Hybrid Power Generation for Distributed Grid Applications

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Abstract: In this paper we propose a new, hybrid integrated topology, fed by photovoltaic (PV) and fuel cell (FC) sources are designed for distributed generation applications, is proposed. It works as an uninterruptible power source that is able to feed a certain minimum amount of power into the grid under all conditions. PV is used as the primary source of power operating near maximum power point (MPP), with the Fuel Cell section, acting as a current source, feeding only the deficit power. The coordination of two sources integrates the power generation at grid unit. The conventional dc/dc boost converter stage required for PV power processing, resulting in a reduction of the number of devices, components and sensors. Presence of the FC source in parallel (with the PV source) improves the quality of power fed into the grid by minimizing the voltage dips in the PV output. Another desirable feature is that even a small amount of PV power (e.g., during low isolation), can be fed into the grid. The main advantages of the proposed system include low cost, compact structure and high reliability, which render the system suitable for modular assemblies and "plug-n-play" type applications. All the analytical, simulation and experimental results of this research are presented.

Key words: Hybrid Systems · Grid connection · Fuel cell · DC-DC Boost Converters · Maximum power point Tracking

INTRODUCTION

The limitations of global resources of fossil and nuclear fuel, has necessitated an urgent search for alternative sources of energy. Therefore, a new way has to be found to balance the supply and demand without resorting to coal and gas fuelled generators. Smart grid is a system that would enable the integration of renewable energy sources and shift from reliance on fossil fuels, while maintaining the balance between supply and demand.

Hybrid power system is a combination of renewable energy technologies. India is becoming one of the developing countries in this world. The developing growth of the population and the increasing amount of energy conservation are the key factors. To prevent consumers from lagging of power and to meet their demands, hybrid system is an exact solution. These resources are going to connect in to the National grid or utility grid. The hybrid power plant is a complete electrical power supply system that can be easily configured to meet a broad range of remote power needs. Solar-wind, hydro-wind, wind-diesel, solar thermal-biomass etc. are the well known hybrid power generation system. The energy management is required to determine the optimum combination of energy systems. A software tool is developed to design hybrid renewable energy system and to determine the optimum combination of technologies for energy management of complex integrated system. This software tool sets the priorities for energy production and energy storage for each system technology [1-5].

Previous Research: Numerous related research works are already existed in literature which based on Hybrid power generation circuit of the system. Some of them are reviewed here.

Chimaobi N. Onwuchekwa *et al*. [6]. presented the modeling and simulation of a switching strategy that modifies the time-sharing concept, alleviates the difficulties associated with controlling multiple switching functions for conventional timesharing MICs and, thus, permits more input legs to be utilized. The proposed strategy enables switching functions for MICs that have

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a greater number of input legs to be generated with relative ease. Another benefit of this scheme is that it allows an MIC's output voltage to be regulated by employing the CDR as the only control variable, irrespective of the number of input legs present.

Sweeka Meshram *et al*. [7], presented simulation modeling of the grid connected DC linked PV/Hydro hybrid system has been done. The DC bus of the PV and hydro system has been common linked to reduce the cost and complexity of the hybrid system. The hybrid system acts as a dominant system and power grid will be acts as a standby to compensate the deficit in the hybrid system. In rainy days/night, the solar energy will be unavailable, hence the power requirement will fulfilled by hydro system and power grid. In summer, the hydro power will be less; in that case the power requirement will be fulfilled by the PV system and power grid. In other days, the power will be fed by the PV/Hydro hybrid system. Thus, the power requirement throughout the year can be satisfied by the proposed system. The proposed system is tested under the linear resistive, RL and Induction Motor (IM) as a dynamic load.

E.M. Natsheh, *et al*. [8], Implemented the model of smart grid-connected PV/Wind hybrid system was developed. It comprises photovoltaic array, wind turbine, asynchronous (induction) generator, controller and converters. The model was implemented using MATLAB/SIMULINK software package. Perturb and observe (P&O) algorithm was used for maximizing the generated power based on maximum power point tracker (MPPT) implementation. The dynamic behavior of the proposed model is examined under different operating conditions. Solar irradiance, temperature and wind speed data is gathered from a grid connected, 28.8kW solar power system located in central Manchester. Real-time measured parameters are used as inputs for the developed system. The proposed model and its control strategy offer a proper tool for smart grid performance optimization.

Lingareddy V., *et al*. [9], has focused in modeling and simulation of incremental conductance algorithm of maximum power point tracking (MPPT) method used in photo voltaic/wind hybrid electric power system inter connected to the electric utility. PV/wind HEPS, taking into account all radiation, temperature, variation of wind speed and load demand. The resultant system is capable of tracking MPPs accurately and rapidly without steady-state oscillation and also, its dynamic performance is satisfactory. The incremental conductance algorithm is used to track MPPs, because it performs precise control under rapidly changing atmospheric conditions. MAT

LAB and SIMULINK were employed for simulation studies. Simulation results indicate the feasibility and improved functionality of the system. The main objective of this paper is maximizing the PV output power and wind energy system (WES) output power independently by tracking the maximum power on every operating condition by using MPPT technique and interconnected to utility grid.

Mohammad Hoseintabar *et al*. [10], presented a comprehensive dynamic modeling and power management of hybrid power generation including renewable power generation and energy storage system in grid connected applications. The studied system consists of Wind Turbine (WT), Fuel Cell (FC) as power generation systems and super capacitor as storage system. Due to unpredictable dynamic behavior of Wind, the FC system was used to enhance the reliability of studied system. However, the FC system have slow dynamic. To solve this problem, super capacitor is used to supply load demand completely. The basic target of this system is that the hybrid system satisfies domestic load completely and the excessive power can be sent to grid system. The real data's of weather are used to be this research more applicable.

The main disadvantages of the above references are that the complexity in the design, cost and power scarcity. To overcome the drawbacks we propose a new model, control and simulation of a smart grid-connected Hybrid power generation system is proposed. Modeling and simulation are implemented using MATLAB/SIMULINK and Sim Power Systems software packages to verify the effectiveness of the proposed system.

Proposed Approach: The proposed topology is built with three sources (Fuel cell, PV1 and PV2) and a buck-boost converter topology capable boosting and bucking the voltage and MPPT. The basic idea behind the proposed integrated configuration is shown in Fig. 1. A combination of PV and FC sources feeds the proposed Hybrid configuration. FC source is interfaced through a buck-boost type dc–dc converter, as shown in the figure. An extra block is added for PWM generation to improve the excess power generated by the PV source.

The proposed system is designed to meet a certain minimum active power demand from the grid side. PV is the main source, which is continuously made to track the MPP, while feeding the required amount of power into the grid. The FC source, with boost type dc–dc converter, acts as a current source in parallel with the PV source. It is only used to supplement the PV source during low or zero isolation.
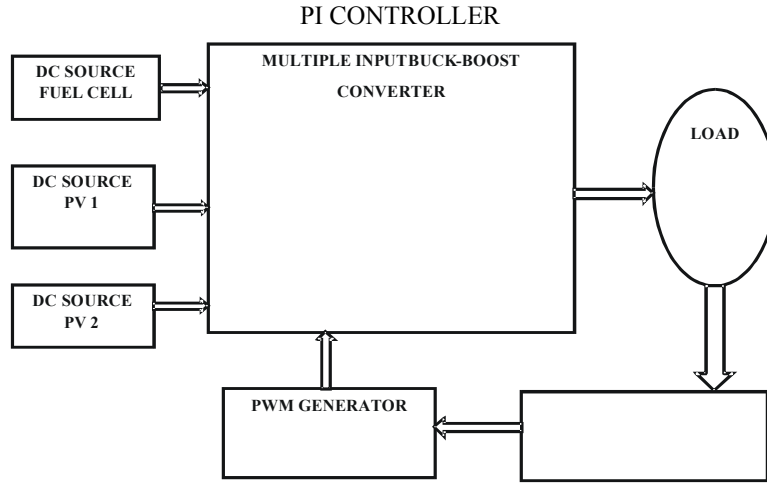
PI CONTROLLER

Fig. 1: Proposed configuration diagram of proposed system

A combination of PV and FC sources forms a good pair with promising features for Grid applications. Of course, the slow response of the FC needs to be compensated with a battery.

The proposed system consists of three operating modes. Those are.

Mode I: Only PV mode (only PV provides power).
Mode II: Hybrid mode (both PV and FC provide power).
Mode III: Only FC mode (only FC provides power).

These operating modes are summarized in Table 1.

Mathematical Model: The inputs to the solar PV panel Air temperature (25°C), solar strength (1000). Then the Maximum power is calculated by using Open circuit Voltage and Short circuit current which is given by.

$I = (Tair, S, V)$
$K = 0.03;$
$T = Tair + K*S$ (1)

The maximum power is obtained from the following values,

$Vm=100.8, Im=28.05, Voc=120.03$ and $Isc=30.3$ (2)

Table 1: Operating Modes

Operating Mode	Condition	Active Sources
I	$P_{pv}-P_{req} \geq 0$	Only PV
II	$P_{req} - P_{pv} \geq 0$	Both PV& FC
III	$Ppv = 0$	FC

where the constant values are,

$a=0.0025$, $b=-0.1949+7.056*0.0001*S$ and $c=0.00288;$

The input signals for the panel are given by,

$Tref = 25;$
$Sref = 1000;$
$AT = T-Tref;$
$AS = S/Sref-1;$

The open circuit Voltage and Short circuit voltage is calculated from the equation (2),

$I\_sc=Isc*S/Sref*(1+a*AT)$ (3)

$V\_oc=Voc*(1-c*AT)*(1+b*AS)$ (4)

$I\_m=Im*S/Sref*(1+a*AT);$
$V\_m=Vm*(1-c*AT)*(1+b*AS);$
$C2=(V\_m/V\_oc-1)/(log(1-I\_m/I\_sc));$
$C1=(1-I\_m/I\_sc)*exp(-V\_m/(C2*V\_oc));$

From the equation (3) & (4)

$I=I\_sc*(1-C1*(exp(V/(C2*V\_oc))-1))$ (5)

The P&O algorithm is easy to implement and is most commonly used in battery charging with commercial PV modules. In this method, the operating voltage or current of the PV module, is perturbed and then the power obtained is observed to decide the direction of further changes in the voltage or current.
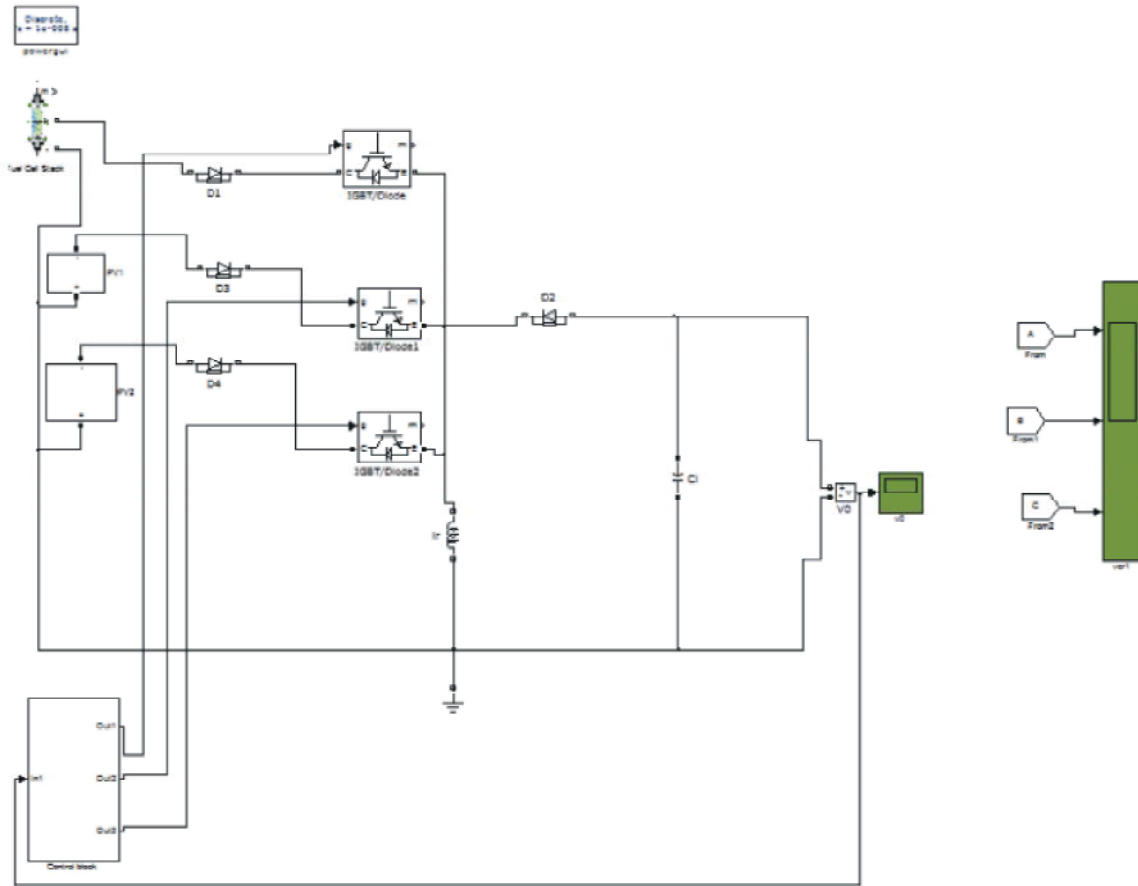
Fig. 2: Simulation circuit diagram of proposed system
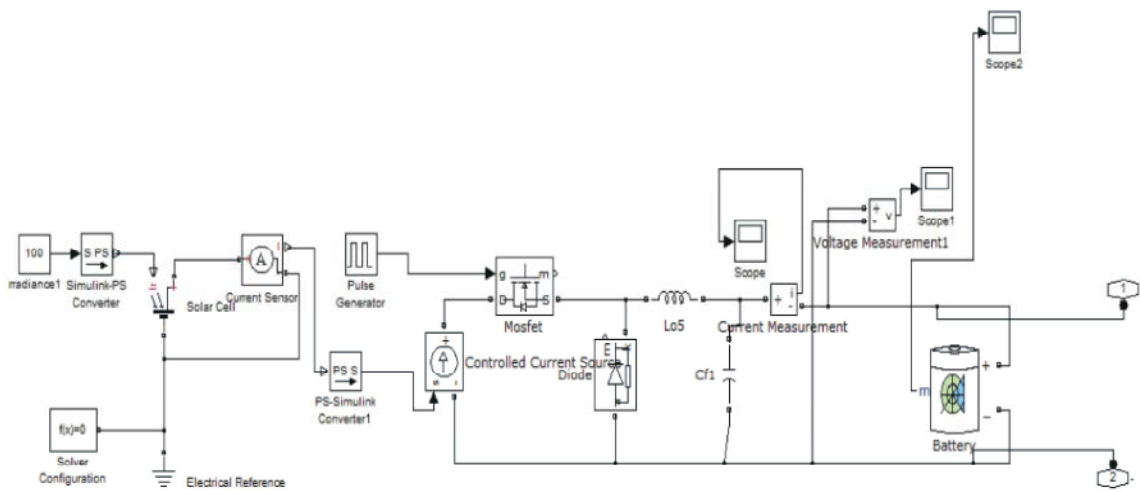
Fig. 3: PV design using MPPT Algorithm

If the power is increased by the perturbation then voltage or current is kept on changing in the same direction until the power begins to fall. The algorithm measures the instant voltage (Vt) and current (It) to calculate the power (Pt) and then compare it with last calculated power (Pt-1). The algorithm continuously perturbs the system if the operating point variation is positive, otherwise the direction of perturbation is changed if the operating point variation is positive [11, 12].

Fig. 4: Simulation result for input Voltage Vin & current I in

The simulation circuit of proposed system implementation is shown in Fig. 2. The system comprises of a Fuel cell stack and PV modes with boost converter power stage controlled by a Switch to achieve highly efficient output using MPPT Algorithm. The panel parameters are shown in the subsystem circuit in Fig. 3. The main components of the proposed system are the Fuel cell, PV generator, boost DC-DC Converter with the user loads.

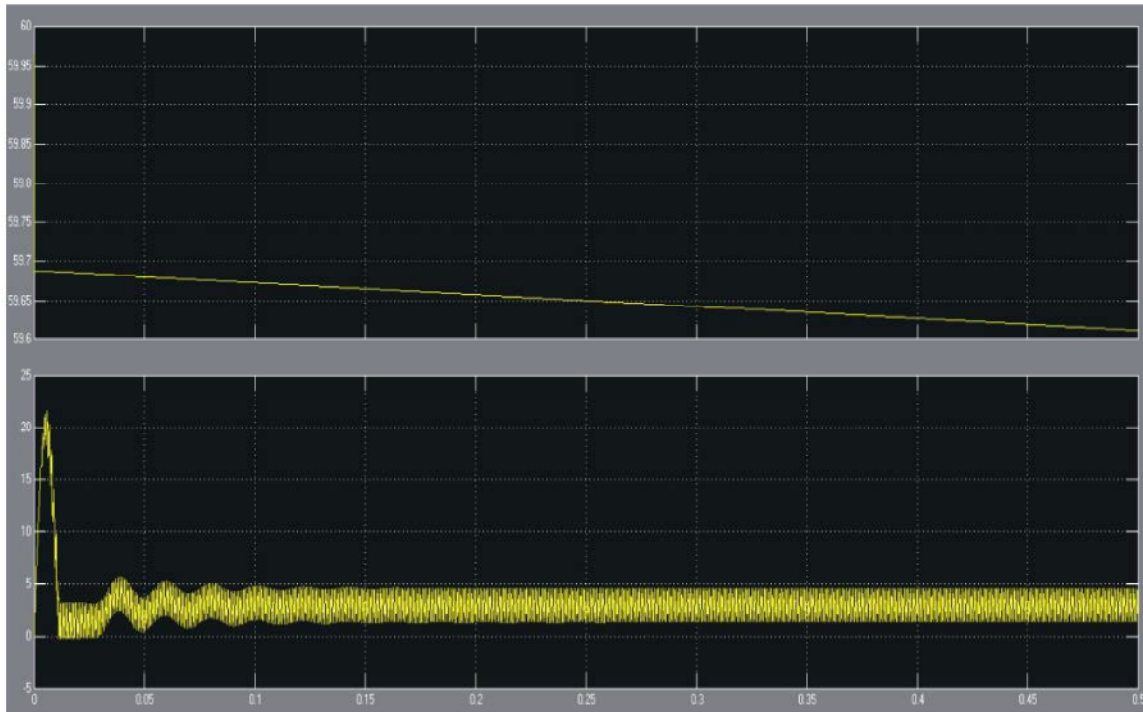The inputs to the solar PV panel are temperature (25°C), solar strength (1000) and the Voltage across the solar cells. The Embedding Matlab function of Proposed MPPT is shown in Fig. 3.

In using solar energy as renewable energy, solar cells offer a potentially attractive means for the direct conversion of sunlight into electricity with high reliability and low maintenance, as compare with solar-thermal systems. The present disadvantage is high cost to build it and the difficulty of storing large amounts of electricity for later use. The cost of solar cells is expected to be considerably reduced when cell are manufactured in large quantities using new production techniques for obtaining ribbons or sheets of single crystal silicon.

RESULTS AND DISCUSSIONS

The major inputs for the proposed PV model were solar irradiation, PV panel temperature and voltage and current information's. The I-V output characteristics for the PV model are shown in following simulation results.

From Table 2, once the electrical power transfers from the solar panel to the load and the controller start function, output value of the solar panel do not provide same input voltage value to controller (Vin). This is because the controller function that varies the value of duty cycle will change the input value that sense by the controller.

Experimental Setup: Hybrid systems and the efficient and ecologic technologies to ensure an optimal use of the sources (solar energy, wind energy, hydrogen energy by using fuel cells, hydro-energy, biomass) in industry and residential buildings. The battery and the fuel cells are also meant to be reserve sources (which ensure the additional energy requirements of the consumers and the supply of both the residential critical loads and the critical loads of the hybrid system-auxiliary circuits for fuel cell

Table 2: Comparison of parameter values

Parameters	Estimated values
Iin (A)	4.7
Vin (V)	59
Pin(W)	277
Iout (A)	5
Vout (V)	128
Pout(W)	640

Fig. 6: Simulation result for Output Current Iout & Voltage Vout

Fig. 7: Hardware setup

start-up and operating), increasing the safety of the system. The fuel cell integration is provided by using a unidirectional DC/DC converter (to obtain regulated high voltage DC), an inverter and a filter in order to accommodate the DC voltage to the required AC voltage (single phase or three phase). The bidirectional DC/DC converter (double arrow, Fig. 5) is used in order to charge/discharge the batteries (placed in order to increase the energy supply security and to improve load dynamics). The unidirectional DC-DC converter prevents the negative current going into the fuel cell stack. Due to the negative current, the cell reversal could occur and damage the fuel cell stack. The ripple current seen by the fuel cell stack due to the switching of the boost converter (unidirectional DC/DC converter) has to be low.

With this respect only one inverter is used in DC-AC conversion for interfacing the stand-alone or grid connected consumer. By its control, the inverter can ensure the efficient operation and the accomplishment of the energy quality requirements related to the harmonics level. The hybrid system can ensure two operation modes: the normal one and the emergency one (as backup system).

Hardware Construction and Operation
Direct Supply from Utility: Consists of direct supply of the residential consumers from Utility via the Static Switch;

Precharge Operation: The DC capacitors in the inverter part of the Power Conditioning.

System (PCS) can be precharged from the AC busutility. After the DC capacitors are charged, the inverter can be switched on. As soon as it is running, the inverter by itself will keep the DC capacitors charged to a DC level higher than the No-Load level of the Solid Oxide Fuel Cell (SOFC). During the precharge operation, the residential consumers will still be supplied from Utility;

Normal Operation: The PCS converts the DC energy from the SOFC into AC and feeds the Utility and the eventual residential consumers.

Island Operation (Failure Operation Mode): If the Utility goes out of tolerance during normal operation, the PCS will change to island operation. The PCS converts the DC from SOFC and battery and supplies the critical loads.

Fig. 8: The three phase load currents, the corresponding duty cycles, the actual and the reference line currents for the accurate tuning of the current regulator parameters: Kp=18, Ki=105
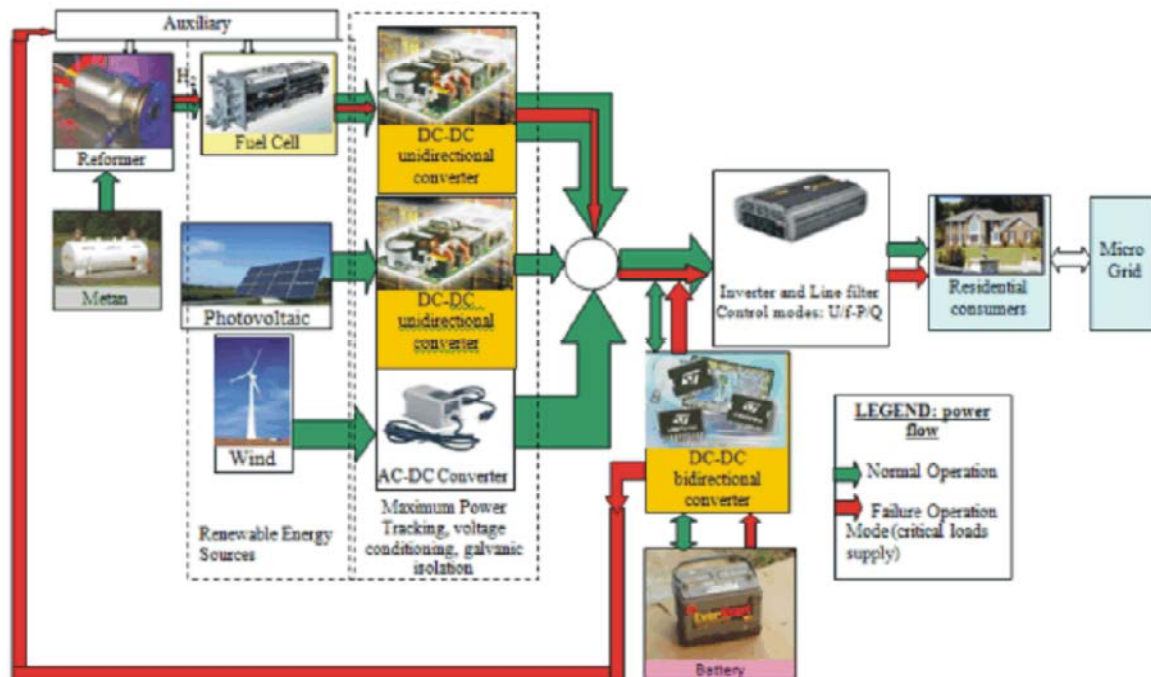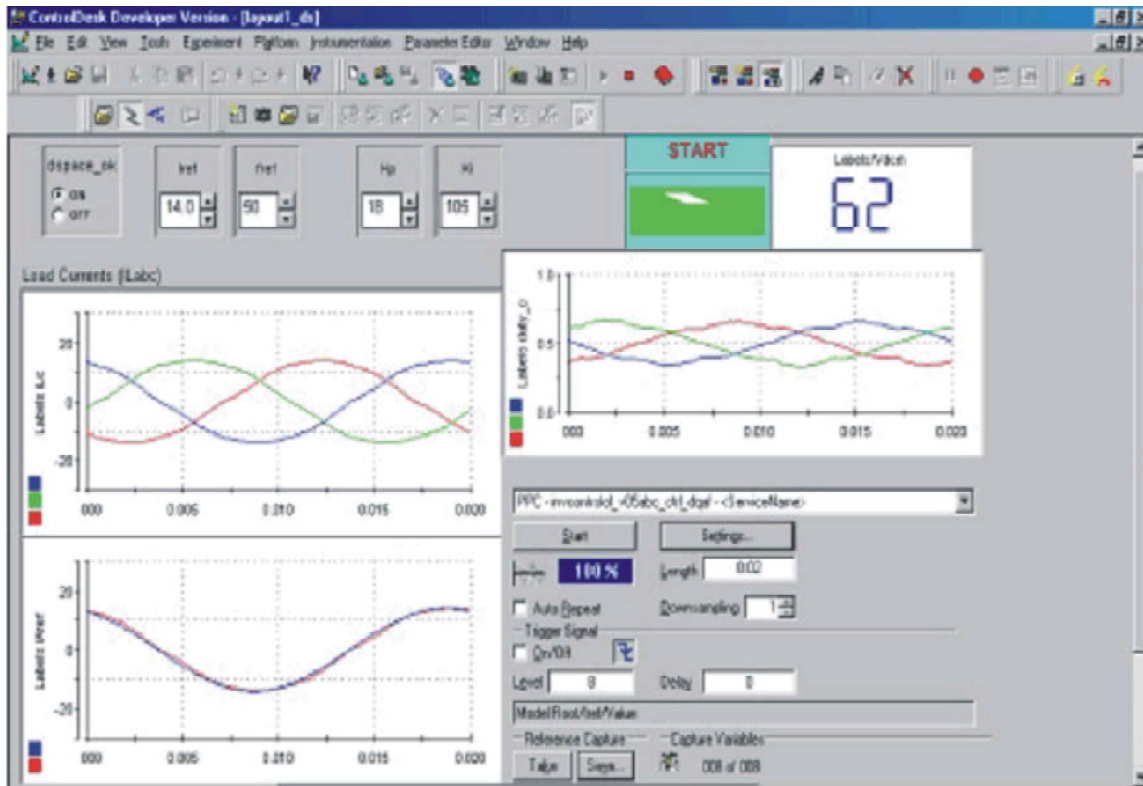
Fig. 8: The three phase load currents, the corresponding duty cycles, the actual and the reference line currents for the inaccurate tuning of the current regulator parameters: Kp=9, Ki=42

Real time implementation of the current control by using dSpace 1103 platform is shown in below results.

CONCLUSION

A compact topology, suitable for grid-connected applications has been proposed. Its working principle, analysis and design procedure have been presented. The topology is fed by a hybrid combination of PV and FC sources. PV is the main source, while FC serves as an auxiliary source to compensate for the uncertainties of the PV source. The proposed system is to increase the awareness of public regarding the renewable energy technologies through the open access and to determine the researchers to implement renewable energy projects. It will contribute the promotion of RES through the formation of experts so that these experts can later carry out RES projects with outstanding results.

The conventional dc/dc boost converter stage required for PV power processing, resulting in a reduction of the number of devices, components and sensors. Presence of the FC source in parallel (with the PV source)

improves the quality of power fed into the grid by minimizing the voltage dips in the PV output. Another desirable feature is that even a small amount of PV power (e.g., during low isolation), can be fed into the grid. The main advantages of the proposed system include low cost, compact structure and high reliability, which render the system suitable for modular assemblies and "plug-n-play" type applications.

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