Integration of Photovoltaic-Fuel Cell Scheme for Energy Supply in Remote Areas

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***Abstract*— A hybrid photovoltaic- fuel cell PV/FC system for supplying an isolated small community with electrical energy is digitally simulated and presented in this paper. The proposed hybrid renewable green energy scheme has four key subsystems or components to supply the required electric loads. The first subsystem includes the renewable generation sources from PV array and Fuel Cell. The second is the interface converters used to connect the renewable energy generators to the common DC collection bus, where all generated energy is collected. The third device represents the added inverter between the common collection DC bus and the added AC bus interface to feed all AC loads. The fourth subsystem comprises all controllers including the modulated power filter. The controller main function is to ensure efficient energy utilization and dynamic matching between loads and green energy generation as well as voltage stabilization. The proposed controllers are coordinated dynamic error driven PI regulators to control the interface converters. The integrated hybrid green energy system with key subsystems are digitally simulated using the Matlab/Simulink/Sim-Power software environment and fully validated for efficient energy utilizations and enhanced interface power quality under different operating conditions and load excursions.**

***KEYWORDS:* Photovoltaic arrays, Fuel cells, Error driven multi loop dynamic control, Modulated Power Filter compensator.**

I. INTRODUCTION

In remote isolated areas and arid communities such as small islands, diesel generator sets and micro gas turbines are usually the main source of power supply. Fossil fuel for electricity generation has several drawbacks: it is costly due to transportation to the remote areas and it causes global warming pollution and green house gases. The need to provide an economical, viable and environmental safe alternative renewable green energy source is very important. As green renewable energy resources such as Photovoltaic (PV) and Fuel Cells have gained great acceptance as a substitute for conventional costly and scare fossil fuel energy resources. Stand-alone renewable green energy is already in operation at many places despite solar and hydrocarbon variations and stochastic nature. Isolated green energy hybrid operation may not be effective or viable in terms of the cost; efficiency and supply reliability unless an effective and robust stabilization of AC-DC interface scheme and maximum energy tracking control strategies are fully implemented [1, 2].

An effective approach is to ensure renewable energy diversity and effective utilization by combining these different renewable energy sources to form a coordinated and hybrid integrated energy system. Integrated green energy system is a valid alternative solution for small scale micro-grid electrification for remote rural and isolated village/island where the utility grid extension is both costly and geographically difficult. Hybrid renewable green energy system incorporates a combination of several diverse renewable energy sources such as photovoltaic, fuel cells and possibly wind, wave energy sources. A system using such diverse combination has the full advantage of supply diversity, capacity and system stability that may offer the strengths of each type [3, 4]. The main objective of integrated green energy scheme is to provide supply security for remote communities. Hybrid integrated green energy systems are also pollution free, and can provide electricity at comparatively viable and economic advantages to micro grid or diesel generator set utilized in village/island electricity.

II. LAYOUT OF THE STUDIED SYSTEM

The paper presents a hybrid PV/FC renewable energy scheme for supplying an isolated community with electrical energy. In order to obtain electricity from the hybrid green system at an economical price, its topology and control design must be optimized in terms of coordinated operation and layout configuration. Many topologies are currently available for integrated green system configurations, depending on the use of interface converters based on common DC/common AC bus interface architecture.

Solar panels can be connected in parallel or in series to obtain required photovoltaic power rating. The power obtained by this way is DC in nature and it should be converted to AC for some AC type loads. Therefore, DC to AC converters are required for such load types. Electrical energy is not only required during day time, but also at night. This key requirement puts forwards the possible use of other renewable green energy sources, such as fuel cells in integrated micro co-generation schemes [8,9]. The Electrochemical voltage behavior of the fuel cell is commonly modeled using the simple equivalent first order (RC). This circuit consists of three passive circuit elements that result in a first order approximation of the dynamic response of the electrochemical capacitor. The circuit includes the double layer capacitance RC in series with ohmic resistance. The equivalent series resistance that represents the energy lost due to the distributive resistance of the electrolyte, electronic contacts and the porous separator [5, 6].

Hydrogen itself is a clean and emission free fuel. Currently Hydrogen technology is concentrating on the storage methods, efficient and safe Fuel Cell Batteries. Enhancing the output efficiency and improving the performance of fuel cell are among main research topics. The industrial applications of fuel cell technology are still limited to hybrid electric vehicles. Little papers are dealing with the power system application of fuel cell and system interactions. Therefore, the interaction of fuel cell with power system components and switching electronic drives, choppers and controllers are crucial.

The generated electrical energy in fuel cell could be directly connected to the common DC bus through DC-DC-Chopper to convert the stored energy in hydrocarbon to DC electrical energy [4,5]. In integrated green energy power system, Fuel cell and solar are fully used as the main energy sources to supply the hybrid DC and AC type loads.

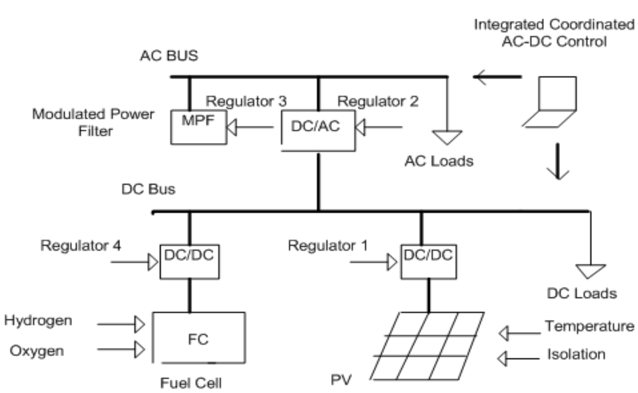


Fig.(1) Integrated (FC-PV) Green Energy Scheme for Electricity Supply

Figure (1) shows the scheme of the studied system with common DC/ common AC collection bus interface. The scheme uses a primary common DC bus collection with an added secondary common AC bus for feeding any AC loads and public grid interface. The proposed hybrid green energy scheme is digitally simulated for different operation conditions and load excursions. The proposed control scheme comprises multi-loop dc-coupled coordinated dynamic error driven controllers with supplementary regulation loops to control the different subsystems [6,7].

III. COORDINATED ERROR DRIVEN TRI-LOOP CONTROLLER

Figure (2) shows the general four regulator coordinated control structure. The hybrid system was digitally simulated and validated using MATLAB/Simulink–SimPower software environment in order to test the controller performance for interfacing devices of PV panels and wind generator under changing weather conditions and load disturbances. The simulation results show that the effects of the change in solar radiation and ambient temperature are compensated by controlling the DC-DC chopper, which interfaces the PV panel to the common DC bus. Similarly the effect of wind speed variations is compensated by controlling the AC-DC rectifier converter, which interfaces the wind generator to the common DC bus. The controller of pulse width modulated inverter reduces the effect of AC load disturbances. Voltage stabilization is achieved by installing the modulated power filter on the AC common bus [10, 11].

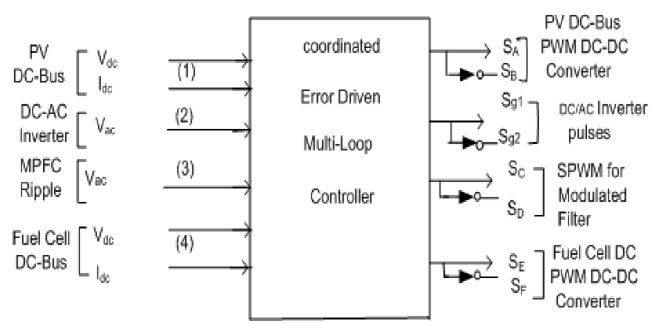


Figure (2) Multi Regulator error driven multi-loop decoupled Daynamic controller

The main controller comprises the following Four Key Decoupled Regulators:

(1) DC-DC converter regulator for PV array.
(2) DC-AC inverter regulator to interface DC –Bus with the grid
(3) MPFC Filter regulator for ripple minimization of AC-Bus.
(4) DC-DC converter regulator of Fuel Cell.

Figure (3) shows the four regulators structure with error driven multi loop configuration.

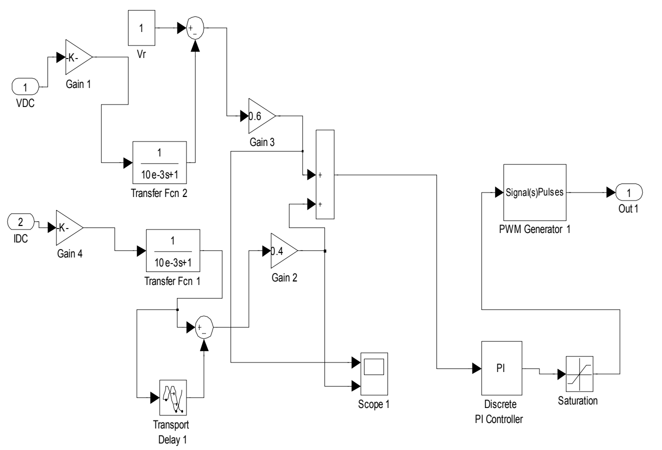


Fig. (3-a) DC-DC Converter Regulator for Photovoltaic PV Array

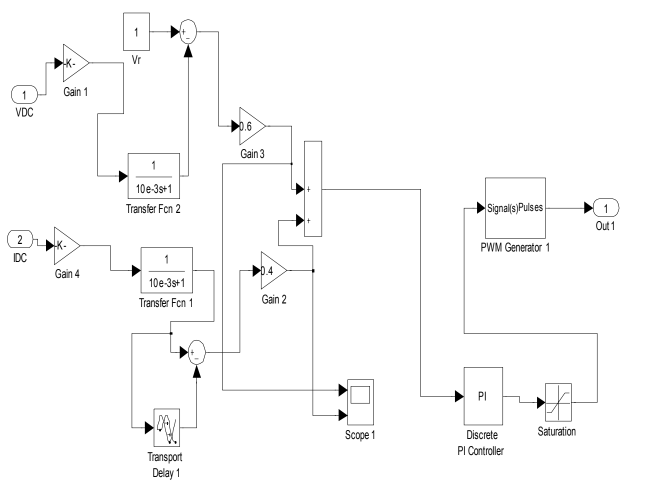


Fig. (3-b) DC-DC Chopper Converter Regulator of Fuel Cell Stack

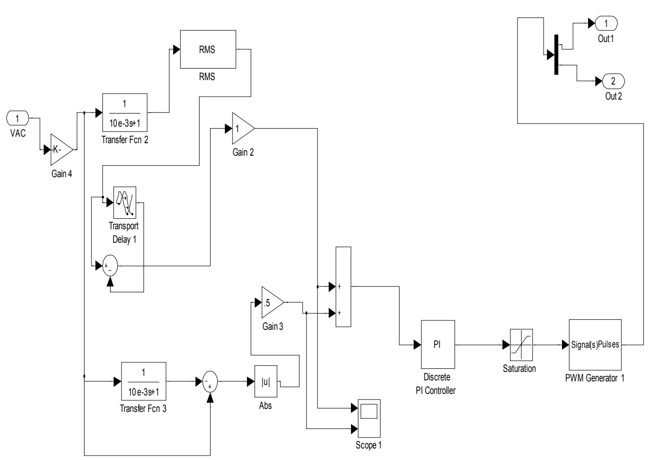


Fig. (3-c) DC-AC Interface Inverter Regulator to Interface Common DC-Bus with Grid

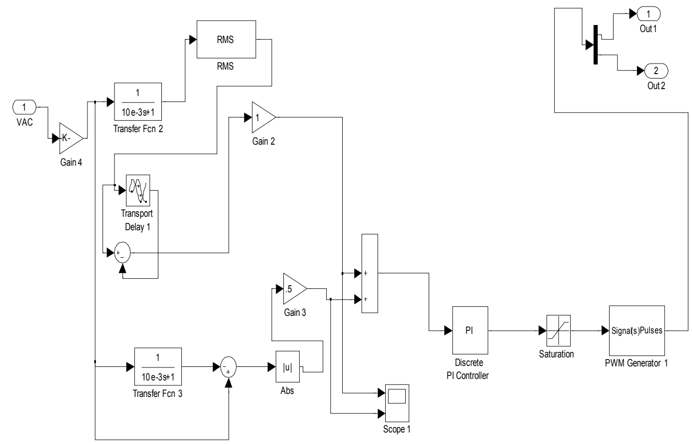


Fig. (3-d) Modulated Power Filter MPF Regulator at the common AC-Bus voltage stabilization

The DC-DC converter regulator compensates for any dynamic oscillations in DC-bus voltage together with the regulator of the PMDC generator voltage. The inverter and modulated power filter regulate the AC-Bus. The loop weighing factors are assigned to ensure loop time scaling and dominant control action. In each regulator the total error signal is the summation of the separate control loops and is fed into PI controller. The total error signal to ensure maximum power utilization of the multi-loop is driven through PI controller that is used to compensate the dynamic total error in order to provide control signal, which is then converted to degrees as phase angles. This phase angles are then sent to the Pulse Width Modulated (PWM) generator through saturation to adjust the sequence of the two IGBT/Diode switch triggering. The parameters of PI controller are off-line selected to minimize the total summation of the error squares. The coordinated control scheme is able to guarantee the tracking of a time-varying trajectory with minimum steady state error.

IV. DIGITAL SIMULATION RESULTS

The integrated AC-DC system was digitally simulated using MATLAB/Simulink/SimPower software environment to validate the coordinated controller effectiveness under varying PV array parameters and load excursions. The integrated system model is subjected to a number of load excursions and wind speed variations. The system static DC load is increased by 50% at t= 6 s and the AC load is doubled at t=10 s. This system is controlled using the described two basic dynamic independent controllers regulating the operation of the electronic interface converters, namely DC-DC choppers and switching stages of the DC-AC inverter which are coordinated for regulated DC and AC-bus voltage control and voltage stabilization in case of sudden load excursions and solar parameter changes.

Figures (4- 5) show the digital simulation of the integrated system dynamic responses of DC-bus voltage and AC-bus voltage using multi-loop dynamic error driven PI control strategy. The PV and FC voltage and current are drawn in Figures (6, 9). The digital simulation using the Matlab/Simulink/Simpower Software Environment indicated that the excursions in system loads are compensated by the error driven controller of the DC-DC choppers, DC-AC inverter and modulated power filter. The change in AC load has a small impact of the system variables as the AC grid compensates this change. The effect of PV array temperature and isolation are investigated and the system response of common DC-bus voltage, voltage and current of PV array and fuel cell are drawn in Figures (10-14). The controller error response of DC Common bus is drawn in Fig. (15). The initial transient is due to charging capacitance of MPF by PWM switching action before stable operating conditions

In addition the simulation results validate the robustness of the coordinated hybrid PV/FC scheme. It is clearly shown that the proposed dynamic error driven error PI controller can ensure maximum utilization and voltage stabilization with acceptable steady state error. Moreover, the common DC and AC bus current is ripple free with minimum inrush currents and ripple excursion. The multi-loop control strategy can be further modified to ensure combined voltage stabilization and loss reduction in different green energy powered systems.

V CONCLUSION

The paper presents a hybrid FC/PV renewable energy utilization scheme for Village/Island electricity generation. The integrated renewable scheme utilized a coordinjated multi regulator error driven coordinated controller to ensure effective energy utilization, common DC and AC bus stabilization, enhanced power quality and near maximum energy utilization under varying operating conditions and load excursions. The integrated DC-AC system is digitally simulated and validated using the Matlab/Simulink/Sim-power Software environment. The sample study system comprises FC, PV array source with all interface, DC-DC converters, DC-AC inverter and modulated power filter compensator for AC bus stabilization. The operation of the multi-loop error driven controller scheme for green renewable energy utilization is fully validated under sudden DC load excursions and solar-radiation variation. A modulated power filter compensator was used as voltage stabilization at the AC common bus. Novel dynamic error driven regulators were utilized to ensure a stable common DC and AC interface buses with minimum voltage, current excursion and near maximum utilization. The concept of multi-regulator decoupled controller is now being extended to other integrated AC-DC Renewable energy systems.

VI- REFERENCES

[1] I. Altas, A. Sharaf, "Novel maximum power fuzzy logic controller for photovoltaic solar energy systems", Renewable Energy, vol. 33, pp 388-399, 2008.

[2] A. Sharaf, R. Chhetri, "A novel dynamic capacitor compensator/green plug scheme for 3-phase 4-wire utilization loads", Proceeding IEEE-CCECE conference, Ottawa, Ontario, Canada 2006.

[3] H. Fargali, F. Fahmy, M. A. El-Sayed, "Control and optimal sizing of PV-Wind powered rural zone in Egypt" Al-Azhar Engineering 10 th International conference, Cairo, Dec. 24-26, 2008.

[4] Eftichios Koutroulis, Kostas Kalaitzaiis and Nicholas C. Voulgaris, Development of a microcontroller-based, photovoltaic maximum power point tracking control system, *IEEE Transactions on Power Electronics*, Vol. 16, No.1, Jan., 2001, pp. 46-54.

[5] Castaner Luis and Santiago Silvestre, *Modeling Photovoltaic systems using PSpice*, John Wiley and Sons Ltd, 2002.

[6] Mohamed A. H. El-Sayed, Adel M. Sharaf, "An Efficient Hybrid Wave/Photovoltaic Scheme for Energy Supply in Remote Areas", accepted for publication in international journal of Renewable Energy Technology.

[7] I. H. Altas, A. M. Sharaf, " A photo-voltaic array simulation model for Matlab-Simulink GUI Environment", International Conference on Clean Electrical Power, ICCEP'07, May 21-23 Capri, Itelay, 2007.

[8] Naik, R.; Mohan, N.; Rogers, M.; Bulawka, A.; A novel grid interface, optimized for utility-scale applications of photovoltaic, wind-electric, and fuel-cell systems Power Delivery, IEEE Transactions on Volume 10, Issue 4, Oct. 1995 Page(s):1920 – 1926.

[9] J.J. Brey, A. Castro, E. Moreno and C. Garcia, "Integration of Renewable Energy Sources as an Optimized Solution for Distributed Generation," 28th Annual Conference of the Industrial Electronics Society 2002, vol. 4, 5-8 Nov. 2002,

[10] Adel M. Sharaf, Mohamed A. H. El-Sayed," Dynamic Control of Fuel Cell Powered Water Pumping Station", Accepted for presentation at International Conf. on Renewable Energies and Power Quality (ICREPQ) Valencia, Spain 15-17 April 2009.

[11] Mohamed A. H. El-Sayed, Adel M. Sharaf, " A Novel FACTS Dynamic Stabilization Scheme for Stand-alone Tidal Energy Conversion Systems", accepted for publication in International Journal of Renewable Energy Technology.

APPENDIX FOR SIMULATED SYSTEM PARAMETERS

PV- ARRAY:

V_{pv} = 200 V DC P_{pv}= 10 kW

Fuel Cell:

R_1 = resistance of first parallel (RC) circuit =0.496 Ω

C_1 = capacitance of first parallel (RC) circuit =1.55 E-3 F

R_m = Ohmic resistance of the fuel cell equivalent circuit =0.08074 Ω

R_2 = resistance of second parallel (RC) circuit =1.508 Ω

C_2 = capacitance of second parallel (RC) circuit =18.12 E-3 F

E_a=nominal fuel cell induced voltage=270 V

Static DC-Bus Load parameters:

DC Heating Load = 10 kW DC Lighting Load =5 kW

Static AC-Bus Load parameters:

AC load = 10 kW, Switchable AC load =10 kW

Modulated Filter at AC Bus:

C_1=C_2 = 85 µf R_f= 0.05 Ω L_f= 0.1 H

PI controller parameters:

PV and Wind DC-DC Chopper Regulators : Kp =5, K_I =1

Inverter and Modulated Power Filter Compensator : Kp =4.5 and K_I =1.25

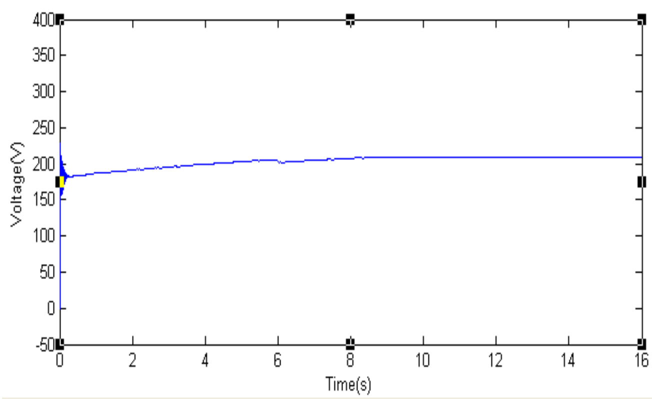
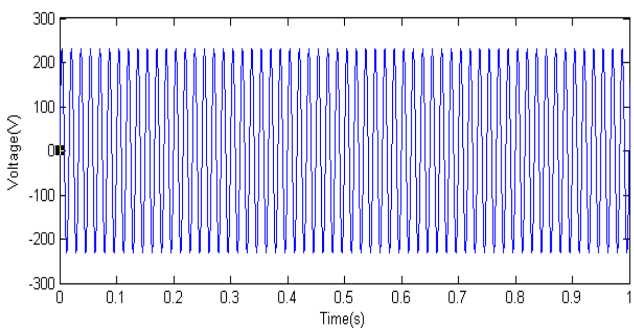


Fig.(4) Common DC bus voltage dynamic Response under



varying loading Conditions (increasing DC load by 50% at t=6 s, doubling AC load at t=10 s)

Fig.(5) Common AC bus voltage dynamic Response under doubling AC load at=0.5 s)

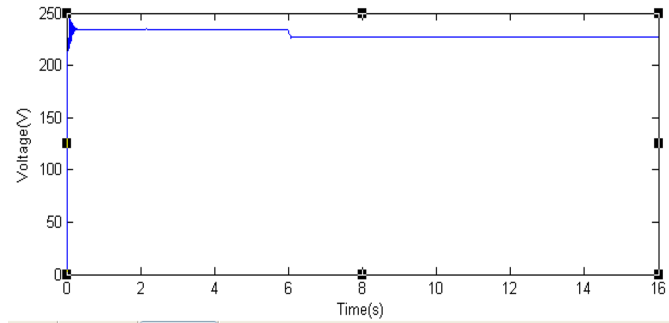


Fig.(6) Fuel Cell voltage dynamic Response under varying loading Conditions (increasing DC load by 50% at t=6 s, doubling AC load at t=10 s)

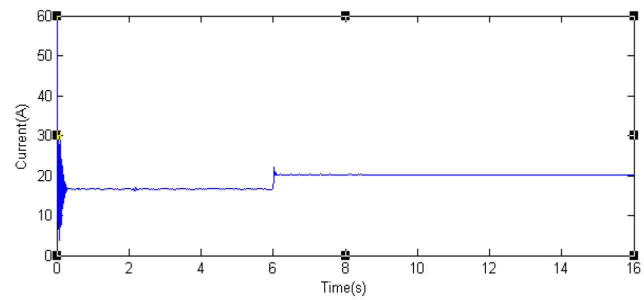


Fig.(7) Fuel Cell current dynamic Response under varying loading Conditions (increasing DC load by 50% at t=6 s, doubling AC load at t=10)

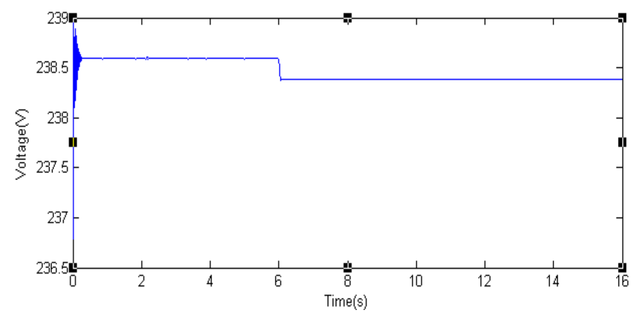


Fig.(8) PV array voltage dynamic Response under varying loading Conditions (increasing DC load by 50% at t=6 s, doubling AC load at t=10 s)

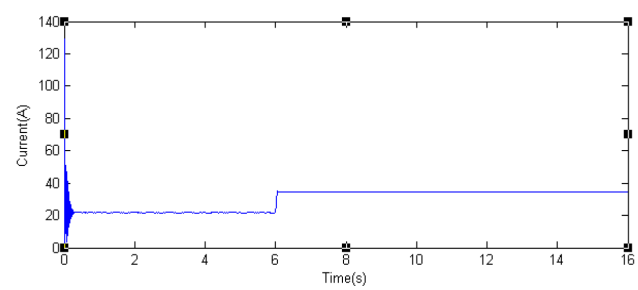


Fig.(9) PV array current dynamic Response under varying loading Conditions (increasing DC load by 50% at t=6 s, doubling AC load at t=10 s)

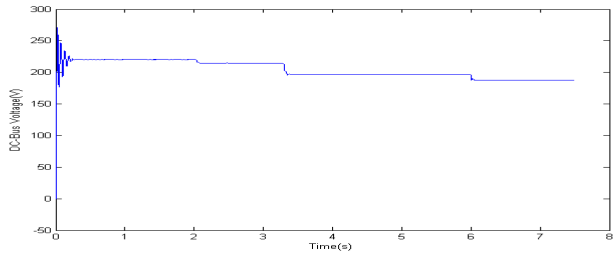


Fig.(10) Common DC bus voltage dynamic Response under varying load and weather Conditions (increasing DC load by 50% at t=6 s, increase PV array temperature by 50% at t=2.2 s and decrease solar isolation by 50% at t=3.5s)

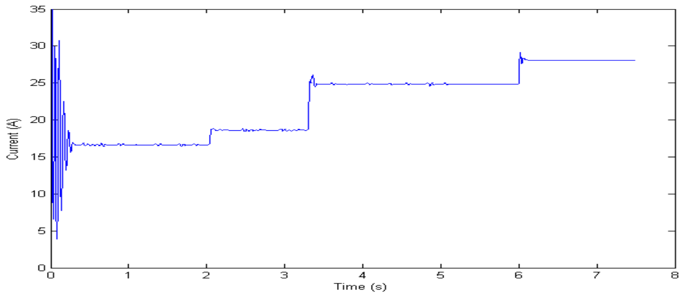


Fig.(11) Fuel cell current dynamic Response under varying load and weather Conditions (increasing DC load by 50% at t=6 s, increase PV array temperature by 50% at t=2.2 s and decrease solar isolation by 50% at t=3.5s)

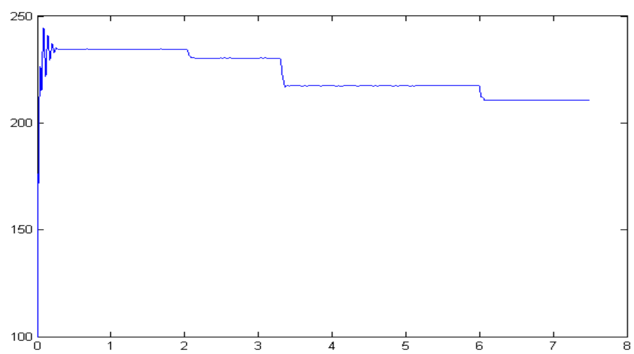


Fig.(12) Fuel cell voltage dynamic Response under varying load and weather Conditions (increasing DC load by 50% at t=6 s, increase PV array temperature by 50% at t=2.2 s and decrease solar isolation by 50% at t=3.5s)

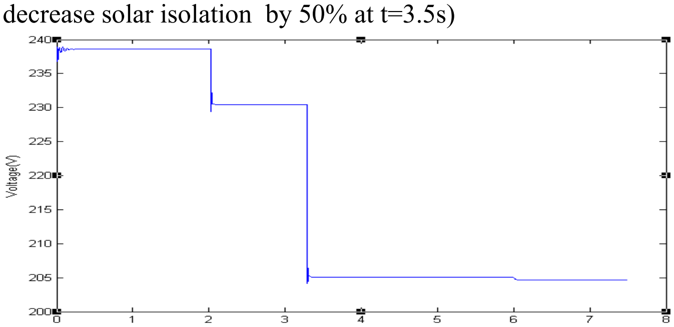
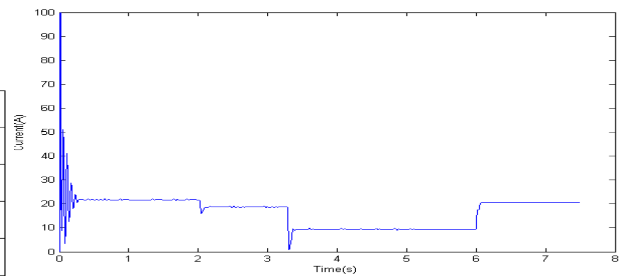


Fig.(13) PV array current dynamic Response under varying load and weather Conditions (increasing DC load by 50% at t=6 s, increase PV array temperature by 50% at t=2.2 s and decrease solar isolation by 50% at t=3.5s)

Fig.(14) PV array voltage dynamic Response under varying load and weather Conditions (increasing DC load by 50% at t=6 s, increase PV array temperature by 50% at t=2.2 s anddecrease solar isolation by 50% at t=3.5s)



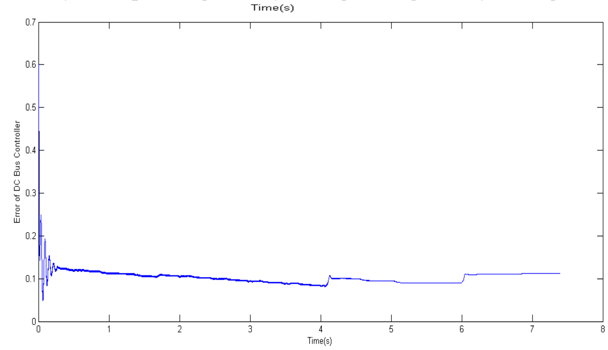


Fig. (15) Control Error of Regulator 4 of DC-DC converter

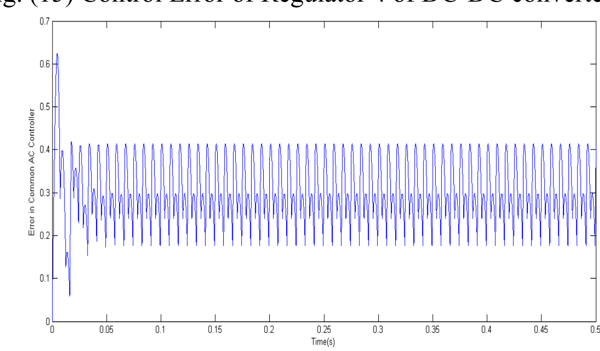


Fig. (16) Control Error of regulator 2 of DC- AC- Interface Inverter.