PERFORMANCE ANALYSIS AND SIMULATION OF A GRID INCORPORATED PV SYSTEM ADOPTING FUEL CELL

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Abstract – The world's energy necessity is increasing steadily as the world's population as well as demand for supply balance in equilibrium, and so the requirement to create electrical energy has increased. In certain isolated places, replacing ageing electrical networks is costly and a complex remedy, necessitating the usage of renewable energy sources. A technology that has seen remarkable improvement in recent years is green energy production with FCs. Fuel cells have a number of merits when compared to traditional batteries since these fuel cells generate energy with burning of fuel rather than accomodating it, like batteries do. Hence forth, a novel approach describing a grid incorporated PV system adopting a fuel cell is proposed. It acts as an alternate solution for fault condition or grid interruption upholding the supply of power. The flow of power within the FC as well as grid is controlled with the described approach. The converter generates optimized voltage level preventing fluctuations and the transformer improves the level of voltage for supplying to the grid. The system's performance is analysed with the exploitation of various conditions of load and the obtained waveforms indicate improved efficiency.
Keywords: Photovoltaic system, fuel cell, boost converter, DC-AC inverter, transformer, utility grid.

1 INTRODUCTION

The necessity to expand electricity production has become critical nowadays owing to the rising energy demand in home as well as commercial utilizations. Electricity is obtained from a variety of sources, with renewable resources being significant because of their economical as well as environmental benefits. Numerous elements like photovoltaic (PV) modules, diesel generators, fuel cells (FC) are integrated for the generation of a hybrid system thus providing an energy system which is stable and cost-efficient [1]. In order to generate energy globally, the utilisation of alternative energy resources is becoming more vital as a result of technological advancements [2, 3]. The energy resources which are renewable are frequently blended with traditional fossil fuel-dependent sources of energy in hybrid systems as an efficient option. In these hybrid systems, an energy source that has the ability to be dispatched is employed to boost system reliability in deficit conditions caused by the uncertainess and lack of predictability of renewable resources. Off-grid hybrid systems and grid-connected systems are also viable options. In grid-tied mode, the hybrid system exchanges electricity with the grid, however for exchange of power, no grid is present in off-grid mode. A storage device is an important element in off-grid hybrid systems [4-8]. In hybrid systems, size optimization and energy control are critical concerns. Energy storage modelling in size problems, regulating ability and component sizing in microgrids, optimum sizing related to energy storage of lithium battery in grid-connected mode, control of multi-operation in hybrid systems have all been investigated [9, 10].

Fuel cells (FC) are the subject of recent research as an energy storage device. Fuel cell systems, among alternative energy sources, are becoming more appealing year after year caused by high electricity generation and low / zero gas emissions. Fuel cells are used in the integration of energy grids in recent years as capacity has increased. The gridconnected fuel cell system is similar to photovoltaic systems in which it integrates grid and fuel cell systems [11-13].

In commercial and domestic applications, FC has seen remarkable expansion. Fuel cells holds an advantage compared to traditional batteries in which they create energy when they have access to hydrogen and oxygen. Commercially constructed buildings, vehicles, data centres, towers for telecommunication, hospitals, off-grid areas benefit from fuel cell-based power generation [14-16]. Moreover, when compared to the intermittent functioning of solar as well as wind energy sources, FCs help enhances the efficiency of system related to power management and stability [17]. Consequently, grid incorporated applications regarding connections of single-phase as well as three-phase electric grid have used fuel cell energy generating units [18-20]. FC energy systems are deliberately situated adjacent to distribution line to bolster the electrical grid, reducing the electric grid's instant variations and boosting its effectiveness and security [21, 22]. The electric energy generated by FC stacks is transferred to electrical grids via regulated interface devices. The grid-tied FC technology assures a shared energy supply within grid and the local load [23]. These systems successfully supply consumers with energy flow, minimum distortion, and safe operation. Unfortunately, various local loads, like electrical machines, transformers, capacitors and inductors lead the reactive power as well as power factor in electrical systems to increase because their currents are phase-inverted compared to the voltage [24-26]. Considering these factors, an efficient grid connected PV system is proposed in this approach which adopts a fuel cell. It generates optimized level of voltage preventing fluctuations. This approach also provides activated power supply from the FC to the grid.

The succeeding part of this work comprises of: Section 2 with related works, section 3 includes proposed topology, section 4 with attained results and section 5 includes conclusion.

2 RELATED WORKS

Mohamed et al [27] presented an improvement of power quality in FC incorporated with a power network across an inverter and a chopper. It utilized a traditional PI controller to drive the connected inverter for governing the driving voltage within the power network and FC. The current regulator is also driven by the controller at various voltage swell and sag conditions.

Okundamiya et al [28] described a size optimization for FC/PV system. An optimal size for the hybrid system is maintained for satisfying the demand for load. The proposed approach generated minimized energy cost and emission of carbon. It also alleviated the carbon emission from other sources of power generation for resulting in eco-friendly environment.

Guiying et al [29] presented a control for grid connected FC plant under changing network parameters and load. A DC-DC converter was adopted to regulate the link voltage and resulted in improved performance related to linear condition. The error in steady state condition was eliminated and did not vary with noise of high frequency.

Mohiuddin et al [30] designed a non linear control for FC which is connected to grid. It dealt with the generation of reactive as well as active power to the grid from FC under various conditions of operations. A linearization approach was applied for the regulation of the current corresponding to the reactive as well as active power.

3 PROPOSED TOPOLOGY

The schematic representation of the introduced approach is given in figure 1. It comprises of a fuel cell and a photovoltaic system connecting to corresponding DC-DC converter. The converter is further integrated to a three phase inverter for the inversion of input DC voltage to AC voltage. The transformer utilized increases the voltage in order to connect to the main / utility grid, and it is also utilized in home appliances in the absence of boosting of voltage. The complete design is linked to the utility grid across a switch.

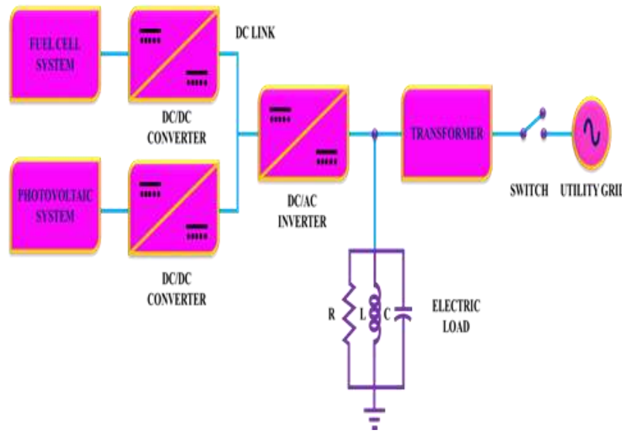

Figure 1 Block diagram of the proposed approach

3.1 Photovoltaic System

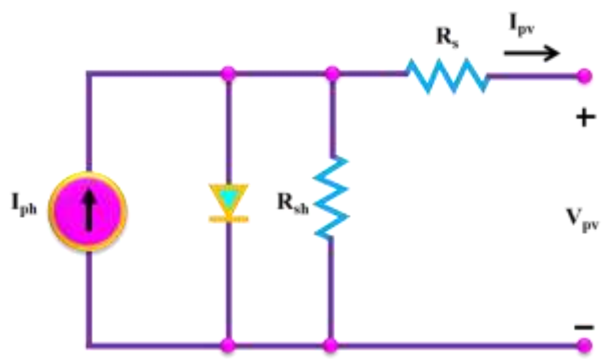

Figure 2 Photovoltaic system

The basic circuit of the PV system is illustrated in figure 2. Modeling of PV cells is performed as a current source which is connected in parallel across a single diode. It also includes the shunt as well as series parasitic effects. The characteristics of the current as well as voltage of the PV panel is given by,

$$I_{pv} = N_p I_{ph} - N_p I_o \left(exp\left[\frac{q}{nK_bT_c} \left(\frac{V_{pv}}{N_s} - \frac{I_{pv}R_s}{N_p} \right) \right] - 1 \right) - \frac{N_p}{R_{sh}} \left(\frac{V_{pv}}{N_s} - \frac{I_{pv}R_s}{N_p} \right) \quad (1)$$

Here, I_{pv} : output current
V_{pv} : output voltage
I_o : reverse saturation current
I_{ph}: photo current
q : charge of electron

T_c : temperature of cell
K_b: Boltzmann constant
n : diode ideality factor
N_s, N_p: series and parallel cells
R_s, R_{sh}: series and shunt resistance

3.2 Fuel cell system

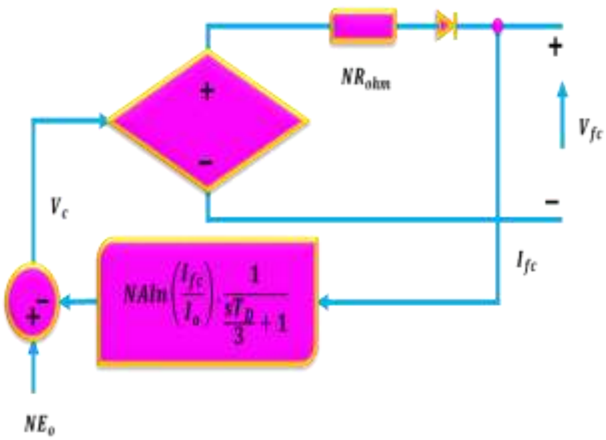

Figure 3 Fuel cell

The fuel cell utilized is depicted in figure 3 and operates at a minimal temperature. It has the ability to initiate its functioning rapidly from the idle situation to full load situation. The FC is of 6kW and the parameters are attained from the provided datasheet or the simple curve for polarization. Owing to the losses generated by diffusion, resistivity and activation, the cell's output voltage is obtained as,

$$V_c = E_o - Aln\left(\frac{I_{fc}}{I_0}\right)\frac{1}{\frac{sT_D}{3}+1} - I_{fc}R_{ohm} \tag{2}$$

Here, E_o, A : empirical coefficients
I_{fc}, I_0 : fuel cell and exchange current
R_{ohm}: resistance of combined cell and diffusion
T_D : cell settling time

The voltage obtained at the output of the fuel cell is given by,

$$V_{fc} = N \times V_c \tag{3}$$

Here N denotes the number of cells.

3.3 EMS for PV and FC System

An improved energy management system (EMS) is developed considering the dynamic sharing of power within the FC and PV sources. It satisfies the power demand of the grid and reduces the effects caused because of the uncertainities of power obtained by PV system. The normal as well as unbalanced modes of operation are considered. This helps the FC-PV source for assisting the grid during voltage sag. The PV system is considered as the primary source for providing power and if any deficiency occurs, it is tackled by the FC.

Considering a normal operation, the real power demand $p^*(t)$ and the reactive power demand $q^*(t)$ is obtained at the grid operator. At the occurrence of voltage sag, $p^*(t)$ is attained from the grid operator and $q^*(t)$ is equal to the reactive power fault $q_{fault}(t)$ and is given by,

$$q_{fault}(t) = \begin{cases} 0\,, \ V_{sag}(t) \le 0.1 \\ 2V_{sag}(t)q^{max}, 0.1 < V_{sag}(t) \le 0.5 \\ q^{max}, V_{sag}(t) > 0.1 \end{cases} \tag{4}$$

Here, q^{max}: maximal value of reactive power generated bt FC-PV source.

$$V_{sag}(t) = \left[1 - \frac{min\left(V_{grid,m}^{rms}(t), V_{grid,n}^{rms}(t), V_{grid,o}^{rms}(t)\right)}{V_{base}}\right] \tag{5}$$

Here, $V_{grid,m}^{rms}(t), V_{grid,n}^{rms}(t), V_{grid,o}^{rms}(t)$: rms voltage at grid terminals.

The scaling factor k_s is also estimated by EMS which avoids the overcurrent caused because of voltage sag. It also performs curtailing of delivered active power to the grid.

$$k_s = \begin{cases} 1 - \frac{k_{s1}}{max(i_m(t), i_n(t), i_o(t)\ )}, V_{sag}(t) > 0.1 \ and \\ \quad max(i_m(t), i_n(t), i_o(t)\ ) > I^{max} \\ 0, \qquad otherwise \end{cases} \tag{6}$$

Here, $k_{s1} \le max(i_m(t), i_n(t), i_o(t)\ )$: positive droop coefficient depending on the value of overcurrent
I^{max}: maximum permissible current in single phase.

3.4 DC-DC Boost Converter

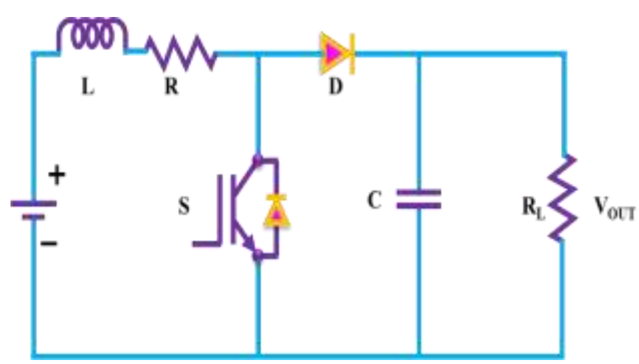

Figure 4 Boost converter

The voltage obtained from the PV system is minimum and hence in order to step up the voltage, a DC-DC boost converter indicated in figure 4 is utilized in this approach. The matching of the magnitude of the input voltage is performed with the appropriate output voltage. The basic circuit comprises of a diode, an inductor as well as a switch of increased frequency. The manipulation of the switch duty cycle is carried out that further stimulates the change of voltage.

The duty cycle of the boost coverter is given by,

$$D = 1 - \frac{V_{IN}}{V_{OUT}} \quad (7)$$

The minimal inductance value is expressed as,

$$L_{MIN} = \frac{(1-D)^2 \times D \times R}{2 \times f} \quad (8)$$

Where : switching frequency

R : output boost resistance

The minimal capacitance is given by,

$$C_{MIN} = \frac{D}{R \times f \times V_R} \quad (9)$$

The value of the inductance is obtained from the continuous conduction mode of operation. The current across the inductor flows continuously and the voltage at the output depends on the output capacitance.

3.5 DC-AC Inverter

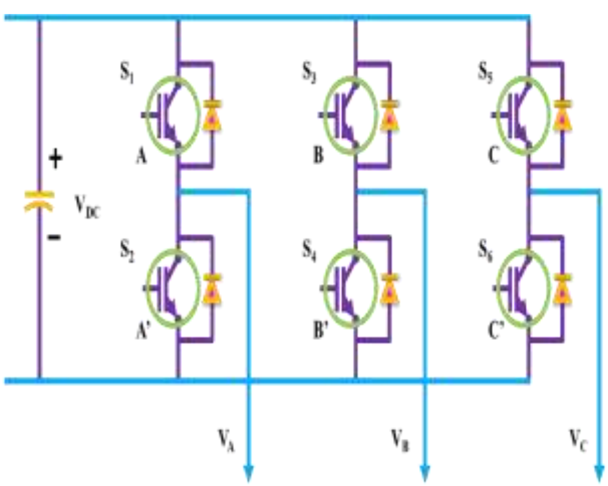

Figure 5 Three phase voltage source inverter

A three phase voltage source inverter indicated in figure 5 is utilized for the inversion of input DC voltage to AC voltage. The circuit comprises of six insulated gate bipolar transistors (IGBT) connected in parallel across corresponding diodes. The IGBTs generate relevant gating signals adopting the PWM gating signal generator utilizing a switching frequency. The inverter is exploited for supplying active power to the control reactive power exchange and grid from the fuel cell.

3.6 Transformer

A transformer is regarded as an discretional component and is utilized for transforming the resulting voltage to an increased value. Here, the rating of power is 20 KVA and it steps up the input AC voltage for connecting the system to the grid.

3.7 Load/Grid

A utility grid of single phase 220 V/50 Hz is adopted in which two resistive loads are linked in parallel across the grid.

4 RESULTS AND DISCUSSION

The simulation of the proposed approach is carried out by MATLAB/SIMULINK. The parameters of the system components are indicated in the table below.

Table 1 System parameters

Parameters	**Value**
PV system	
Maximal power	235.06W
Open circuit voltage	36.9V
Voltage at MPP	29.4V
Short circuit current	8.48A
Current at MPP	7.9A
Temperature coefficient of open circuit voltage	-0.343%/^{o}C
Cells /module	60
Temperature coefficient of short circuit current	0.046%/^{o}C
Ideality factor of diode	0.97
Series resistance	0.395 Ω
Shunt resistance	238.7 Ω
Fuel cell	
Cell number	110
Voltage at 0A, 1A	106.1V,104.6V
Nominal operating point	260A,73.4V
Maximum operating point	320A, 64V
Boost converter	
Inductor	0.5mH
Capacitor	20µF
Switch	IGBT

The obtained output waveforms are given as follows.

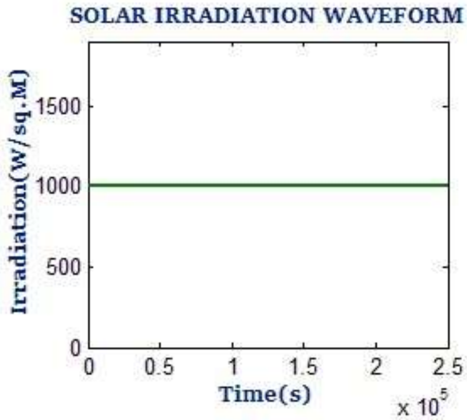

Figure 6 Solar irradiation waveform

Figure 6 represents the waveform for solar irradiation and figure 7 represents the waveform for temperature.Figure 8 indicates the waveform for solar panel output which is equal to 30V.

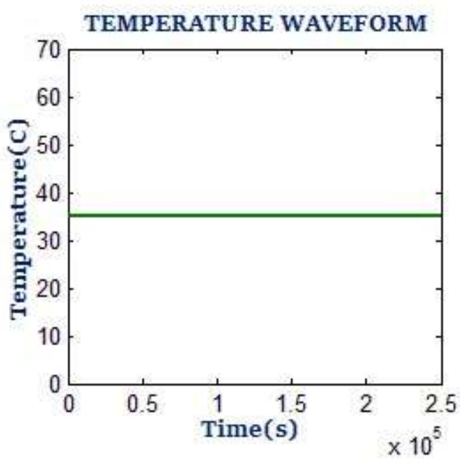

Figure 7 Temperature waveform

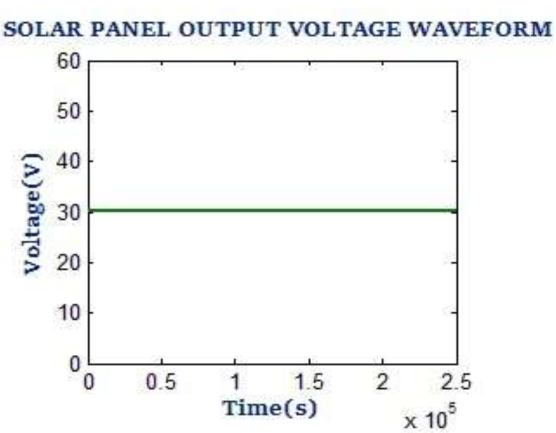

Figure 8 Output of solar panel

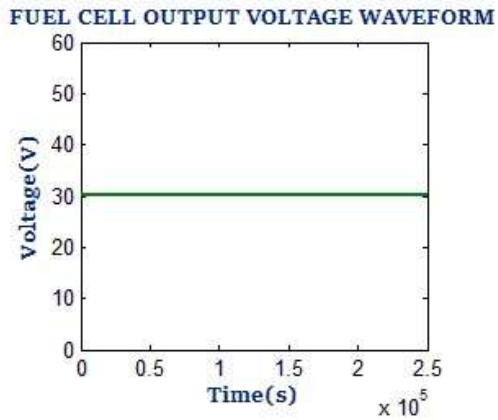

Figure 9 Output of fuel cell

Figure 9 indicates the output of the fuel cell which shows a constant voltage of 30V.

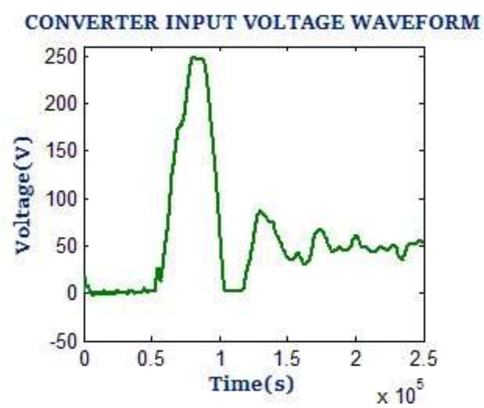

Figure 10 Input of converter

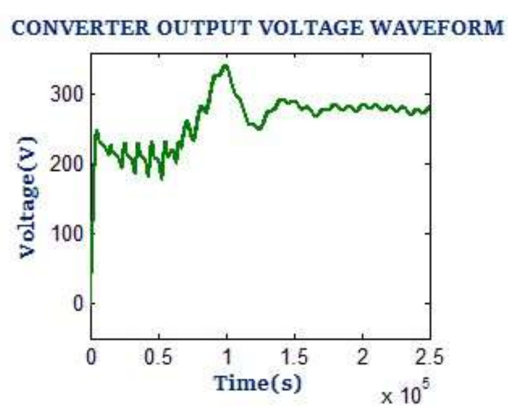

Figure 11 Output of converter

Figure 10 and 11 represents the input and output waveforms of the converter respectively. The maximum input of 250V is boosted upto an output voltage of 350V.

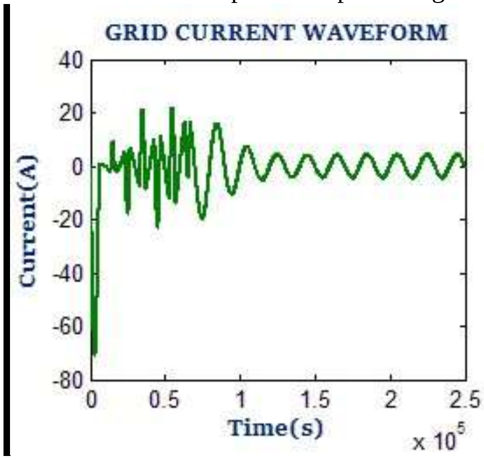

Figure 12 Current waveform of grid

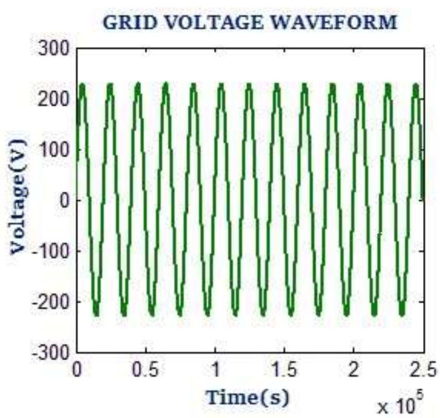

Figure 13 Voltage waveform of grid

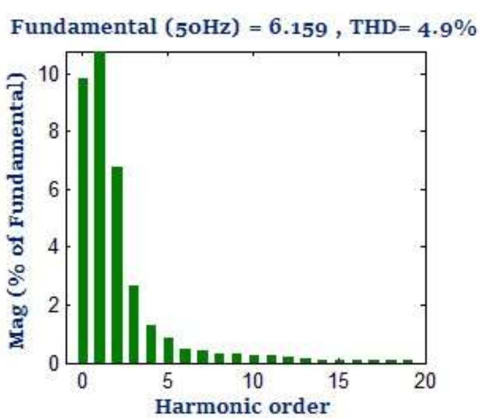

Figure 14 THD output

Figure 12 and 13 represents the waveforms for grid current and grid voltage respectively. The obtained grid voltage is fixed ranging from -200 to +200V. Figure 14 denotes the obtained THD which is a minimal value of 4.9%.

5 CONCLUSION

The grid incorporated PV system along with a fuel cell is analysed in this approach and its performance is evaluated. The proposed system is tested with various loads for analyzing the flow of power from the FC to the grid and load or from the FC and grid to the load. The proposed approach generates voltage and current which are stable in nature. The simulation is carried out in MATLAB and the obtained waveforms indicates improved efficiency of the proposed approach.

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