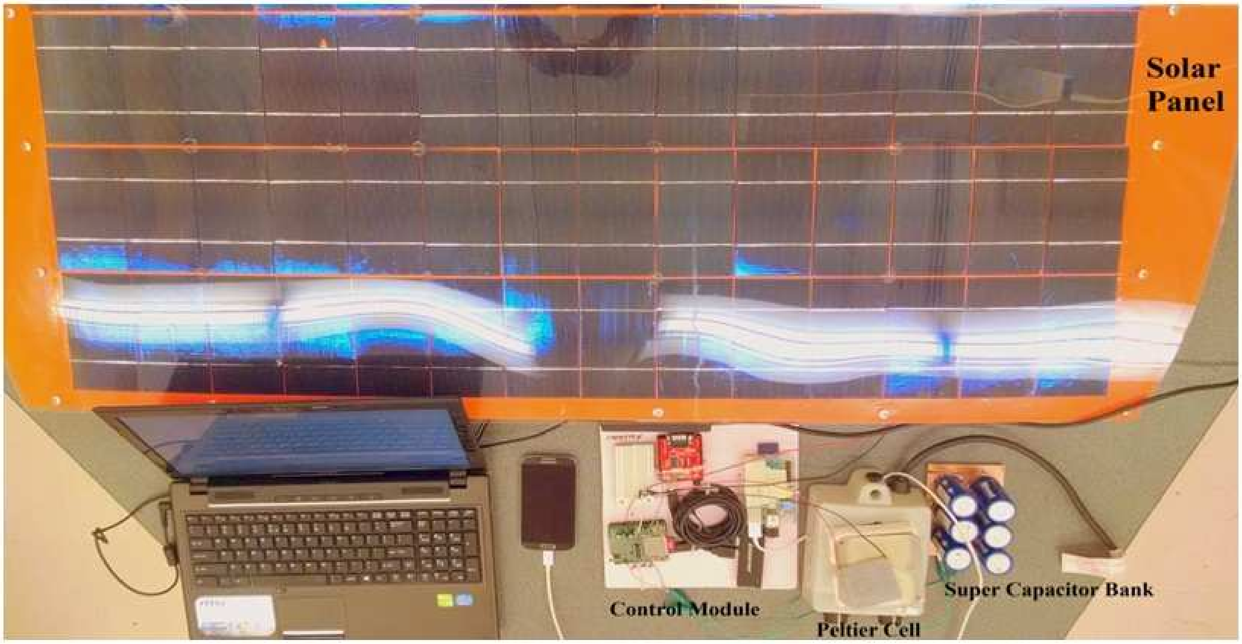

Figure 19. Equipment Used for Implementation Results in CAPPlab

CHAPTER 5

RESULTS AND DISCUSSION

In this work, we develop a modeling and simulation platform to study complex APS for HEV. We study various communication network types for the target system. We consider multiple alternate energy sources in this research. In this section, we present some results showing the network latency due to communication types and energy produces due to solar panels and Peltier cells. All these performance evaluation has been discussed in details in following subsections. Finally, we also do some cost benefit analysis for our proposed EREMS system for HEV.

5.1 Intra-vehicle Network Medium

In this chapter we describe our experimental results in details for all three communication network mentioned above. We use four different transaction sources to transfer required data and measure the network latency. The data rate and the payload size for all three communication network was kept constant as 400 data / second and 100 bytes respectively. The properties of all three communication network during experiments are shown in table 5. These properties has been kept fixed throughout the whole experiment and only the data transfer rate the payload size has been changed to observe different network behavior. We observe that with the change of the payload size and data transfer rate the behavior of a particular network changes from the previous data rate and payload size but all if we compare all three network changes it shows similar pattern that FlexRay remains fastest and Bluetooth remains slowest.

TABLE 5.

Properties of Intra-vehicle Communication Networks

Name	Speed	Queue Length	Topology
CAN	1 mbps	128	Single CAN bus
FlexRay	10 mbps	32	2-channel star
Bluetooth	625 kbps	64	Wireless Master/Slave

5.1.1 Network Latency

First of all we observe the network latency for CAN, FlexRay and Bluetooth for the fixed parameters of data rate and payload size. We observe that FlexRay has the best performance in term of network latency. CAN provides better result over Bluetooth but lags a little behind FlexRay. We also observed that with the increase or decrease of the data payload size, different network latency also increases or decreases but the trends remains the same as FlexRay is fastest and then comes CAN and then Bluetooth. For example For 100 bytes payload size highest network latency for FlexRay, CAN and Bluetooth are 1.335, 4.0 and 15.1 milliseconds respectively. But for 300 bytes payload size network latency of FlexRay, CAN and Bluetooth will be 3.8, 10.0 and 169 milliseconds respectively. Figure 20, 21 and 22 shows the network latency for CAN, FlexRay and Bluetooth respectively. In these figures X- axis represents the simulation time and Y-axis represents the network latency time period. We also compare the network latency by putting all the information in same time frame so that it can be visualized all three communication network on the same platform and decides which one provides better results. Table 6 shows the results of all three communication network in same time parameter.

TABLE 6.

Network Latency of Different Communication Mediums

Description	**FlexRay**	**CAN**	**Bluetooth**
Max. Latency (ms)	1.33	4.0	15.10
Min. Latency (Ms)	0.45	1.0	3.80
Cost	High	Low	Very High

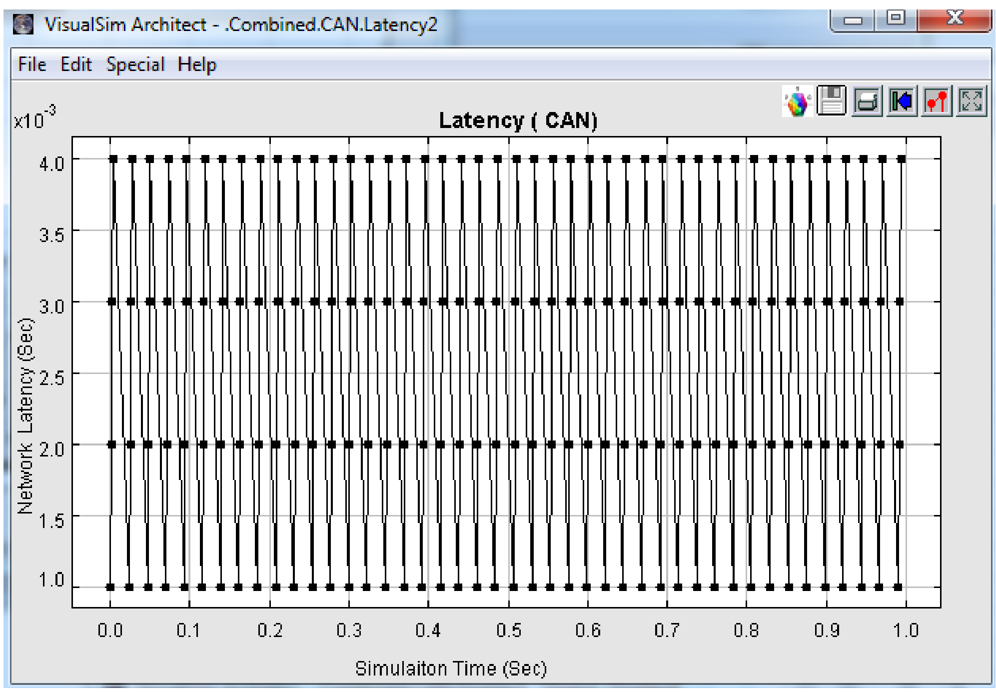

Figure 20.Network Latency of CAN

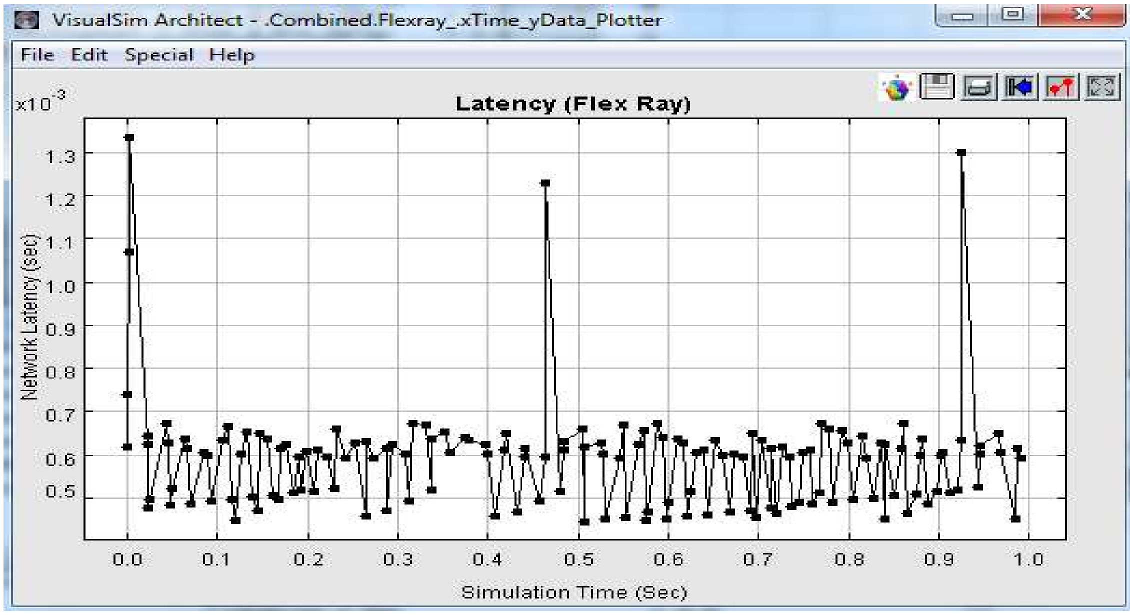

Figure 21. Network Latency of FlexRay

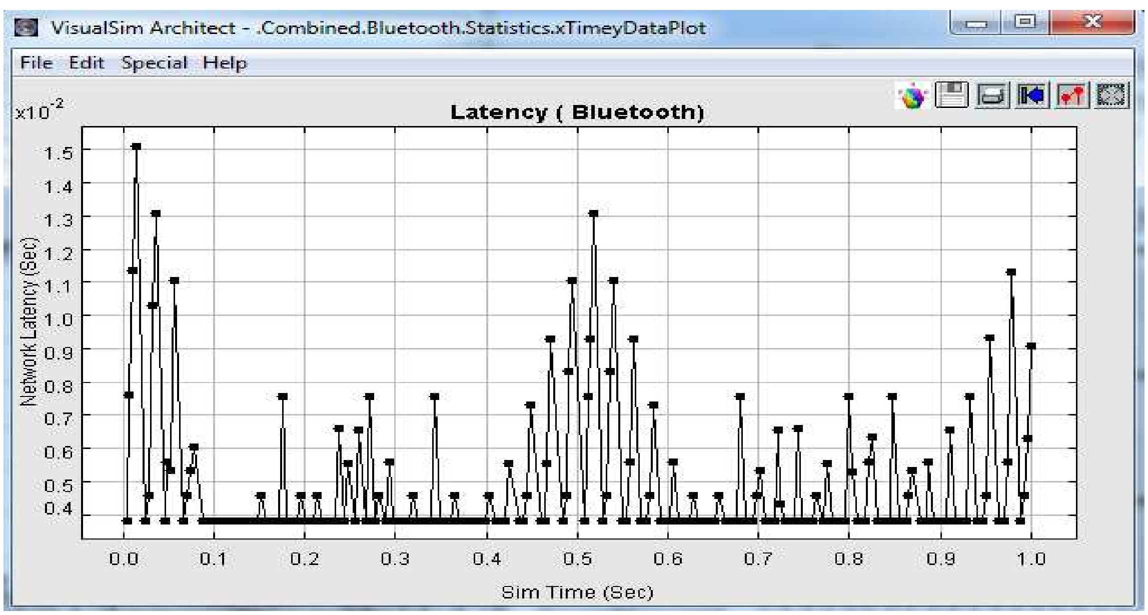

Figure 22. Network Latency of Bluetooth

5.1.2 Other Network Properties

We also have observed other network properties of all three communication network like channel occupancy. We have observed that with the payload size of 100 bytes the channels mostly remains idle in case of FlexRay communication network. Therefore, with the increase of payload size the capacity utilization of this network can be increased. But even with payload size of 100 bytes Bluetooth channels are already bust and having many retransmission of data as the channel is busy at time of transmission. Furthermore we have observed the network failure scenario. For example if we increase the payload size to 600 bytes FlexRay network fails due to smaller queue length. Table 7 shows some other physical parameters of all three communication network that has been considered.

TABLE 7.

Physical Properties of Intra-vehicle Communication Mediums

Name	**Node Control**	**Bandwidth**	**Physical**
CAN	Autonomous	Up-to 1mbps	2- wire (twisted pair)
FlexRay	Autonomous, Master/Slave	Up-to 10 mbps	2-channel, 2-wire
Bluetooth	Master/Slave	Less than 1 mbps	Wireless

5.1.3 Selection of Intra-vehicle Network

By observing all the results it might look like FlexRay is the best option as it provides the lowest network latency. But if we compare all three network as a whole for both performance and cost the scenario might look different cause we see that among all three networks that we have considered Bluetooth is most expensive [41] and therefore, has limited uses in intra vehicular communication like cell phone or in-vehicle infotainment system . But CAN provides relatively high speed data communication and also in the cheapest among the three communication network that we have compared in our work. Therefore, we proposed that CAN will be the best solution for in-vehicle communication for autonomous power system management for a hybrid electrical car.

5.2 Renewable Energy Generation Modules

In this chapter we are going to validate our renewable energy generation modules of EREMES with implementation data. Two different renewable energy generation modules has been designed in our simulation platform; one is thermoelectric energy generator or Peltier cell energy generation module and the other one is solar energy generation module. We validate Peltier cell energy generation module with experimental results done in CAPPlab, Wichita State University, KS. But for evaluation of solar energy generation we have used two different results; one is from the experimental setup in CAPPlab and the other one is the implementation results that carried out in Yoder, KS area. The detailed description of evaluation of both implementation results for renewable energy modules are described in the following subsections.

5.2.1 Thermoelectric Energy Generation Module

Thermoelectric energy generator or Peltier cells was selected to be installation on the exhaust system of a car cause most of the post combustion heat losses occurs in that region Therefore, we created an environment of exhaust system in our lab and tested the output results. We use TEGs which has maximum hot side temperature tolerance limit of 300° C. To produce 14 Volts we need to connect two TEGs in series and therefore, we used four sets of TEGs (each contains two TEGs) in the exhaust system of regular sedan car. Table 8 shows different properties of TEG that we have used to obtain our simulation and implementation results.

TABLE 8.

TEG Properties Used for Implementation in CAPPlab

Description	**Value**
TEG dimension (L X W)	56 mm X 56 mm
Hot Side Max Temperature	300° C
Cold side maximum temperature	100° C
Load Resistance	5.7 Ohms
Matched Load Voltage	7.2 volts
Matched Load Current	3 amps
Open Circuit Voltage	13.7 Volts
Number of TEG in every set	2
Total Number of TEG set	4

We explore the energy generated due to Peltier cells as shown in Figure 23 for both simulation and implementation results. To get those results, the cold side temperature is kept constant at 30 °C and we vary the hot side temperature from 190 to 270 °C. We find it difficult to manage the heat exchange system. Figure 23 shows that the thermoelectric energy generation in simulation is much higher than that due to the actual implementation. This is because the initial simulation uses values from the data sheet specifications from the TGE vendor. Another problem for getting lower results than that of simulation result in this case is failure to keep cold side temperature constant and increase the hot side temperature. But the energy generation trend follows the same pattern in both simulation and implementation results as we can see that with the increase of hot side temperature energy generation increases both cases. Therefore, we can conclude if we can design a good heat exchange system (which we are working on) implementation results will improve.

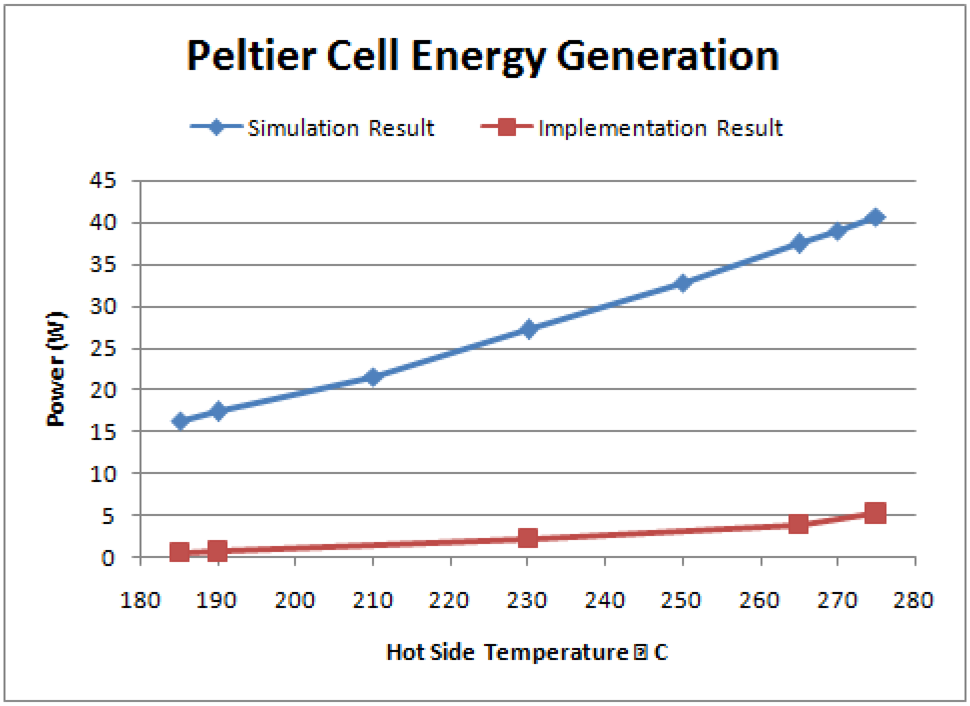

Figure 23. Thermoelectric Energy: Simulation vs Implementation

5.2.2 Solar Energy Generation Module

Similar to that thermoelectric energy we also have implemented solar energy modules in CAPPlab has observed energy generation results in compare to simulation results. We implement solar energy modules on roof, hood and trunk of a regular sedan car and measured the energy output. During the entire implementation the solar panels were kept with a fixed angle which was horizontal north direction. The properties of solar cells and the implementation area are given in Table 9.

TABLE 9.

Properties of Solar Panels and Car Dimensions

Description	Value
Car roof area dimension (L X W)	3.75' X 3.25'
Car hood area dimension (L X W)	4.50' X 2.75'
Car trunk area dimension (L X W)	3.75' X 1.25'
Solar Cell Length	6"
Solar Cell Width	3"
Short Circuit current	3.4 amps
Open Circuit Voltage	0.53 volts
Efficiency	15 %
Number of Solar Cells used in total car	210

Figure 24 shows the comparison between simulation and implementation results in CAPPlab. We observe that the simulation results are higher than the implementation result cause first of all the data used for simulation is from the datasheet supplied by the solar panel manufacturer which is always based on standard condition but for implementation it is always not the case. Another important factor that the solar irradiance data that has been used for implementation is from NREL, Oklahoma location (Explained in details for other implementation result). Therefore, the geographical location is also different for both simulation and implementation results. There are other factors that affect the implementation results is due to error instrumental reading and also issues regarding wiring and soldering of the solar panels as all of them were done manually. But the simulation and implementation results shows the same behavior and therefore, we can conclude that the simulation doesn't provide any ambiguous results.

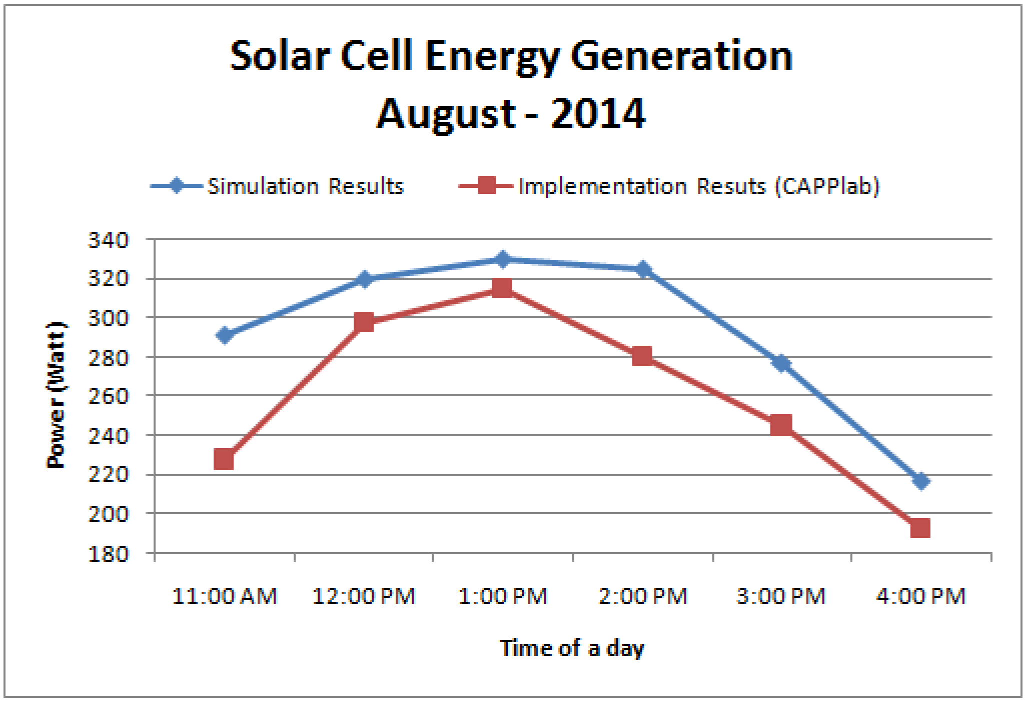

Figure 24. Solar Energy: Simulation vs Implementation (CAPPlab)

Similarly in this work, we use the results from a physical implementation in Horst, Yoder, Kansas area (37.9483° N, 97.8761° W)and the specifications of such solar cells [42]to evaluate our proposed modeling and simulation platform. Results from the actual implementation represent the average values collected in August 2014. As solar cell electrical output depends on the solar irradiance for simulation purpose we use solar irradiance data from National Renewable Energy Laboratory(NREL) which is located in Southern Great Plains Central Facility, Oklahoma (36.606° N, 97.486° W) [43]. It would have been really interesting to find the data for solar intensity where the experimental results has been obtained but the best we could find is from

NREL is not in Yoder, KS but from Oklahoma. Table 10 represents the data used for simulation and experimental results. Only 07:00 AM to 07:00 PM data for the month august has been shown in the table cause before and after that time period the solar energy generation is quite negligible as there is no sunlight in the early morning and late evening.

TABLE 10.

Data Used For Simulation and Implementation (Yoder, KS) Results

	Results From NREL	**Simulation Results**		**Implementation Results**
Hours of Day	*Solar Intensity (W/M^2)*	*Solar Intensity (W/M^2)*	*Total Energy (Watt)*	*Total Energy (Watt)*
7 AM	54	54	213	0
9 AM	381	381	1503	729
11 AM	684	684	2699	2000
1 PM	775	775	3058	2482
3 PM	651	651	2569	2336
5 PM	376	376	1484	1604
7 PM	64	64	252	151

Figure 25 illustrates the energy generate due to solar panels used in the study. It should be noticed that the solar energy due to initial simulation is higher than that due to the actual implementation. Also we can observe that the peak power generation for simulation is around 13:00 PM for simulation results but it is 14:00 PM for experimental result meaning there is a shift of about one hour in peak energy generation. This is due to the cause that simulation results uses values from the data sheet specifications from the solar vendor and it also uses the data of solar irradiance from NREL [43] and therefore, the geographical location is already different from that of experimental geographical location. Also vendor data is based on the best case result of temperature and solar panel angle with respect of sun, it is understandable that as for the experiment was done without controlling the temperature and with a fixed angle the experimental results are low in compare to simulation result. Again as there are factors (such as poor cell alignment, loose wire connections, or weak wireless signal) that negatively affect energy generation. Given all these constraints we find that there is a average 20% error in between simulation and experimental result. Therefore, we will be easily able to estimate the actual amount of energy generation from the simulation result and therefore, will be able to design the solar panels as per requirement.

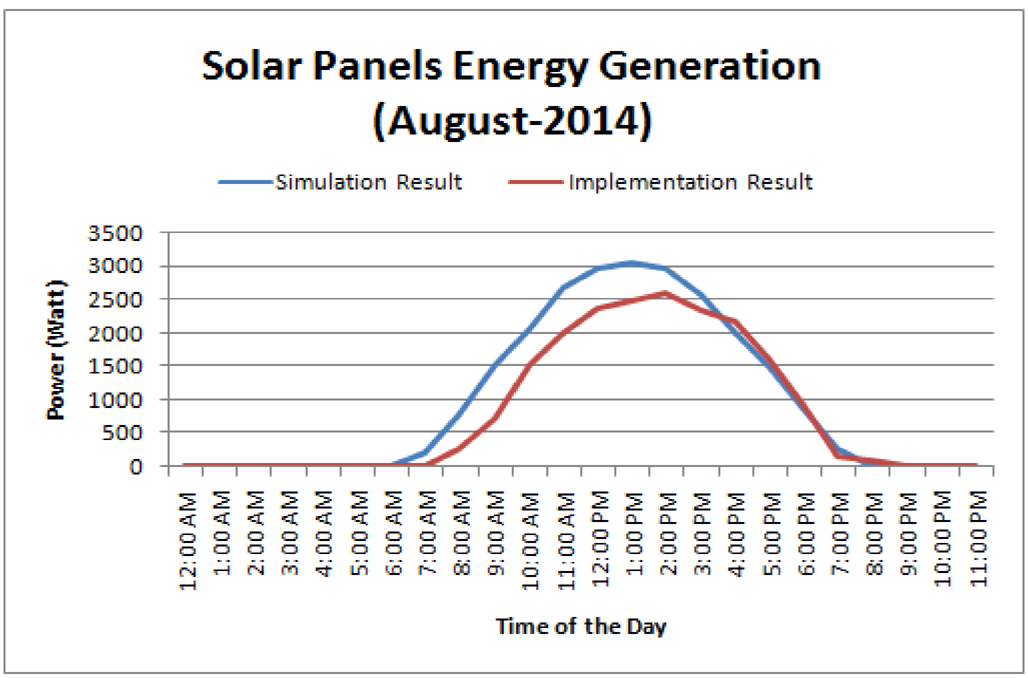

Figure 25. Solar Energy: Simulation vs Implementation (Yoder, KS)

From Figure 25 we see that there is no significant amount of energy generation by solar energy generation module as there is no sun during that period. The most interesting part is from 7:00 AM to 7:00 PM. Therefore, we furthermore analyzed the results of different period of the year rather than August just from 7:00 AM to 7:00 PM. We analyze the total output power based on simulation and as well as experiment for the month of February, May and November. Figure 26, Figure 27 and Figure 28 shows the comparison of simulation and experimental results of the month of February, May and November consecutively. Similar data like Table 11 has been used for comparing experimental and simulation result but the only difference is that in Table 11 data for month of august has been shown and for Figures 26, 27 and28 different data has been used respectively for different months. Again in this case also we see that simulation and implementation results follows close to each other and we observe that there is no ambiguous result obtained by the simulation.

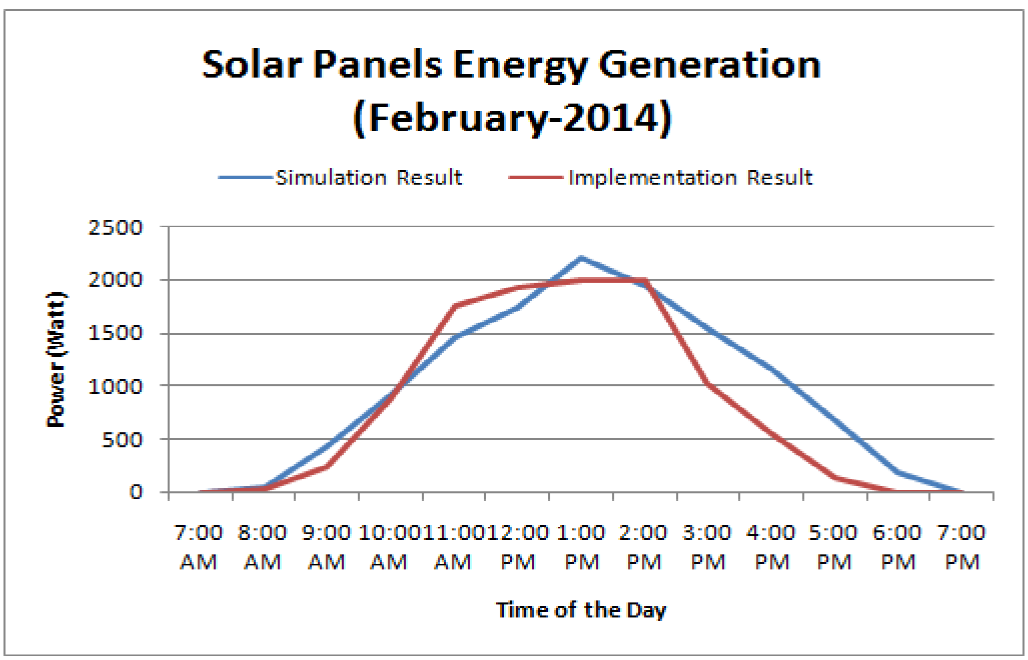

Figure 26. Solar Energy Generation in the Month of February

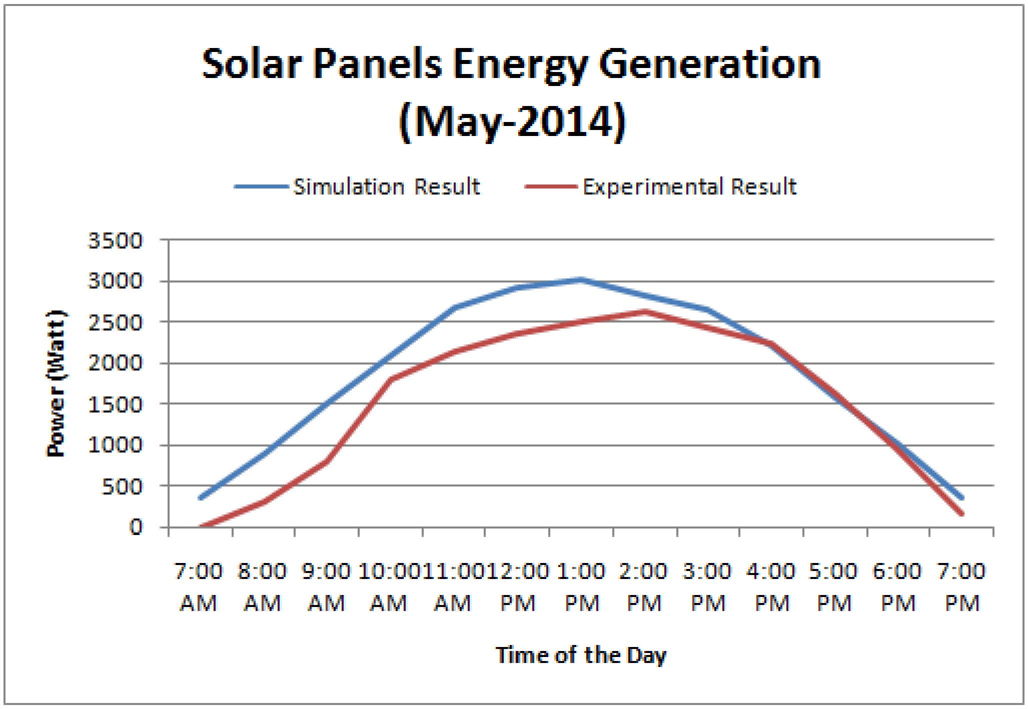

Figure 27. Solar Energy Generation in the Month of May

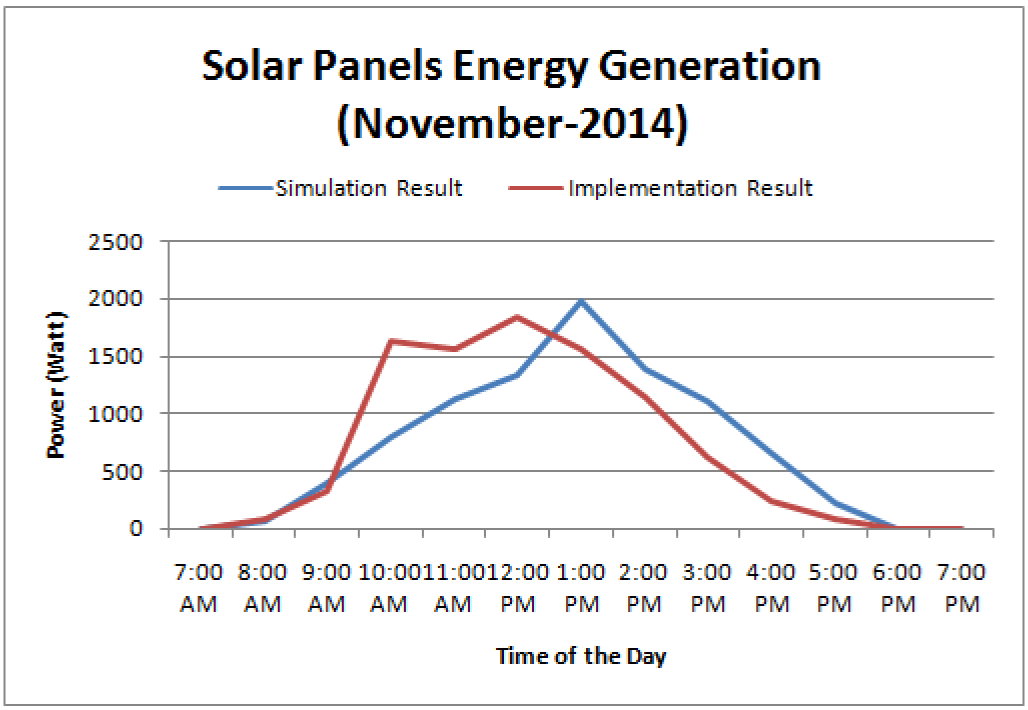

Figure 28. Solar Energy Generation in the Month of November

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPES

We hope the experimental results and discussion presented in this work motivates the interested scholars into considering research in the challenging but prosperous area of renewable energy management systems. Our work will provide very good simulation platform to work on renewable energy management system prior to real implementation which will provide more insight of the whole system. This chapter concludes our work and offers some possible future extensions.

6.1 Conclusions

Modern autonomous power systems are expected to have various sporadic non-traditional energy sources along with conventional energy source(s). Designing such an APS for vehicular and/or household applications also involves many sensors, devices, and computations. In order to provide a standard quality of services, such a system must transfer/process a large amount of data in a real-time manner. Therefore, it becomes very important and challenging to assess such a complex system for feasibility and cost effectiveness. Most contemporary simulation tools solar power simulator and free sun power which are available online for simulation of solar power generation are not flexible: there is no option to add and/or remove energy sources, consumer devices, etc. Also there is no option to control the parameters like area available for solar power generation, solar cell efficiency, light intensity etc. whereas our proposed system has the flexibility to control these parameters and see what happens in overall power generation for changed scenarios. Moreover, to best of our knowledge there is no such simulator available online for the Peltier cell energy generation calculation. In this work, we present an efficient modeling and simulation using VisualSim software technique to investigate autonomous power systems.

Hierarchical models (lower levels to higher levels to very high level) are developed using VisualSim building blocks. Simulation programs are developed using VisualSim libraries. We model and simulate an APS for hybrid electrical vehicle with solar panels, Peltier cells, and gasoline sources. The target APS has sensors to collect information such as available alternate energy, fuel level, and driving status; microcontrollers to process data and make decisions; interconnection network to connect components. We explore CAN bus, FlexRay bus, and Bluetooth in this work. Simulation results show that CAN bus is better than FlexRay and Bluetooth; CAN bus optimizes the communication required by the vehicular system. Comparing simulation results with those obtained through a physical implementation, simulation results are slightly lower than those from implementation. We stay on the conservative side by fine-tuning the simulation programs so that the proposed simulator does not overestimate the alternate energy production. Both simulation and implementation results are always lower than the specification values, as expected. We find the proposed modeling and simulation platform easy, fast, and reliable to assess the components required in autonomous power systems.

6.2 Future Scopes

The proposed method can be extended to offer the following features:

- *Addition of other renewable energy modules:* Integration of other energy system such as wind energy, ocean energy and geothermal energy module in this tool will provide broader opportunity of using our simulation platform for other industries including household uses.

- *Improvement in existing simulation modules:* There are also possibilities to improve the simulation modules. For example, we considered the temperature and the angle of the solar panels to be constant which is normally not the case. This simulation platform can be improved to assess various temperature and angle of solar panel.

REFERENCES

REFERENCES

[1] Kant, Krishna, and M. M. Srinivasan. *Introduction to computer system performance evaluation*. McGraw-Hill College, 1992.

[2] Obaidat, Mohammad S., and Georgios I. Papadimitriou, eds. *Applied system simulation: methodologies and applications*. Springer Science & Business Media, 2003.

[3] Ghanbari, Mohammed, et al. "Principles of performance engineering for telecommunication and information systems." *IEE telecommunications series*(1997).

[4] Reitman, Julian. "A concise history of the ups and downs of simulation."*Proceedings of the 20th conference on Winter simulation*. ACM, 1988.

[5] VisualSim software from mirabilisdesign. http://www.mirabilisdesign.com/new/visualsim/. Last accessed 25th May 2015.

[6] Sims, R.E.H., R.N. Schock, A. Adegbululgbe, J. Fenhann, I. Konstantinaviciute, W. Moomaw, H.B. Nimir, B. Schlamadinger, J. Torres-Martínez, C. Turner, Y. Uchiyama, S.J.V. Vuori, N. Wamukonya, and X. Zhang (2007). Energy supply. In: Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.), Cambridge University Press, pp. 251-322.

[7] "Peak oil definition from Financial Times Lexicon". *Financial Times Lexicon* 2009. Retrieved 26 Aug 2013. Last accessed 20th February 2015.

[8] Rogner, H.-H., F. Barthel, M. Cabrera, A. Faaij, M. Giroux, D. Hall, V. Kagramanian, S. Kononov, T. Lefevre, R. Moreira, R. Nötstaller, P. Odell, and M. Taylor (2000). Energy resources. In: World Energy Assessment. Energy and the Challenge of Sustainability. United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council, New York, USA, pp. 30-37.

[9] IEA (2010a). Energy Balances of Non-OECD Countries. International Energy Agency, Paris, France. Last accessed 25th May 2015

[10] Budischak, Cory, et al. "Cost-minimized combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9% of the time."*Journal of Power Sources* 225 (2013): 60-74.

[11] Yu, F. Richard, et al. "Communication systems for grid integration of renewable energy resources." *Network, IEEE* 25.5 (2011): 22-29.

[12] U.S. Energy Information Agency (EIA), Monthly Energy Review 2014, Table 3.1,3. 7c, 2014. Last accessed 22nd March 2015.

[13] U.S. Department of Energy. Transportation Energy DataBook, Table 2.5,2014. http://cta.oml.gov/data/chapter2.shtm. Last accessed 15th January 2015

[14] Free Solar Energy Simulation Platform . http://www.solarpowersimulator.com/. Last accessed 30th May 2015.

[15] Free solar energy simulation platform. http://www.freesunpower.com/solar_simulator.php. Last accessed 30th May 2015.

[16] Navet, Nicolas, et al. "Trends in automotive communication systems."*Proceedings of the IEEE* 93.6 (2005): 1204-1223.

[17] A. Albert. Comparison of event-triggered and time-triggered concepts with regard to distributed control system. Embedded world, 17 pp. 235-252. Nuernberg, February 2004.

[18] OPEN Alliance SIG, OPEN Alliance; About, 2012.

[19] AVnu Alliance, No Title 2012[Online] Available:www.avnu.org. Last accessed 10th May 2015.

[20] JasPar, JasPar 2013[Online], https://www.jaspar.jp/english/index_e.php. Last accessed 12th april 2015.

[21] Keskin, Ugur. "In-vehicle communication networks: a literature survey."*Computer Science Report* 09-10 (2009).

[22] Asaduzzaman, Abu, Sandip Bhowmick, and Md Moniruzzaman. "Design and evaluation of controller area network for automotive applications." *American Journal of Embedded Systems and Applications* 2.4 (2014): 29-37.

[23] Xia, Feng, et al. "Feedback based network scheduling of networked control systems." *Control and Automation, 2005. ICCA'05. International Conference on*. Vol. 2. IEEE, 2005.

[24] A.S. Shinde and V.B. Dharmadhikari, “Controller Area Network for Vehicle Automation,” Int’l J. of Emerging Tech. and Advanced Engineering, 2(2), 2012.

[25] Forsberg, Andreas, and Johan Hedberg. "Comparison of flexray and can-bus for real-time communication." *IEEE transactions on industrial electronics* 58.3 (2012).

[26] International Standard Organization. Inhttp://www.iso.org/iso/home/search.htm?qt=17458&published=on&active_tab=standards&sort_by=rel. Last accessed 25th April 2015.

[27] Pop, Traian, et al. "Timing analysis of the FlexRay communication protocol."*Real-time systems* 39.1-3 (2008): 205-235.

[28] Xu, Yi-Nan, Chang-Ha Jeon, and Jin-Gyun Chung. "Design of FlexRay communication network using active star." *Modern Applied Science* 4.4 (2010): p34.

[29] Mohammad, U., Al-Holou, N., “Development of Wireless Protocols for Automotive Applications”, Worldcomp ICWN’07, Las Vegas,pp.

[30] Matthew B. Shoemake, “Bluetooth, Wi-Fi and Coexistence Mastered in Handheld Devices”, Wireless Electronics.

[31] Jadhao, J. S., and D. G. Thombare. "Review on Exhaust Gas Heat Recovery for IC Engine." *International Journal of Engineering and Innovation Technology (IJEIT) Volume* 2 (2013).

[32] Energy Efficiency and Renewable Energy. http://energy.gov/eere/office-energy-efficiency-renewable-energy. Last accessed 20th May 2015.

[33] The basics of solar electricity generation. http://www.cheapsolarpanelssale.com/. Last accessed 15th May 2015.

[34] Solar energy production dependency on solar panel angular position with respect to incoming sunlight. http://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-tilted-surface. Last accessed 20th May 2015.

[35] http://www.mpoweruk.com/semiconductors.htm. Last accessed 30th May 2015.

[36] Liu, X., Deng, Y.D., Chen, S., Wang, W.S., Xu, Y., and Su, C.Q. A case study on compatibility of automotive exhaust thermoelectric generation system, catalytic converter and muffler. In *Case Studies in Thermal Engineering*, 2 (2014) 62-66.

[37] Ulgen, Onur M., et al. "Simulation methodology: A practitioner’s perspective." (2006).

[38] http://www.amazon.com/Raspberry-Complete-Starter-Kit-Model/dp/B00GGM0Y66/ref=sr_1_3?ie=UTF8&qid=1403218832&sr=8-3&keywords=raspberry+pi. Last accessed 15th January 2015.

[39] https://www.foxytronics.com/products/265-funduino-uno-r3. Last accessed 15th January 2015.

[40] http://www.dx.com/p/can-bus-shield-automotive-industrial-control-mcp2515-uno-r3-development-board-black-blue-298645?tc=USD&gclid=CK2H07S158QCFZaKaQodt6IAGQ#.VSV-C_nF-4Q. Last accessed 15th January 2015.

[41] Wolf, Marko, André Weimerskirch, and ChristofPaar. "Security in automotive bus systems." *Workshop on Embedded Security in Cars*. 2004.

[42] Technical Specification of LG Solar Cells. http://www.lg.com/us/commercial/solar-panels/lg-LG260S1C-A3. Last accessed 15th January 2015.

[43] National Renewable Energy Laboratory Oklahoma location. http://www.nrel.gov/midc/arm_rcs/. Last accessed 30th May 2015.

APPENDIX

APPENDIX A

INPACT OF THE SIMULATED AUTONOMOUS POWER SYSTEM

In this work we show that under some certain condition [A-1] up to 25.4 % of total energy requirement can be meet up by using the proposed APS system in HEV. Further we also calculated that on an average considering 20 % less actual generation our proposed APS of HEV will produce 15% of the total energy requirement. The installation cost for all these equipment (solar cells, Arduino controller, Peltier cell, super capacitor banks, etc.) are also less than thousand US dollars which will give immediate payback due to high gas price. Another advantage of using this system will be the CO2 emission reduction. As on average 15% less fossil fuel will be consumed in the proposed system it will also reduce CO_2 emission by 15%. Figure-A1 shows the results of the total energy requirement to run a car and the amount of energy produced by renewable source and the conventional fossil fuel energy source. The solar cells that have been used only 15% efficiency but the amount of energy generation can also be maximized by using higher efficiency solar panels which can be up to 40% [A-2]. The following assumptions have been taken to calculate the energy requirement and amount of energy savings [A-3, A-4]:

1. Basic car alternator gives maximum 100 Amps

2. Car runs at 14 volt

3. Average of sunny day sunlight intensity.

Therefore, we see that if the total energy requirement for a regular sedan car is 1400 Watts [A-3] around 15% of the total energy requirement is generated from renewable energy sources. Figure A-1 shows the energy savings for proposed EREMS.

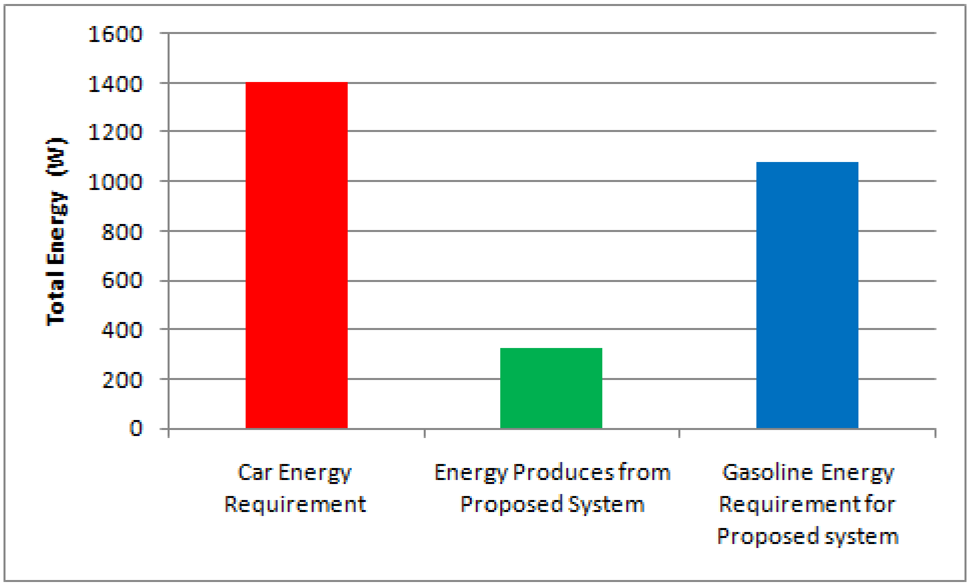

Figure A1. Energy Savings by Renewable Energy for Proposed EREMS

APPENDIX REFERENCES

[A-1] "Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks," http://www.epa.gov/otaq/consumer/420f08024.pdf

[A-2] Razykov, T. M., et al. "Solar photovoltaic electricity: Current status and future prospects," *Solar Energy*, 85.8 (2011): 1580-1608.

[A-3] "Average sedan car alternator amperage requirement," http://www.omallycylinders.com/2012/10/17/how-to-choose-an-alternator/

[A-4] "Yearly sunshine records of different areas in Kansas," http://www.crrentresults.com/Weather/Kansas/annual-days-of-sunshine.php