iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** X **Month of publication:** October 2021

DOI: https://doi.org/10.22214/ijraset.2021.38497

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue X Oct 2021- Available at www.ijraset.com

Grid Integration using ANFIS for Hybrid DG and Storage Units to Control and Manage Power

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Abstract: The significant role in the DC micro grid is renewable sources like hydrogen energy, Photovoltaic (PV), and wind systems. However, the difficult task in the DC micro grid is to balance the power generation and load demand due to the continuous changes in sustainable sources. In this study, focused on the power control and stabilize the power at different dynamic conditions with power management approaches. In this paper, fuel cell (FC), lithium-ion based batteries and super capacitors (SC) are proposed with PV based DC micro grid system for improving the system performance. Furthermore, adaptive neuro-fuzzy inference system (ANFIS) is suggested in this system for mitigating the deviations in PV plant due to variations in temperature. The suggested system has been designed on the MATLAB environment. The simulation results reveal that the suggested approaches give better improvement in various operating conditions with ANFIS approach.
Keywords: PV system, Fuel cell, supercapacitor, ANFIS, DC Microgrid.

I. INTRODUCTION

Increasing demand for electrical power and severe environmental problems caused by fossil energy justify the need for developing a green, renewable power generation system. To make the best use of renewable energy, microgrids have been widely studied and play an important role in the future smart power system. Microgrids are generally defined as a combination of different distributed generations, energy storage systems, loads, and supervisory control, protection, and energy management systems. Compared with a single DG unit, microgrids show higher reliability, flexibility, and efficiency. According to different types of bus, micro grids can be divided into AC microgrids, DC microgrids, and AC/DC microgrids. Among them, AC microgrids are the most widely microgrid type. AC microgrids can operate either in the grid-connected or islanded mode; and several control techniques have been developed to perform active and reactive power sharing, frequency and voltage regulation, and power quality disturbance compensation [6–8].Now a days, DC microgrids are continuously demonstrating the advantages over AC microgrids, and have become an increasingly popular solution for small-scale power systems in close physical proximity [9,10], due to the less energy loss from power transmission lines over long distances. In DC microgrids, the distributed generators (e.g., photovoltaic (PV), fuel cells (FCs)), energy storage systems (e.g., batteries, supercapacitors), and loads (e.g., electronics, chargers, LED lighting) are connected without DC/AC conversion, which contributes to a higher system efficiency, higher system stability, and lower system cost.

Furthermore, DC microgrids are not afflicted with frequency synchronization, reactive power flow, and other power quality issues that are common in AC systems. Therefore, the DC microgrids show great potential in building electrical systems, datacom centres, and plug-in hybrid electric vehicles in the future. Energy management and optimal control of microgrids are the prerequisites of continued stable and economically efficient operation. At present, a large number of studies have been performed on PV/Battery DC microgrids and PV/Wind/Battery DC microgrids. FCs is characterized as low-polluting and high efficiency systems that have low maintenance costs, but they are still considered to be developing technologies. With the development of hydrogen utilization technology, hydrogen DC microgrids have been found in several studies, which rely on batteries for short-term energy storage whilst FC works as a long-term energy storage system. Various hybrid topologies and control method shave been proposed. Because of the stochastic output power of PV arrays and great wind generators fluctuation under varying weather conditions, controlling the power flow between FC systems and energy storage systems is a huge challenge for energy management strategy.

Nowadays, few studies have developed real hydrogen DC microgrid system due to technical constraints, and these approaches are generally very computationally demanding and place greater demands on the computing performance of the controller. Meanwhile, these proposed strategies have not adequately considered the coordination control of multiple control objective sand the operating efficiency for the FC. Since FCs have higher generation cost compared with other distributed generation types, FC efficiency will have a great influence on system efficiency and economy [11].

A. Problem Statement

The difficult task in the DC microgrid is to balance the power generation and load demand due to the continuous changes in sustainable sources. In this work, various control approaches are used to stabilize the power between the generation and load in suggested DC based microgrid with PV plant. For decreasing the fluctuations in PV plant, an ANFIS approach is suggested. Further, fuel cell (FC), lithium-ion based batteries and supercapacitors (SC) are proposed to control the system and enhance the system performance at abrupt changes in load.

B. Objectives

1) To stabilize the power between the generation and load in suggested DC based microgrid with PV plant, various control approaches are used.
2) To decrease the fluctuations in PV plant, an ANFIS approach is suggested.
3) To control the system and enhance the system performance at abrupt changes in load fuel cell (FC), lithium-ion based batteries and supercapacitors (SC) are proposed.

C. Proposed System

In this work, various control approaches are used to stabilize the power between the generation and load in suggested DC based microgrid with PV plant. For decreasing the fluctuations in PV plant, an ANFIS approach is suggested. Further, fuel cell (FC), lithium-ion based batteries and supercapacitors (SC) are proposed to control the system and enhance the system performance at abrupt changes in load.

II. LITERATURE SURVEY

The paper titled “Neuro-Fuzzy-Based Model Predictive Energy Management for Grid Connected Microgrids (Ulutas A, et.al. May 2020)” is proposed an energy management algorithm is for a grid-connected microgrid consisting of loads, a photovoltaic (PV) system and a battery for efficient use of energy. A model predictive control-inspired approach for energy management is developed using the PV power and consumption estimation obtained from daylight solar irradiation and temperature estimation of the same area. An energy management algorithm, which is based on a neuro-fuzzy inference system, is designed by determining the possible operating states of the system. The proposed system is compared with a rule-based control strategy. Results show that the developed control algorithm ensures that microgrid is supplied with reliable energy while the renewable energy use is maximized.

The paper titled “Convergence analysis of distributed control for operation Cost minimization of droop-controlled DC microgrid based on multiagent (Li C et.al. March 2016)” is proposed a distributed control method for minimizing the operation cost in DC microgrid based on multiagent system. Each agent is autonomous and controls the local converter in a hierarchical way through droop control, voltage scheduling and collective decision making. The collective decision for the whole system is made by proposed incremental cost consensus, and only nearest-neighbor communication is needed. The convergence characteristics of the consensus algorithm are analyzed considering different communication topologies and control parameters. Case studies verified the proposed method by comparing it without traditional methods. The robustness of system is tested under different communication latency and plug and play operation.

The paper titled “Overview of power management strategies of hybrid AC/DC microgrid (Nejabatkhah, F. and Li, Y.W. December 2014)” is presented an overview of power management strategies for a hybrid ac/dc microgrid system, which includes different system structures (ac-coupled, dc-coupled, and ac-dc-coupled hybrid microgrids), different operation modes, a thorough study of various power management and control schemes in both steady state and transient conditions, and examples of power management and control strategies. Finally, discussion and recommendations of power management strategies for the further research are presented.

The paper titled “Real time experimental implementation of optimum energy management system in standalone Microgrid by using multi-layer ant colony optimization (Marzband, M. et al., 2016)” proposed an algorithm for energy management system (EMS) based on multi-layer ant colony optimization (EMS-MACO) is to find energy scheduling in Microgrid (MG). The aim of study is to figure out the optimum operation of micro-sources for decreasing the electricity production cost by hourly day-ahead and real time scheduling. The proposed algorithm is based on ant colony optimization (ACO) method and is able to analyze the technical and economic time dependent constraints. This algorithm attempts to meet the required load demand with minimum energy cost in a local energy market (LEM) structure. Performance of MACO is compared with modified conventional EMS (MCEMS) and particle swarm optimization (PSO) based EMS.

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Analysis of obtained results demonstrates that the system performance is improved also the energy cost is reduced about 20% and 5% by applying MACO in comparison with MCEMS and PSO, respectively. Furthermore, the plug and play capability in real time applications is investigated by using different scenarios and the system adequate performance is validated experimentally too.

The paper titled "Control technique for enhancing the stable operation of distributed generation units within a microgrid. (Mehrasa, M. et al., 2015)" described a control technique for enhancing the stable operation of distributed generation (DG) units based on renewable energy sources, during islanding and grid-connected modes. The Passivity-based control technique is considered to analyze the dynamic and steady-state behaviors of DG units during integration and power sharing with loads and/or power grid, which is an appropriate tool to analyze and define a stable operating condition for DG units in microgrid technology. The compensation of instantaneous variations in the reference current components of DG units in ac-side, and dc-link voltage variations in dc-side of interfaced converters, are considered properly in the control loop of DG units, which is the main contribution and novelty of this control technique over other control strategies. By using the proposed control technique, DG units can provide the continuous injection of active power from DG sources to the local loads and/or utility grid. Moreover, by setting appropriate reference current components in the control loop of DG units, reactive power and harmonic current components of loads can be supplied during the islanding and grid-connected modes with a fast dynamic response. Simulation results confirm the performance of the control scheme within the microgrid during dynamic and steady-state operating conditions.

III.SYSTEM DESIGN

System design thought as the application of theory of the systems for the development of the project. System design defines the architecture, data flow, use case, class, sequence and activity diagrams of the project development.

A. System Architecture

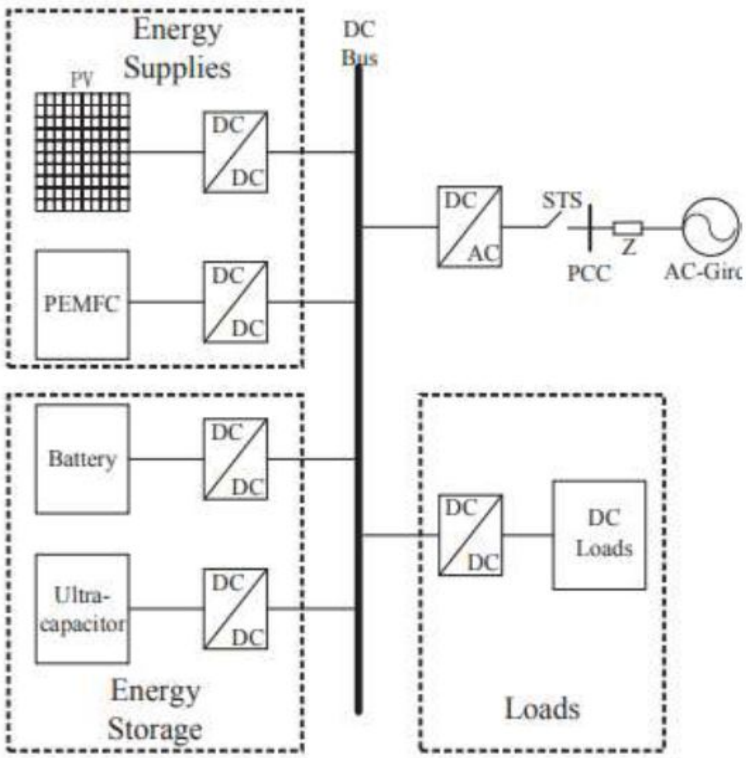

Fig. 1 Architecture Diagram of PV-Fuel Cell-Hybrid Energy Storage-Based Dc Microgrid

A micro-grid is a distributing system which provides low voltage or medium voltage supply from a bunch of micro sources in a controlled and coordinated way by being connected to the main power grid, operated in islanded mode or be completely off-grid [2]. A lot of studies have been done on the hybrid micro-grid system. The performance and cost viability of a PV, fuel cell (FC) and battery-based hybrid grid-tied system with intermittent load conditions are analysed in [3].

B. Structure of the Microgrid

As shown in Fig.1, PV/fuel cell/hybrid energy storage-based DC microgrid integrate PV generation unit, hybrid energy storage consisting of batteries and ultra-capacitors, grid-connected voltage source converter (G-VSC), static transfer switch (STS), load, load converters and so on. The PV unit is connected to the DC bus through a boost DC/DC converter. The converter is the three-phase two-level voltage source converter and the grid side is a connected second-order LC filter. a bidirectional DC/DC converter, which has the bidirectional flow of power, realize the connection between energy storage and DC bus. For load in the microgrid, DC Load is directly connected to the DC Bus while AC load connect to the DC bus through AC converter.

C. Model of PEMFC

PEMFC, which transforms the chemical energy of hydrogen into electrical energy, has widely commercialization potential in many applications ranging from electric vehicles to DGs. The output voltage V_{cell} of single cell is expressed as (1)

$$V_{cell} = E - \eta_{act} - \eta_{con} - \eta_{ohmic} \quad (1)$$

V_{cell} is the output voltage of a single cell. E means the Thermodynamic electromotive force
From the Butler-Volmer, activation voltage is represented below:

$$\eta_{act} = \frac{RT}{aF}\ln\left(\frac{i}{i_0}\right)$$

i is the current density. ais the coefficient determined by fuel cell. 0 i is the initial current value.
Concentration polarization overvoltage equation is shown as:

$$\eta_{con} = m\exp(ni)$$

m and n as empirical parameters, they are related to the conductivity of electrolyte and the porosity of gas diffusion layer. i is the current density.

D. ANFIS Method

Fuzzy logic control (FLC) is a technique very often used in control systems based on microprocessors, since it does not require an exact model of system and is insensitive to variations of the parameters and operating points. It is based on rule basis and membership functions (MF), which are usually obtained by a trial-and-error method and thus is a very time-consuming and error-prone process.

Artificial neural networks (ANNs) are mathematical models with learning and parallel data processing abilities, which use computational neurons (nonlinear cells) organized in layers and connected to each other by weight factors. ANNs are also used in microprocessor control systems due to their nonlinear and adaptive structure, generalization skills, and design independence from system parameters. However, their disadvantages are the lack of rules for defining the structure (cells and layers) due to their "black box" nature and the instruction problem of network.

FLC and ANNs are complementary technologies in the design of intelligent control systems. Neuro-fuzzy systems combine the inference ability of fuzzy logic like a human and the learning and parallel data processing abilities of ANNs. With these systems, the development time is reduced and the accuracy of the fuzzy model is improved.

ANFIS is one of the most successful neuro-fuzzy systems developed by Jang in 1993, which applies neural learning rules to identify and tune the parameters and structure of a fuzzy inference system, based only on the available data.

Its main characteristics are:

1) The implementation is easy
2) The learning is fast and accurate
3) It has strong generalization skills
4) The fuzzy rules make easier its understanding and
5) It is easy to incorporate both linguistic and numeric knowledge for problem solving.

ANFIS structure allows the rules to be constructed using a decomposition strategy. ANFIS method as shown below in Fig 2 represents a multi-layer feed-forward network in which each node (neuron) performs a specific function on the incoming signals and there are two types of nodes: adaptive and fixed. The rules are first extracted at individual node levels within the neural network and then aggregated to capture the global dynamics of the system.

The fuzzy if-then rules with appropriate membership functions generate the preliminary stipulated input-output pairs and these membership functions take their final forms during training due to regression and optimisation procedures.

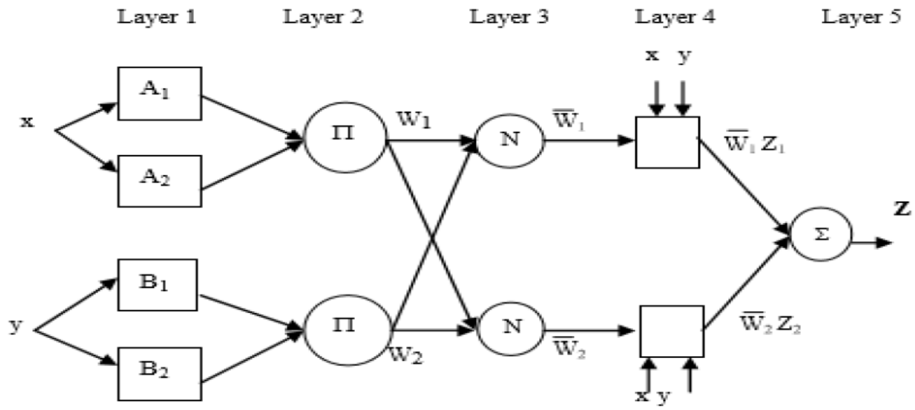

Fig. 2 ANFIS model

The gradient vector provides a measure of how well the system is emulating the given training data set for a given set of parameters. Once the gradient vector is got, the optimisation routines are applied to adjust the parameters in such a way as to reduce a chosen error criterion. The system converges when the training and checking errors are within an acceptable limit.

E. Implementation Models

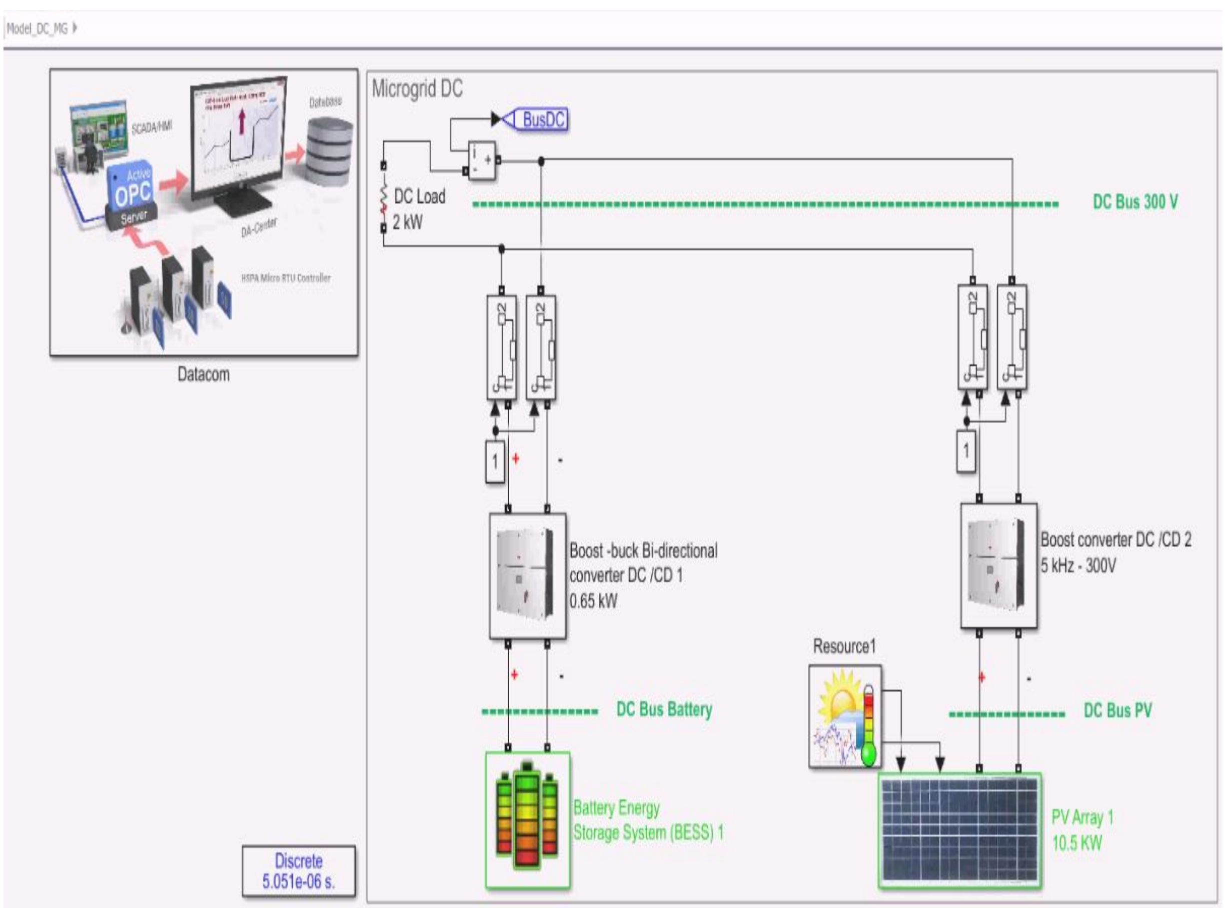

Fig. 3 Micro-grid DC model

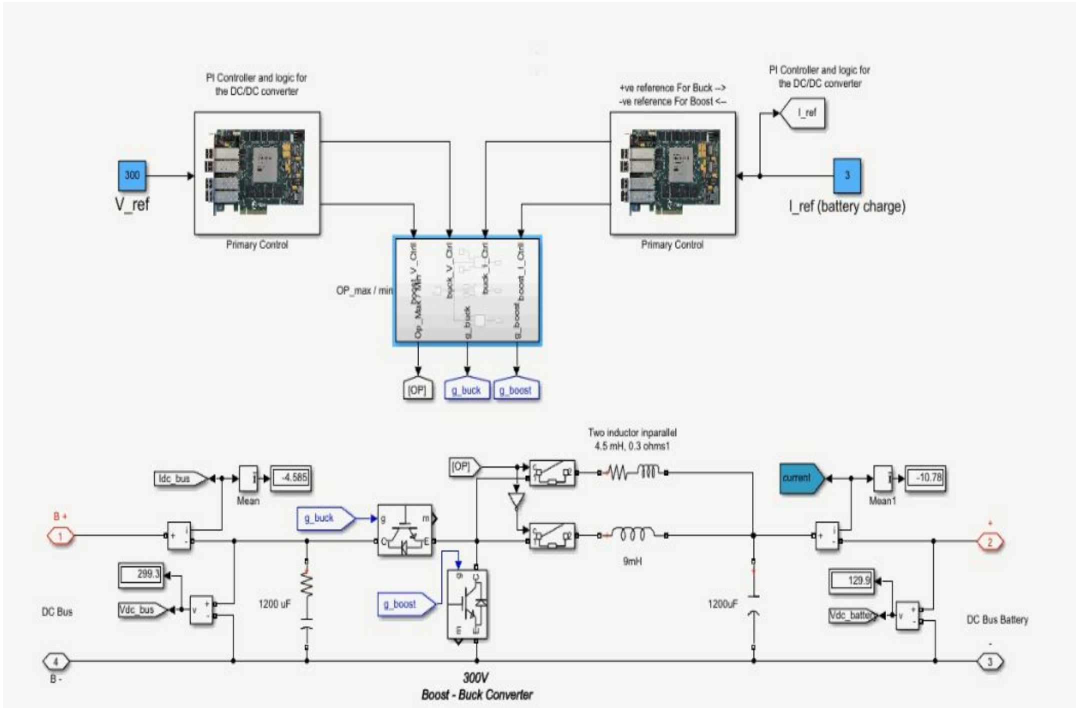

Fig. 4 Boost-buck Bi-directional converter DC/CD module

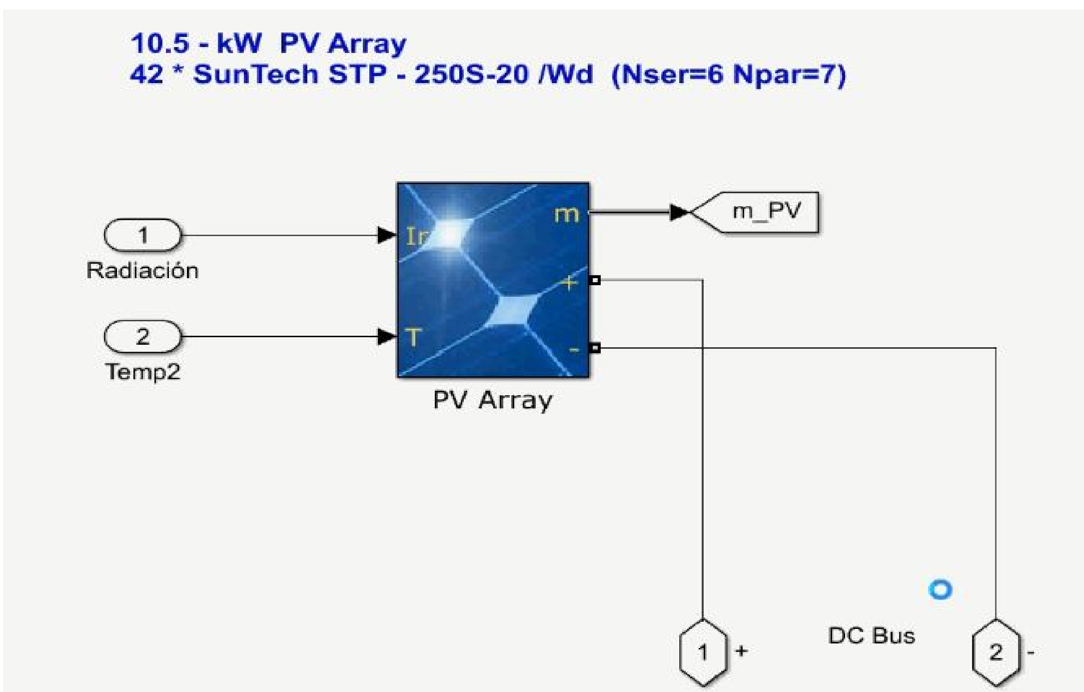

Fig. 5 Energy Supplies Module

In a PV system, the solar energy is converted to electrical energy by using one or more PV modules. Mainly, the system consists of panels, and various mechanical electrical connectors in order to produce the desired output. The panels are connected in series and parallel connection to provide the desired amount of voltage and current. The photovoltaic cell is used to describe electrical variables such as current, voltage, and resistance as they change in response to sunlight.

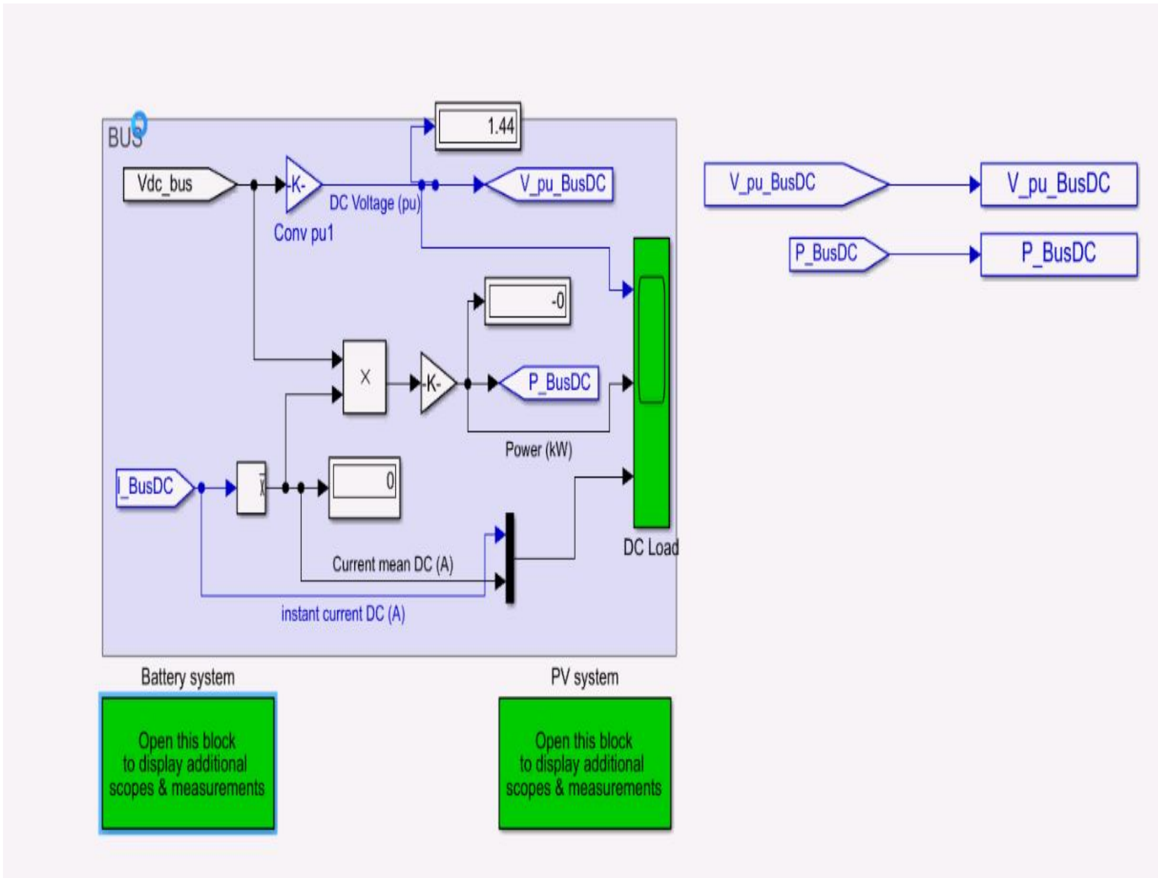

Fig. 6 Datacom Model

IV. RESULTS

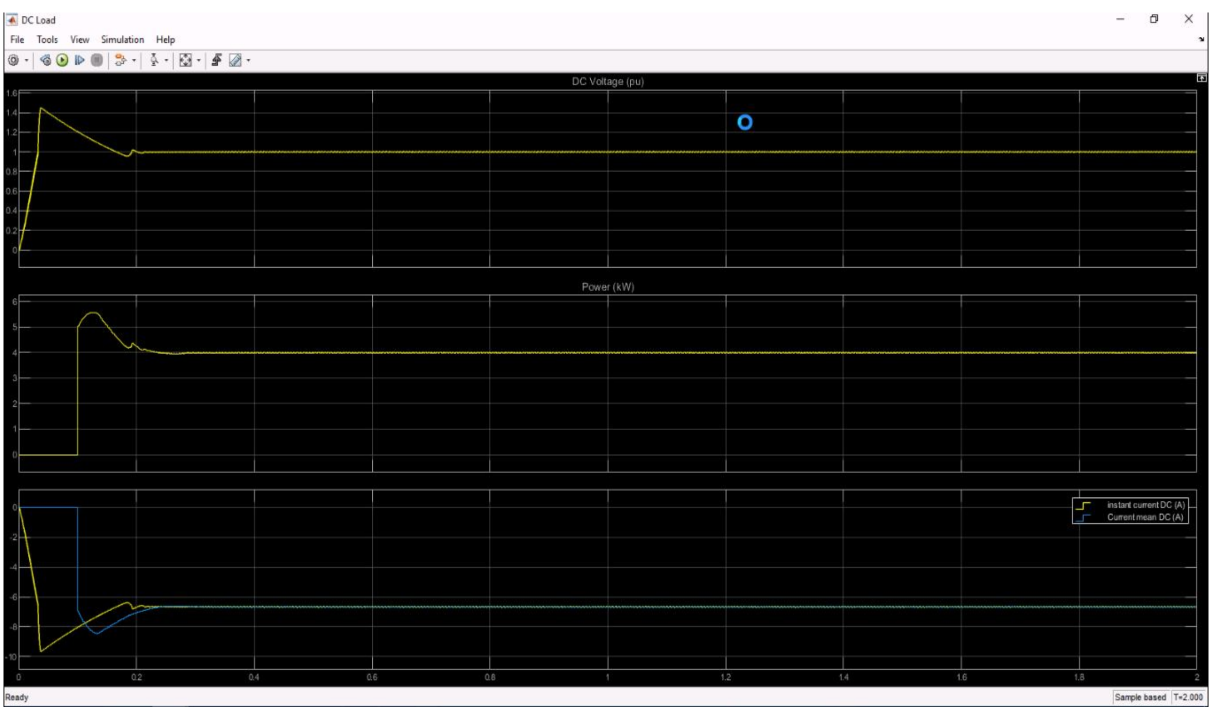

Fig. 7 DC Load

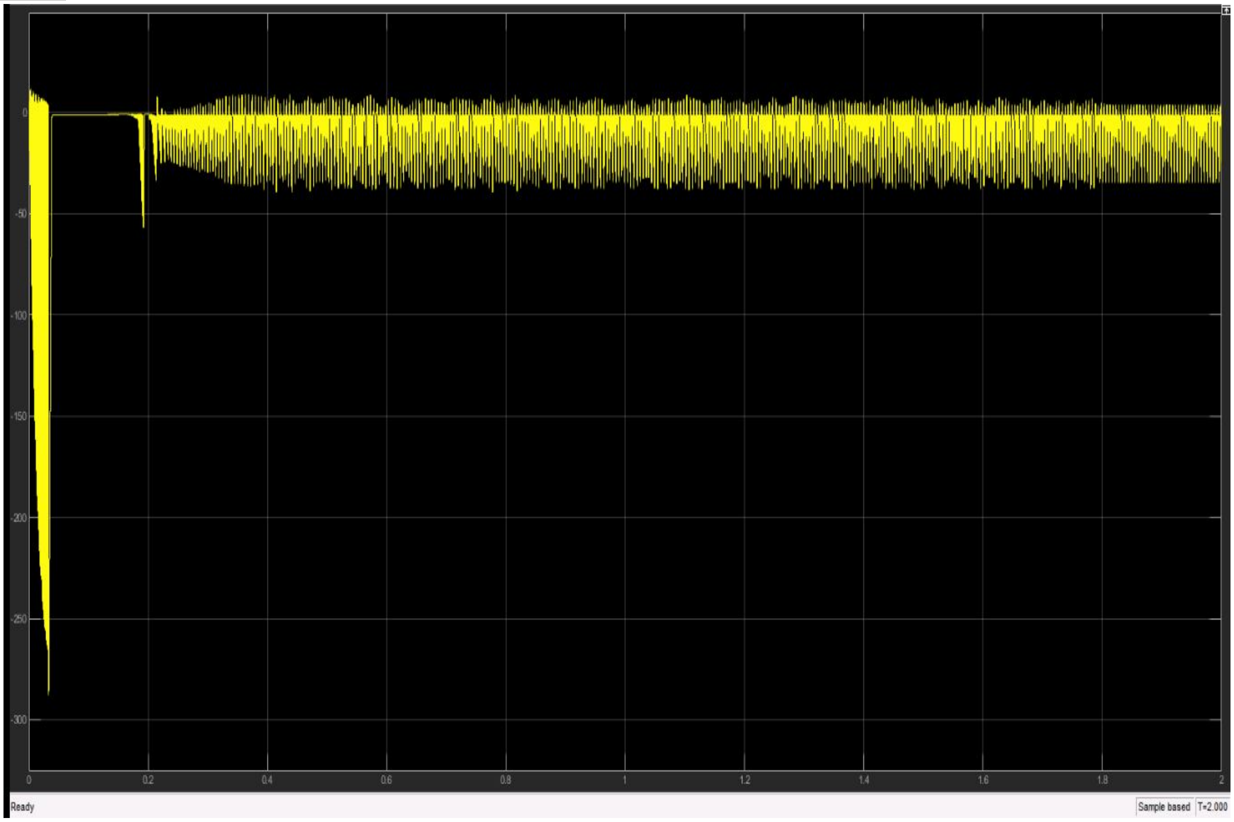

Fig. 8 Current Instant

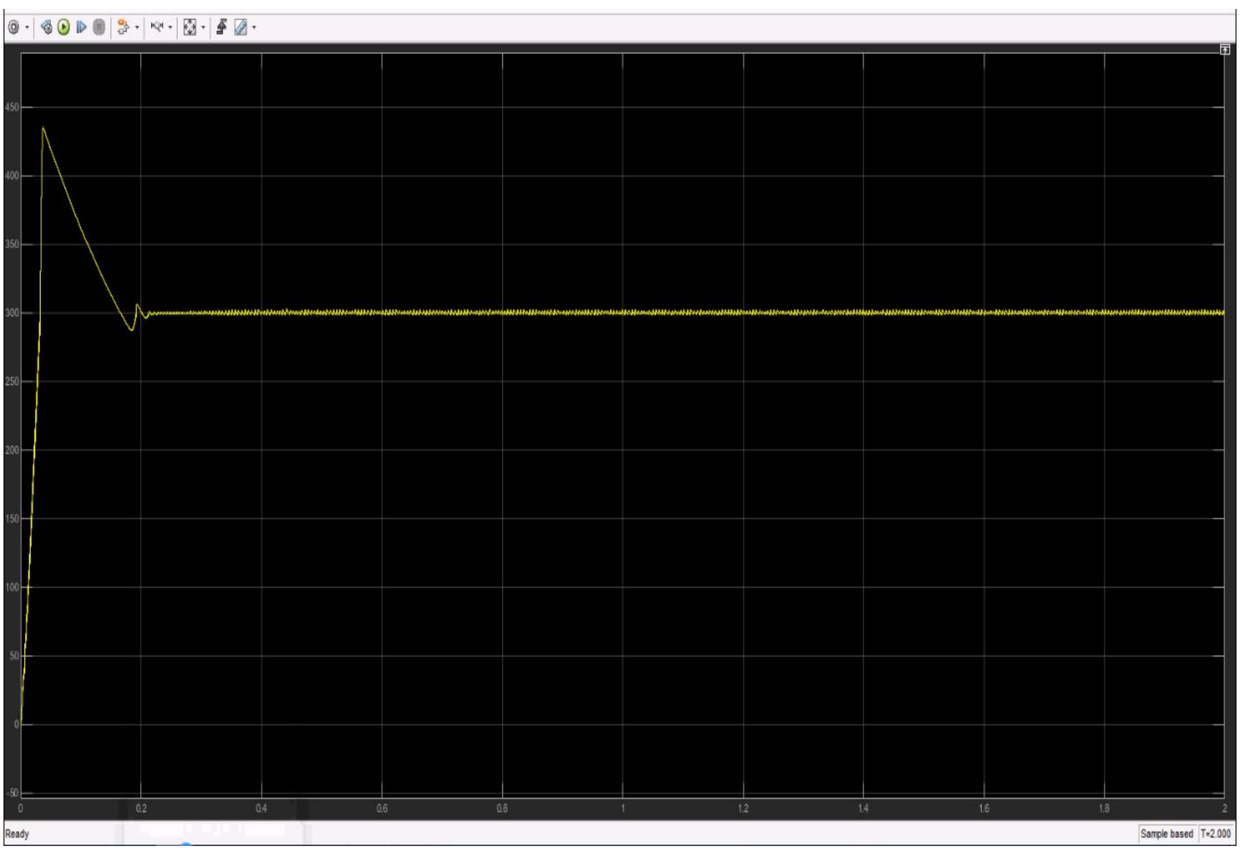

Fig. 9 VDC

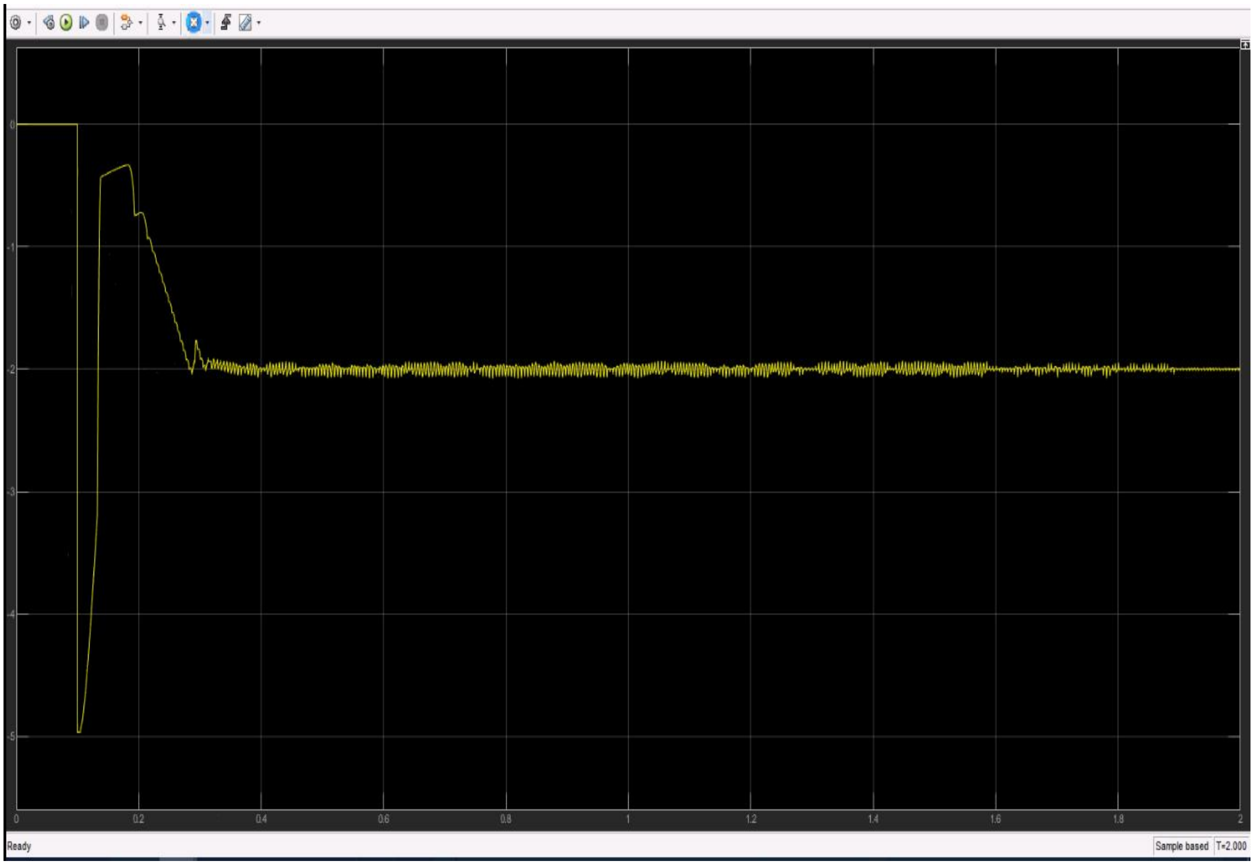

Fig. 10 Power Bass

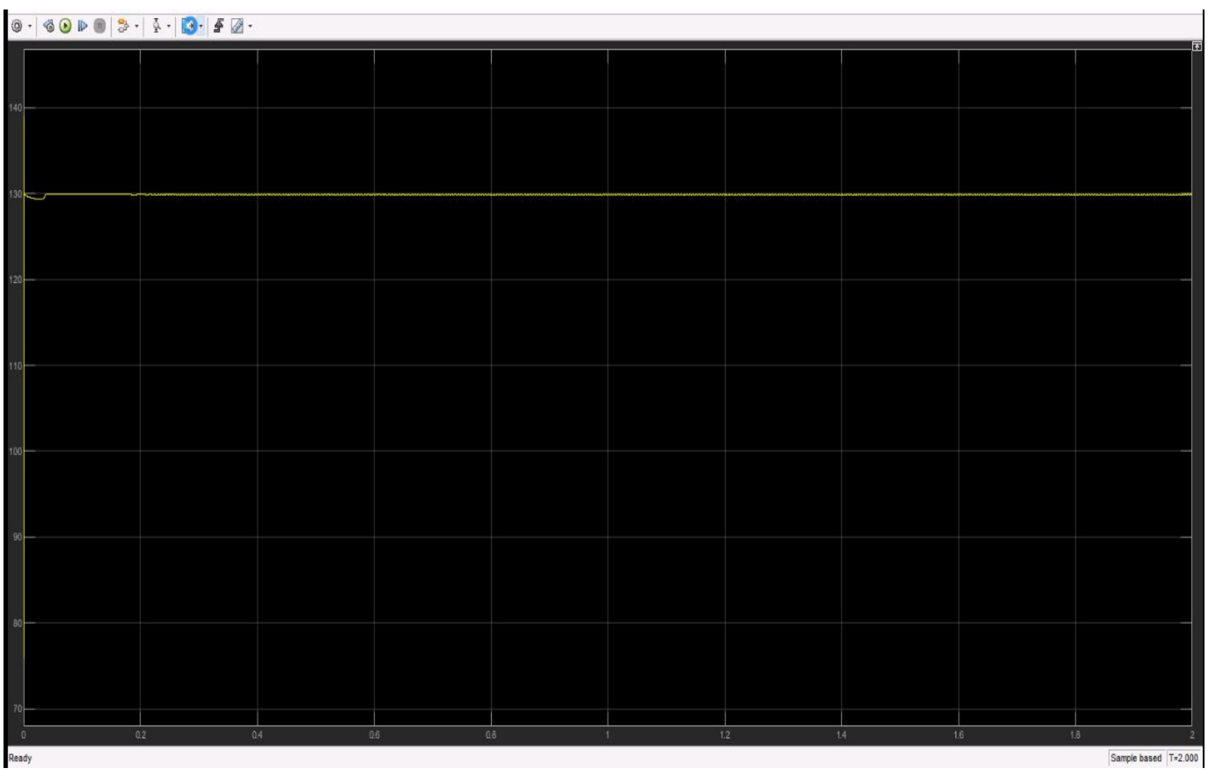

Fig. 11 Voltage Battery

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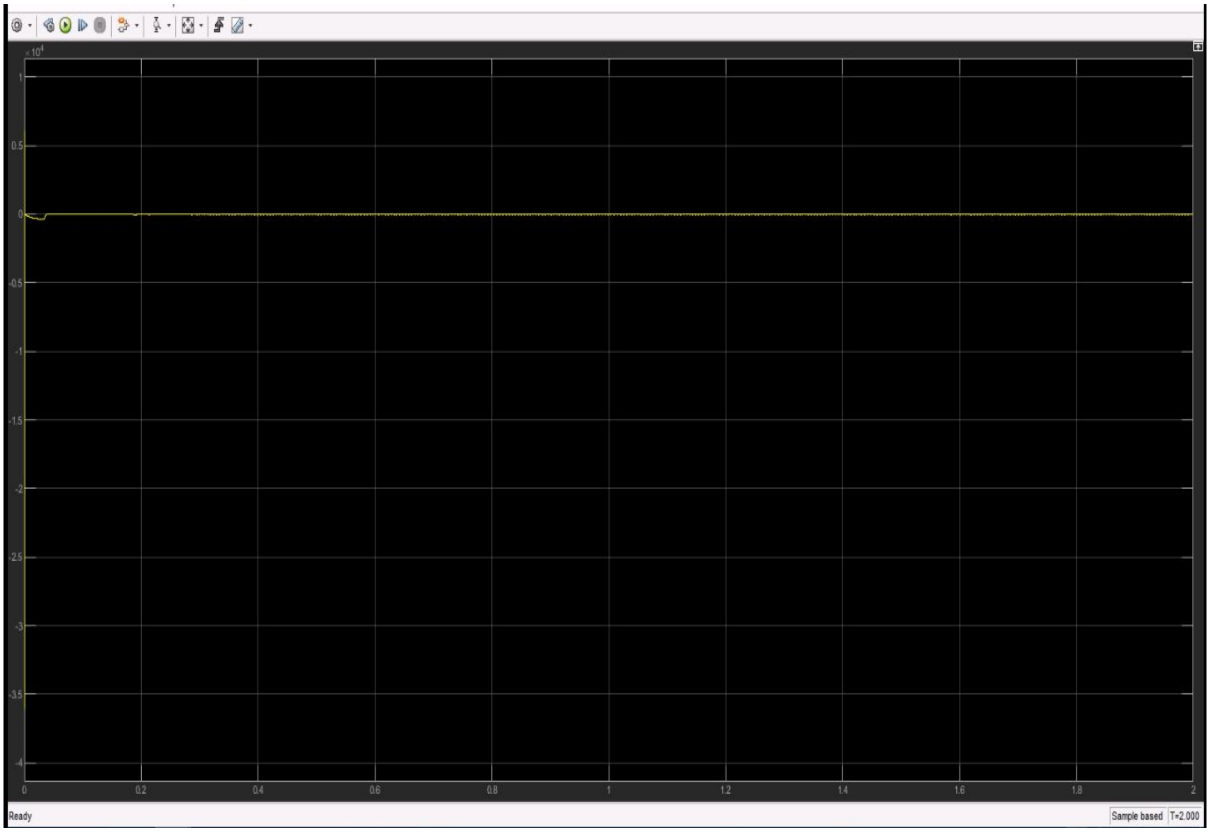

Fig. 12 Current going to/from the battery

V.CONCLUSION

In this paper, a control and energy storage management strategy for PV/fuel cell/ hybrid storage based micro grid is suggested. In this study, focused on the power control and stabilize the power at different dynamic conditions with power management approaches. In this work, fuel cell (FC), lithium-ion based batteries and super capacitors (SC) are proposed with PV based DC micro grid system for improving the system performance. Moreover, adaptive neuro-fuzzy inference system (ANFIS) is suggested in this system for mitigating the deviations in PV plant due to variations in temperature. The proposed system has been constructed on the MATLAB environment.

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