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A SOLID-STATE DEVICE BASED IMPROVING POWER QUALITY USING DC-DC MMC

NANDAMMAGARI VENKATA SURESH , K.SIVA KUMAR

Abstract— This paper proposes a thermoelectric generator DC micro grids (MGs) have been gaining a continually increasing interest over the past couple of years both in academia and industry. The advantages of converts heat energy into electrical energy. Thermal capacity and heat transfer are major factors which effect on the thermal performance of TEG. As the thermal energy of exhaust gas extracted by thermoelectric modules, a temperature gradient appears on the heat exchanger surface. This project presents for power generation and sensor based solar tracking system to utilize the maximum solar energy through solar panel by setting the equipment to get maximum sunlight automatically. This proposed system is tracking for maximum intensity of light. Then the multifunctional control method is presented, including the virtual impedance-based ripple distribution strategy. The proposed control method is able to balance super capacitor voltage while store the Input Power. The converter topology and control method are validated with simulations and experimental results.

Keywords — DC-DC Converters, Distributed generation, Thermoelectric generator (TEG), Electromotive force (EMF), Energy Storage System (ESS), Maximum power point tracking (MPPT)

I. INTRODUCTION

In recent years, the structure of the electrical power system has changed, and power generation has shifted towards Distributed Generation (DG). Although the increase in the demand for energy and environmental concerns about traditional power generation have been mentioned as reasons for this shift, another crucial motive is the large amount of energy lost in traditional methods: when power is generated from fossil fuels, 40%–70% of the energy present in the resource is lost as heat. Another 2% and 4% is then lost in transmission lines and distribution, respectively. Renewable energy sources like solar, wind, and hydro power is preferred, but it has limited use and depends on law of nature, prevailing weather condition and topography. The thermoelectric generators can utilize waste heat from systems and convert it into electrical energy directly [1]. Thermoelectric power generation is maintenance free, silent in operation as it does not involve any moving parts.

The proposed system using embedded controller for monitoring of parameters at the input side of boost converter and temperature monitoring over the period of time of TEG will improve the performance and efficiency of the system. This proposed scheme is going to be implemented in a practical scenario involving a battery deployed for health monitoring of operators in industries in which toxic gases in some sections are unnoticed but has an influence on health of operators. The Simulation of the system model was carried out and tested with temperature parameter. This autonomous battery powered by exhaust heat which supplies power to medical server through TEG will improve monitoring activities of plant operators. Likewise the battery charged using this TEG based system can also be used for relaying actions, and act as independent source for operating different loads in critical situations.

II. OBJECTIVES OF THE WORK

The objective of this thesis is to design and simulate a high performance DC/DC converter for the purposes of interfacing a battery system with a PV system. The converter should provide a solid dynamic response and transfers power from and to the battery system with high efficiency and fast response to power demand. A battery model will be developed to simulate a real lead acid battery and a simulation of the model will be performed to verify its behaviour compared to a real lead acid battery. A number of converters will be evaluated and compared through simulation and the converter with best performance will be selected for battery interface.

Nandammagari Venkata Suresh , Department of Electrical and Electronics Engineering , Chadalawada Ramanamma Engineering College , JNT- University, Anantapur , Andhrapradesh , India
(Email : sureshnandammagari228@gmail.com)

K.Siva Kumar , Associate Professor , Department of Electrical and Electronics Engineering , Chadalawada Ramanamma Engineering College, Tirupati , JNT- University, Anantapur , Andhrapradesh , India.

The main part of the distributed energy resources of future grids is expected to be connected to the system through power electronic devices. In this doctoral dissertation, the design and operating requirements for the hierarchical control of power electronic devices are addressed. To investigate the hierarchical control of mgs, the dissertation investigates the control of power generation from the zero level up to the third control level. Moreover, different technologies and applications of less in modern grids are analyzed to find the most suitable storage technologies for implementation in mgs. The challenges related to the reliability, sustainability and overall energy efficiency of the electricity distribution network including renewable power generation, energy storage and controllable loads need to be managed in a future Smart Grid. The proper control methods need to be developed by using information and communication technology. The target is to provide uninterrupted and high quality electric power supply to the end customers.

The performance criteria will be based on efficiency, ripple in current, voltage gain and cost. A smart energy management system will be developed to operate as a master controller to coordinate the power transfer between the battery bank, the PV panel, and the grid. The objective of the energy management system is to maximize the power coming from the PV panel, minimize grid power, and minimize the charging and discharging of the battery and protect the battery from overcharging and discharging. It should also coordinate the power flow when the system is grid connected or islanded.

1) BACKGROUND AND MOTIVATION

Renewable energy systems have gained a lot of support from the government and in the past several years because they allow contributing for clean power minimizing fossil fuels consumption, and lowering the emissions greenhouse gases. Solar photovoltaic (PV) installations have been significantly installed all over United States in the past decade [1]. The intermittency of PV power generation is the challenging issue for widespread public acceptance [2]. In order to improve intermittency problem, energy storage systems can be placed to store excess energy and provide it at times of deficiency [3] and improve stability of the micro grid [4]. In order to properly integrate an energy storage system, such as a battery bank, along with a PV installation, a bidirectional power converter must interface the connection to a DC link feeding an inverter. Such battery-based power converter must have high efficiency and provide smooth charging and discharging to extend the life-span of the battery bank. In addition to the power converter, a smart-energy management system is required to coordinate the power transfer from PV as well as the charging and discharging of the battery bank according to the demand and the grid state as well as energy cost. Energy storage systems have proven to be a vital part of any renewable energy system [3] and [4]. In fact, the deployment of more PV installations and wind turbines would require more energy storage systems to compensate the fluctuation in power generation and increase the stability of the system. Therefore, it is vital to have a high performance power converter to interface the storage system with the grid along with the PV system. In addition, a smart energy system is required to increase the system's stability and reliability and provide coordination between different parts of the system.

The focus of this thesis is to design and simulate a Bidirectional DC/DC Converter to interface a battery-bank for a standard residential scale PV installation and develop a smart-energy management system to coordinate the operation of the battery bank along with the PV system, considering the utility grid connection.

2) THERMOELECTRIC GENERATOR

Thermoelectric generator (TEG) is a device works on the principle of 'thermoelectric effect' which directly converts thermal energy into electrical energy [5], [6]. The principle used in TEG is See back effect. See back effect is responsible for electrical power production i.e., it produces an electromotive force (EMF) and accordingly an electric current in a closed loop formed by at least two dissimilar conductors when two junctions are maintained at different temperatures. Thermoelectric generator consists of thermopile sandwiched between two thin ceramic wafers. Thermopile is developed by means of series and parallel combinations of thermocouple which is made up of p-type and n-type semiconductor material. The schematic diagram of TEG is shown in Fig.1. TEG generates electricity when exposed to hot and cold junctions.

The EMF (voltage) produced is proportional to the temperature difference present between the two junctions. The proportionality constant (α) is called as the Seeback coefficient, which is the ratio of voltage generated by the seebeck effect and temperature difference between the two junctions, and it is also known as the thermoelectric power or thermo power[7]. Almost any heat source can be used in this TEG to generate electrical power such as solar heat waste heat from the thermal and biomass power plants etc.

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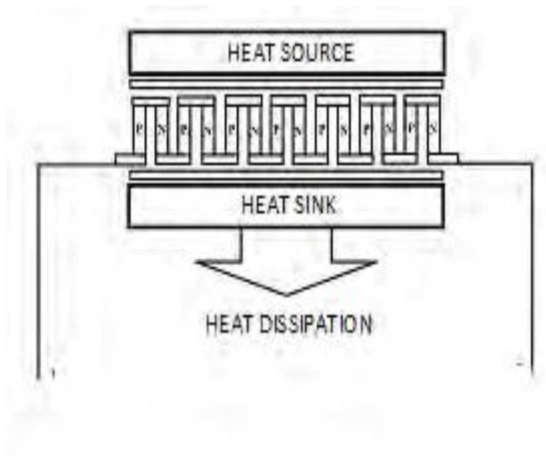

Fig 1. Thermo Electric Generator

Thermoelectric technology has revealed the potential for automotive exhaust-based thermoelectric generator (TEG), which contributes to the improvement of the fuel economy of the vehicles. Thermal capacity and heat transfer are major factors which effect on the thermal performance of TEG [8],[9]. As the thermal energy of exhaust gas extracted by thermoelectric modules, a temperature gradient appears on the heat exchanger surface. In order to achieve uniform temperature distribution and higher interface temperature, the thermal characteristics of fishbone heat exchangers with various heat transfer enhancement features are studied, such as internal structure and surface area. Various thermodynamic cycles have been proposed and studied for waste heat recovery system. In absorption cooling cycles which is used in hybrid and electric vehicles transfer waste heat from the exhaust gases into the boiler of ejector for cabin cooling. The present work reviews the existing exhaust heat exchangers and optimized shape, internal structures of exhaust heat exchanger to find out best heat exchanger to get uniform temperature distribution. In parallel with the improvement of the efficiency of the internal combustion engines, many researchers actively investigate the use of thermoelectric (TE) technology to recover the waste heat energy for gasoline vehicles, and hybrid vehicles. If some amount of the large waste heat could be recovered and converted into electricity, large amount of heat would be saved and the efficiency of vehicle system would increase drastically.

However, this recycled electric energy can be stored in a super-capacitor and reused later or can be used to drive low-power portable electronics such as MP3 players or PDA, which only consume about 110mW and 200mW, respectively [7],[8],[9]. Although the current efficiency of the TEG is low (less than 10%), with the advancement of technology, we can get high efficiency TEGs and use them in a computer to harvest wasted energy from the microprocessor and use it to drive other components. Hence, it is necessary to develop an accurate model for the TEG and the die thermal profile, which can predict its efficiency and detect whether the junction temperature is below a threshold after attaching the TEG.

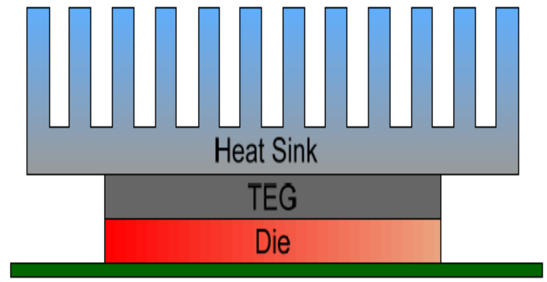

Fig 1(a).TEG integrated on the die. It is placed between the package and the heat sink.

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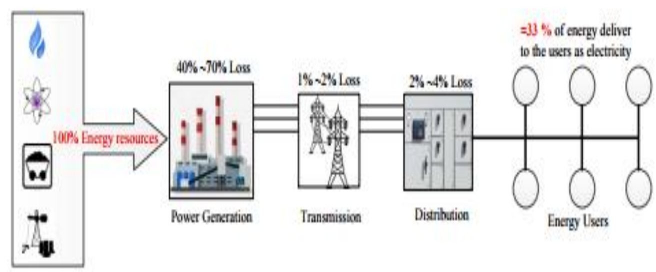

Fig 1 (b). Energy generation and Distribution in traditional grid

The main control objectives in an AC MG are voltage stability, frequency synchronization, loads sharing considering inverter ratings, and managing power to create ancillary services for the main grid. On the other hand, there are some advantages to DC MGs over AC MGs: they are highly efficiency because of the reduction in conversion loss; frequency and phase control is not required, and there is no need for synchronization. Indeed, the main control objectives in DC MGs are adjusting the DC voltage to the acceptable value, sharing power based on the rate of conversion, and regulating the current flow to or from an external DC source.

3) ELECTRICAL POWER PRODUCTION:

Though primarily used as heat pumps, Peltier devices nonetheless generate a thermo voltage, Vth, when subjected to a temperature gradient, ΔT. An electrical current, I will flow if the Peltier device is connected to a load resistor, R load. In this case, the Peltier device converts heat energy to electrical energy quantified by the dissipated power, P = IV load, where V load is the voltage drop across the load resistor. In the laboratory, P can be determined by measuring I and V load. The Peltier device is not an ideal voltage source; therefore, its internal resistance, RI, must be included in the analyses of power data. Furthermore, RI is typically on the order of a few tens of Ohms. Therefore, the resistance of the ammeter, Ra, cannot be ignored.

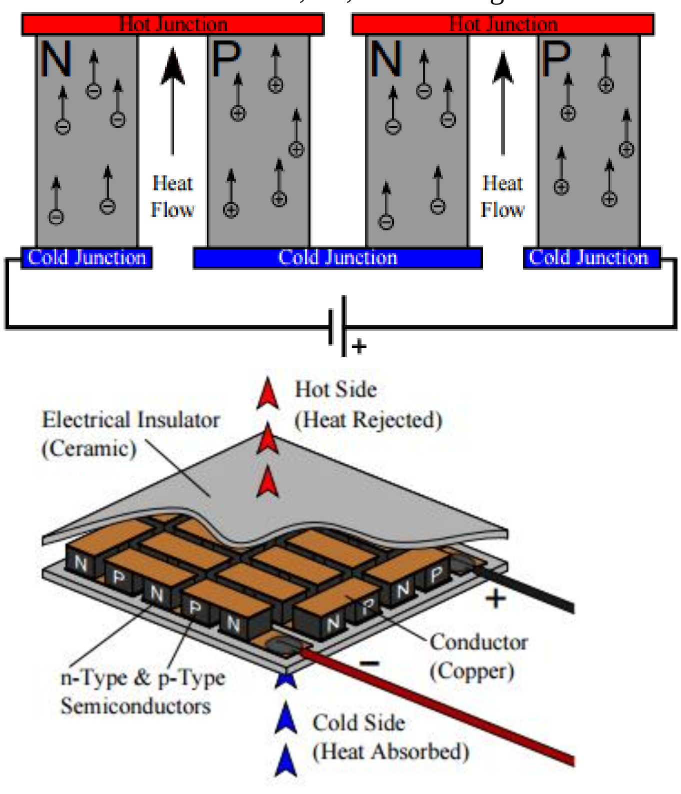

Fig 1(c). Peltier device

4) THERMAL CONDUCTANCE:

When current, I, flows through the Peltier device, heat flow Pel = ΠI generates a temperature difference, ΔT. In response, heat conducts from the hot to the cold side of the Peltier device given by Pth = −κΔT. The electrical power dissipated in the Peltier device (that is, the Joule heat) is PJ = RI2 , where R is the resistance of the Peltier device. PJ flows into both sides of the Peltier device. Finally, heat Pair flows from the hot side to the surrounding environment.

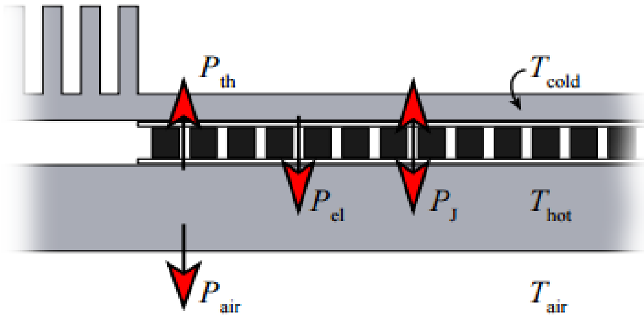

Fig 1 (d). Thermal Conduction Process

Heat flows in the Peltier device. Current, I, flowing through the Peltier device pumps heat Pel = ΠI and generates the temperature gradient, ΔT = T hot – T cold. In the opposite direction as Pel, heat flux P the conducts through the Peltier device from hot to cold. Joule heat, PJ, flows into both sides of the Peltier device. Heat Pair conducts from the heat block to the surrounding air at temperature T air. A number of simplifications and approximations can be made to reduce the complexity of these heat flows during measurements[10]. The first simplification is to perform the experiments in the open-circuit regime where I = 0. Therefore Pel = PJ = 0. The approximations are to assume that T cold ≈ T air and that Pair ≈ 0. These assumptions are fulfilled when ΔT is small and when the heat block is thermally insulated. In this situation, only P the affects the heat content of the hot block because T cold is constant. The heat stored in the heat block is Q hot = mc T hot, where m = 0.22 kg is the mass of the heat block, and c = 897 J/(kg K) is the heat

5) ENERGY STORAGE SYSTEM

Managing power balance and stability is a challenging task in MGs, as they depend on a number of variables. There are different techniques for dealing with this challenge, including de-loading sources (especially in RESs), load shedding during a shortage to provide energy to the user, and combining ESSs with DGs to manage power during surpluses and shortages of energy[11]. Storage units can be located beside each DG and connected through individual power electronic interfaces or they can be connected to MG through a central ESS, operating on similar principles to the master unit. Electrical energy can be stored by converting it to another form of energy, such as chemical, mechanical, thermal, or electrochemical. There are different methods available for each of these forms.

Energy storage is most useful when the system is operating in island mode, where the main control objective of ESSs is to control the voltage and maintain the frequency of the system during island operation. Moreover, storage units should be able to respond sufficiently rapidly to transient power changes in grid connected mode and to keep themselves fully charged. There are also many other applications that can utilize ESSs in MGs, such as ancillary services, customer energy management and the integration of RESs.

The control of such a system is critical, and implementing a hierarchical control system is necessary if optimum performance is to be achieved. For MGs and ESSs, hierarchical control can be described as consisting of four levels with different definitions and responsibilities. Generally, hierarchical control level needs to exert control over the power generated by the DG units, the power management and interface between the ESSs and DGs so as to provide a highly reliable system.

III. PROJECT DESCRIPTION

1) BLOCK DIAGRAM

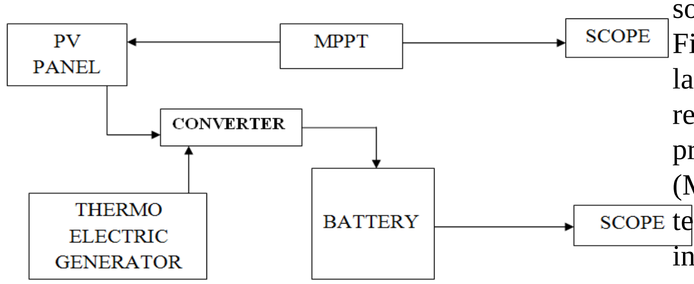

Fig 2.Block diagram of DC to DC Conversion using TEG

2) DESCRIPTION

This thesis project is scheduled in two major phases. The work starts from definition and development of the concept of TEG-based DC-DC conversion network for automotive applications, followed by the development of a bottom-up design approach for this network. For the second phase, the solar energy has linked to the DC – DC Converter, the optimal solutions for DC – DC Converters utilized in the proposed network will be investigated. The discussion Should base on comparison study and analysis, while the optimal solution should be refined and verified by modelling and simulation.

Thermal capacity and heat transfer are major factors which effect on the thermal performance of TEG. Thermoelectric generator (TEG) is a device works on the principle of ‘thermoelectric effect’ which directly converts thermal energy into electrical energy. The principle used in TEG is Seebeck effect. Seebeck effect is responsible for electrical power production i.e., it produces an electromotive force (EMF) and accordingly an electric current in a closed loop formed by at least two dissimilar conductors when two junctions are maintained at different temperatures. Thermoelectric generator consists of thermopile sandwiched between two thin ceramic wafers. Thermopile is developed by means of series and parallel combinations of thermocouple which is made up of p-type and n-type semiconductor material.

This thesis proposes the innovative concept of thermoelectric-generator-based DC-DC conversion network. The proposed structure is a distributed multi-section multi-stage network. The target is to tackle problems facing the traditional single-stage system and to advance TEG application in automotive settings. The objectives of the project consists of providing optimal solution for the DC-DC converter utilized in the network, as well as developing a systematic and bottom-up design approach for the proposed network.

The main problems of the DC-DC converters utilized in the TEG system are presented and analyzed, with solution to dynamic impedance matching suggested. First, theoretically-possible approaches to balance the large TEG internal resistance and small converter input resistance are discussed, and their limitations are presented. Then, a maximum power point tracking (MPPT) regulation model is developed to address the temperature-sensitive issue of converters. The model is integrated into a TEG-converter system and simulated under Simulink/Simscape environment, verifying the merits of MPPT regulation mechanism. With the developed model, MPPT matching efficiency over 99% is achieved within the hot side temperature range of 200°C ~300°C.

IV. SIMULATION AND RESULTS

In this chapter, the overall simulation of the converter and the energy management control system will be presented and discussed. The complete simulation will be performed in Matlab software and the energy management algorithm will be applied using C code. The performance of the energy management algorithm will be compared to another algorithm and four case studies will be presented. The first case study will be at high load and long daylight time. The second case study will be at light load and short daylight time. The third case study will be at light load and long daylight time.

Finally, the fourth case will be at high load and short daylight time.

1) SYSTEM LAYOUT

The system is built in PSIM software using all the previously mentioned models for all the parts of the system. The grid connected inverter and all its control loops and design is explained in [14]. The system layout is as follows:

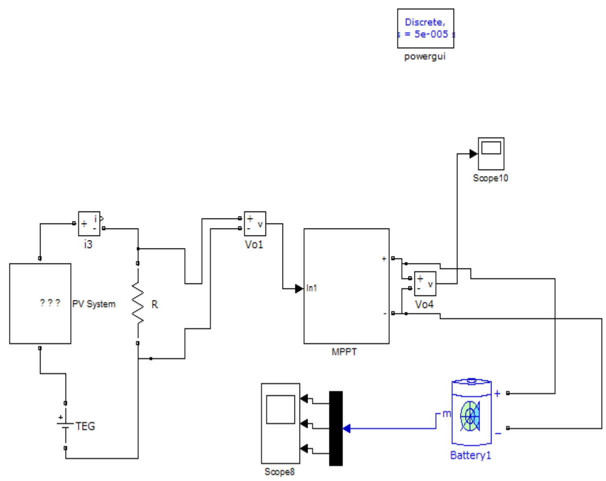

Fig 3. Complete System Simulation

The simulation will present 24 hours of data resized into 48 seconds. This means that every hour will be represented by two seconds. The reason for that is to capture both the response of the low level controllers, which have very small timeframe, and capture the response of the high level energy management control, which takes place at a large timeframe. Every simulation case will be performed using lookup tables that send the wanted values to the load current source and the PV current source. The load forecast parameters are also performed using lookup tables. The simulation results will be explained individually in the next section.

2) MPPT

Maximum power point tracking (MPPT) is a technique that ensures the maximum power extraction from non energy sources like solar PV systems[16],[17]. The algorithm allows the controller to operate PV module at optimum voltage and current so the extraction of maximum power is ensure.

Among several MPPT algorithms method is recommended for solar PV operation [9 Incremental conductance method estimates the relation between the operating point voltage, power point voltage, *Umax* conductivity follows three conditions;*U*= *Umax.* To realize the maximum power point (MPP) a reference voltage *Uref* is applied. When light intensity and outside temperature changes, the incremental conductance method control the output voltage to track the maximum power point voltage smoothly and also reduces oscillation phenomena near the maximum power point.

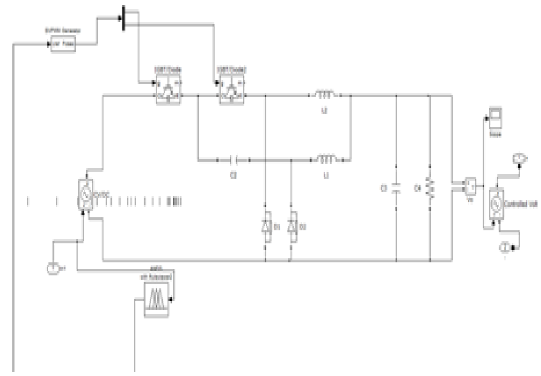

Fig 3 (a). MPPT Circuit

However, this control algorithm is very complicated, and the setting of adjusting voltage *JU* influences the maxim tracking accuracy greatly. The method can be expressed like following formula:

$$\frac{dI}{dU} = -\frac{I}{U};\ \left(\frac{dP}{dU} = 0\right) \text{at MPP thus} U = U_{max}$$

$$\frac{dI}{dU} > -\frac{I}{U};\ \left(\frac{dP}{dU} > 0\right) \text{left of MPP thus} U < U_{max}$$

$$\frac{dI}{dU} < -\frac{I}{U};\ \left(\frac{dP}{dU} < 0\right) \text{right of MPP, thus} U > U_{max}$$

A power electronic interface is required to operate MPPT and extract maximum power from solar PV.

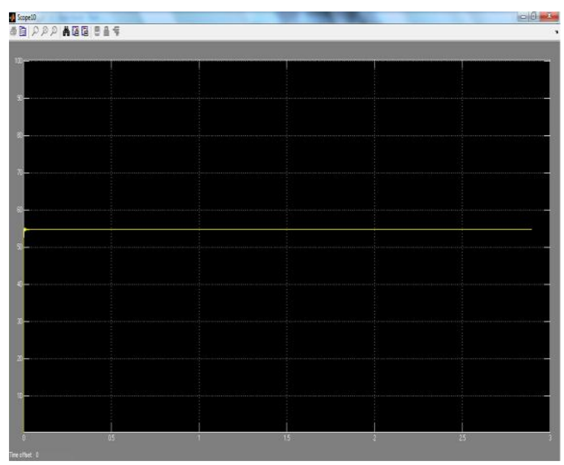

Fig 3(b). MPPT Efficiency

3) NEURO FUZZY LOGIC CONTROL

The creation of Neuro-Fuzzy systems which utilize fuzzy logic to construct a complex model by extending the capabilities of Artificial Neural Networks. Generally speaking all type of systems that integrate these two techniques can be called Neuro-Fuzzy systems. Key feature of these systems is that they use input-output patterns to adjust the fuzzy sets and rules inside the model[18],[19]. The paper reviews the principles of a Neuro-Fuzzy system and the key methods presented in this field, furthermore provides survey on their application for technical diagnostics.

A Neuro-fuzzy approach to solve fault diagnostic problems by pattern classification while obtaining a model which remained easily interpretable. The problem of finding membership functions and appropriate rules is frequently a tiring process of attempt and error. This lead to the idea of applying learning algorithms to the fuzzy systems. The neural networks, that have efficient learning algorithms, had been presented as an alternative to automate or to support the development of tuning fuzzy systems.

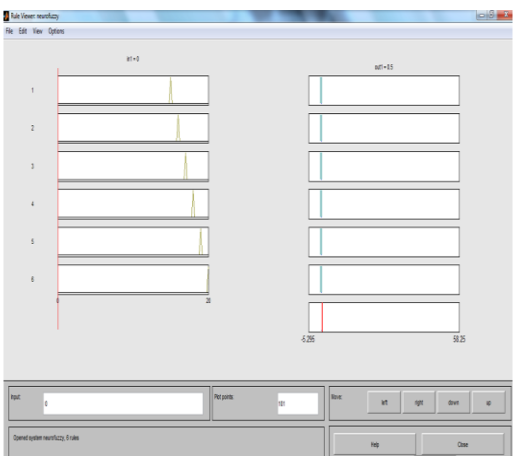

Fig 3(c). Development of Logic Control Systems

4) BATTERY POWER

In this case, PV starts to produce power early in the morning (5 a.m.) at which the price of electricity is very low. The initial SOC of the battery is 0.2 which is lower than the critical limit[11],[12]. Therefore, based on forecasts and future price, the energy management control system decides to divert PV power that is available now to the battery because the price is low. Even though there will be excess PV power later, the current price is less than the future price and hence injecting power to the grid at high price is the better decision:

The average power generated by solar PV is approximately 6 kW. Thermal Electric Generator generates up to 10kW depending on load demand. The load power in kW consumed by resistive main load, additional load and dump load is plotted in Fig. 7. The breaker for first additional load bank is closed when both solar PV and TEG Power conversion system is in operation and empowering 10kW main load. Another breaker for second additional load is closed when total power generation reaches 12.5kW.

In order to regulate the frequency, all dump loads are being added along with additional loads between 0.8s to 1.5s. The frequency regulator turns them off gradually when the frequency is stable at 60Hz after 1.5s. Fig. 8 shows the regulation of voltage at load side and the status of system frequency. Some fluctuation in load voltage is noticed between the period of 0.6s to 0.8s when both solar and wind energy are added in operation. The system frequency is being affected during the same period due to same operation[12],[13].

5) ENERGY STORAGE

The system will store the excess energy in a suitable storage device (e.g. super capacitors) for future use.

Apart from these basic functions, the system should be able to make control decisions to maximize energy saving at the sinks or minimize the energy loss at the acquisition end or routing paths. The system should also be responsible for the maintenance of the energy sources and sinks to ensure longer lifetimes, by dynamically turning off energy sources when not required and by cutting off power supply to energy sinks, when not in use, to eliminate power dissipation due to standby leakage current [20].

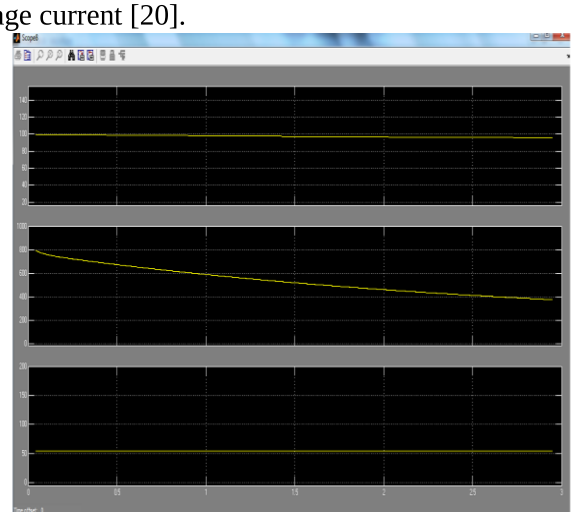

Fig 3 (d).Battery Power Storage

The initial SOC of the battery is 0.2 which is lower than the critical limit. Therefore, based on forecasts and future price, the energy management control system decides to divert PV power that is available now to the battery because the price is low. Even though there will be excess PV power later, the current price is less than the future price and hence injecting power to the grid at high price is the better decision:

6) Evaluation of Results

The management system has shown that it could provide decisions and the local controller has shown their ability to perform the commands. In addition, the management system has presented decisions that proven to reduce electrical cost and reduce the number of charging and discharging in one day. It has been noticed that changing the forecasted period gives different results which could presents an opportunity to improve the performance of the system.

V. CONCLUSION

As all the power stages are DC-to-DC, thus the efficiency is increase and such kind of conversion yields an easy implementation and control. The system is based on solar energy it has great potential to reduce the pollution in the environment. The control methods and stability of both the AC and DC micro grids are intensively studied during the last years. It can be concluded based on the studies that the control might be simpler and the grid operation more reliable if the conventional AC grid would be replaced by DC grid. This work can be further extended to increase the power with the use of exhaust heat in power plants like thermal power plants and biomass power plants to operate essential loads in case of emergency. Both the energy production and consumption will vary on a large scale but, at the same time, the customers are highly dependent on high quality and uninterruptable power supply. Hence considerable amount of power can be produced from the exhaust heat and will increase the system efficiency and performance. By combining several TEG modules and group of batteries which are charged using this TEG system and by employing fuzzy logic techniques an advanced TEG based storage and utilisation system can be developed and implemented for critical loads.

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