Performance Study of Grid Connected Fuel Cell Based Distributed Generation System with Ultracapacitor

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***Abstract*-- Fuel cell based power generation is becoming one of the promising distributed generation system. Fuel cell system can generate power as long as fuel is supplied. However fuel cells cannot respond quickly to sudden load change due to slow dynamic response. Hence energy storage system is required during transient period. In this paper a grid connected fuel cell system performance is studied considering the ultracapacitor as energy storage device. To interface ultracapacitor with fuel cell bidirectional converter is used. Simulation results presented here show that the bidirectional converter effectively controls power flow from ultracapacitor. The dynamic responses of the fuel cell system under different load conditions are presented. The results presented in this paper demonstrate the load transient mitigation capability of ultracapcitor.**

***Index Terms*-- Distributed generation system (DG), DC-DC converter, solid oxide fuel cell (SOFC), Ultracapacitor (UC).**

I. Introduction

Increasing electrical power demand, a slow growing generation capacity and environmental issues have made to think of alternative energy sources which are environmental friendly and easy to harness the power from them[1],[3]. Renewable energy resources like wind and photovoltaic are of the great potential to meet the power generation requirements in terms of distributed generation. An extensive research and development is going on these technologies to extract maximum benefit from these energy resources. But the uncertainty in environmental conditions and technological difficulty in storing the electrical energy generated by these resources made the usage limited.

Due to environmental uncertainty associated with wind and PV power generation, Fuel cell can be one of the solutions for these difficulties. Fuel cells use hydrogen as main energy source which is generated from variety of fuels like hydrocarbons and other means like water. For generation of hydrogen the wind and PV can be used to power the hydrogen processing units which make fuel cell as complete environmental friendly. Solid oxide fuel cells are considered as most efficient systems because of their qualities like fuel flexibility and CHP (combined beat and power) applications. SOFC has other advantages like eco friendly, modularity and silent operation. Fuel cell performs best in continuous energy supply mode, preferably under constant operating conditions. They are not suited for fluctuating power levels due to their slow dynamic response. To mitigate instant load transients an energy storage system is required which will supply power during load transients. Ultra capacitors are alternative for batteries because of their high power density [9], high charging discharging cycles and large transient power delivery capability.

In this paper a dynamic model of SOFC in grid interconnected mode is implemented. The performance of SOFC system with Ultracapacitor has been studied. The system discussed in the paper has been simulated in Matlab/Simulink environment. The fuel cell output voltage varies as load changes. In order to regulate fuel cell output voltage a dc- dc boost converter is required. A bidirectional DC-DC converter is used to interface ultracapacitor with fuel cell system which controls the charging and discharging of ultracapacitor. The power generation system comprising SOFC and UC is then interfaced with grid through inverter with suitable control scheme. The load transient capability of system is evaluated under different load conditions. The performance of system during transients is evaluated. Results show that ultracapacitor provides the power during transient period.

II. MODELING OF SOLID OXIDE FUEL CELL AND ULTRACAPACITOR

A. Modeling of SOFC

Accurate fuel cell models are needed to predict and evaluate their steady state and dynamic responses. The dynamic models are also required to predict and evaluate fuel cell system under different transient conditions. The fuel cell output voltage and power are influenced by the electrochemical and physical properties of the fuel cell. Dynamic models are required for designing controllers to control fuel cell terminal electrical quantities as required. The dynamic model of SOFC used in this study is adopted from [4].

Fuel cell can be modeled considering partial pressures at electrodes and the developed terminal voltage. The partial pressure of hydrogen can be written as follows (1)

$$P_{H_2} = \frac{1/K_{H_2}}{1+\tau_{H_2} S}(q^{in}_{H_2} - 2K_r I) \qquad (1)$$

Where:
P_{H2} is partial pressure of hydrogen.
q_{H2} and q_{O2} are molar flow of hydrogen and oxygen.

According to the electrochemical relationships, the amount of hydrogen that reacts can be calculated by (2)

$$q^r_{H_2} = \frac{N_O I}{2F} = 2K_r I \qquad (2)$$

Where:
P_{H2} is partial pressure of hydrogen.
$q^{in}_{H_2}$ and $q^{in}_{O_2}$ are molar flow of hydrogen and oxygen.

Considering the Nernst equation and the ohmic loss, the stack output voltage can be written as

$$V = N_O([E_O + \frac{RT}{2F}[\ln \frac{P_{H_2}.P_{O_2}^{0.5}}{P_{H_2O}}]) - rI \qquad (3)$$

where:
V: fuel cell output voltage
E_0: open cell voltage (based on the Gibbs free energy)
R: gas constant
r: ohmic losses of the stack
I: fuel cell stack current

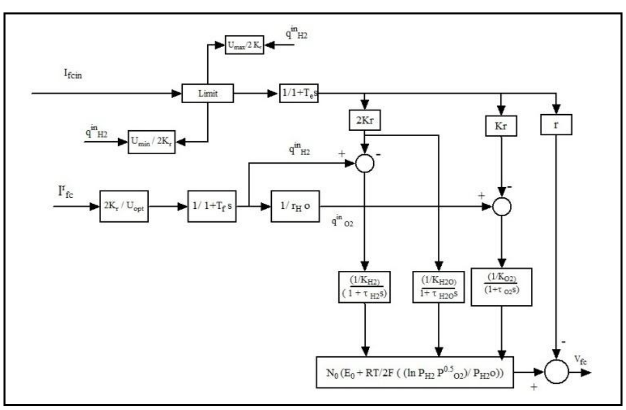

Fig. 1. Solid oxide fuel cell system dynamic model [1]

B. Ultracapacitor

The figure shows equivalent circuit of an ultracapacitor unit, it consists of capacitance C, a series resistance (ESR) representing the charging and discharging resistance and a equivalent parallel resistance (EPR) representing the self discharging losses[6],[8]. In our model the EPR is neglected as it affects the ultracapacitor in long duration storage.

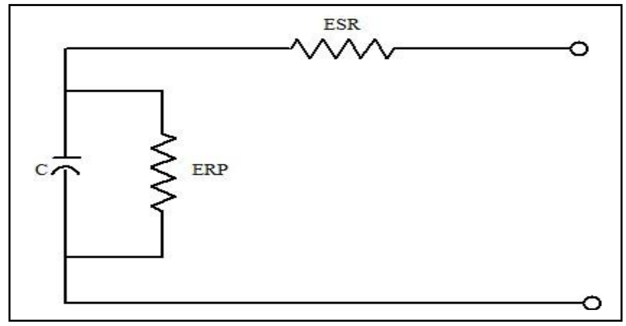

Fig. 2. Classical equivalent model of UC

III. POWER ELECTRONIC INTERFACING SYSTEM FOR DISTRIBUTED GENERATION SYSTEM

The fuel cell power interfacing system consists of three power electronic converters. One is dc-dc boost converter to regulate the fuel cell voltage; second one is bidirectional converter to interface the UC to common dc-link. And third one is three phase dc-ac converter to integrate FC and UC systems with grid

A. Dc-Dc Boost Converter

The SOFC output is unregulated DC, this output will vary as load conditions changes. This is evident from characteristic of the fuel cell. To connect a fuel cell system to the grid, the fuel cell voltage need to be regulated and, if necessary , raised[12]. The dc/dc converters accomplish both functions and satisfy the fuel cell's operational limitations. Hence to get constant higher voltage level, DC-DC boost converter is used. The DC-DC boost converter output voltage is regulated by feedback control scheme [13],[8].The schematic diagram of boost converter is shown Fig.3 (a).

B. Bidirectional Converter

Bidirectional converter is required to connect the ultracapacitor to dc link [7], [9].The control of boost and buck operation of converter can be achieved from same controller [11]. This converter controls charging and discharging of UC bank depending upon load condition. If the load is higher than fuel cell power output the converter discharges the UC bank. When the load on the system is less the UC will be charged. Bidirectional converter model is shown Fig.3(b).

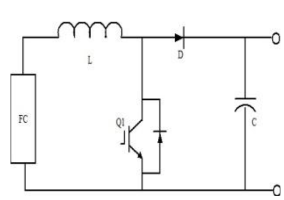

Fig.3. (a)

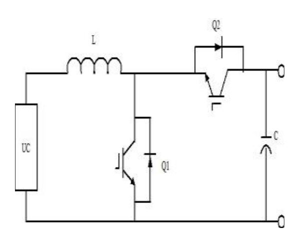

Fig.3. (b)

C. Three Phase Dc/Ac Inverter

To interface the fuel cell system with grid an inverter is required. The regulated dc output of dc/dc boost converter feeds the inverter which will is then connected to the grid through coupling inductor. The inverter is of typical three phase six switch, voltage source inverter (VSI). Sinusoidal pulse width modulation (SPWM) is one of the modulation techniques used to control and shape the VSI output voltage[12]. In this paper P-Q control theory is used. P_{ref} and Q_{ref} are the set points which are dependent on load demand [13]. The controller generates reference signals for active and reactive power injection into the grid depending upon set points. The d-q rotating reference frame is adopted in this control system. By using current controller and d-q reference frame decoupling of active and reactive can be achieved. A PLL is used to measure the phase angle which is required for the d-q reference frame implementation. Hence inverter output synchronizes with grid. As the system is connected to the grid, voltage and frequency are controlled by the grid. The P-Q control scheme is shown in Fig

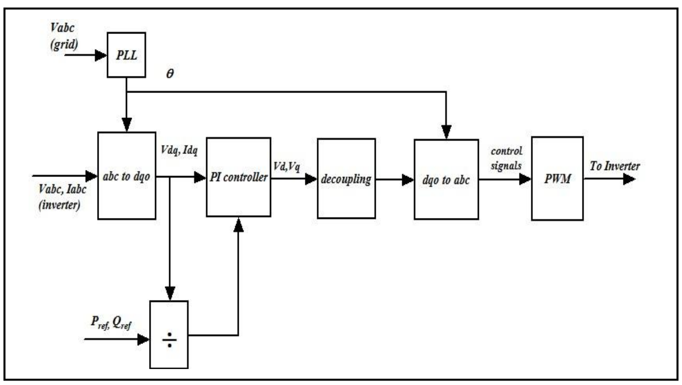

Fig.4.P-Q control scheme.

IV. RESULTS

The FC system is interfaced with grid, considering the UC as energy storage device. The Ultracapacitor is connected to dc- bus using bidirectional converter. The voltage of the dc-bus regulated at 900V. The grid considered in this paper is of 440V, 60 Hz system. The simulation is carried out with Initial 40kW resistive load. At time t=5s the load is increased to 95kW. The dc bus voltage is shown in Fig.6.

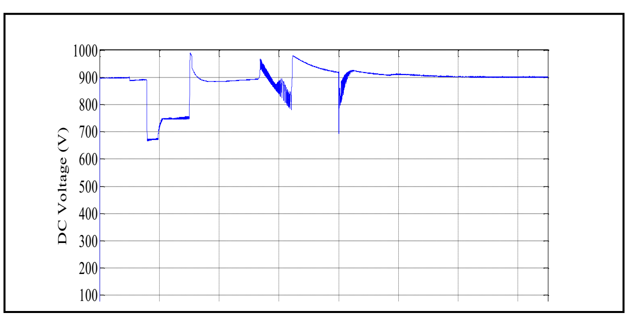

Fig.5.DC bus voltage

The simulation results of Ultracapacitor, FC and load current at dc-bus are shown Fig.7. At initial stages the FC delivers the required load. When load is increased suddenly at time t=5 sec, the fuel cell power is less than load requirement, so UC starts discharging. During time interval of 10s-30s the FC reaches to required power level. Hence UC stops discharging

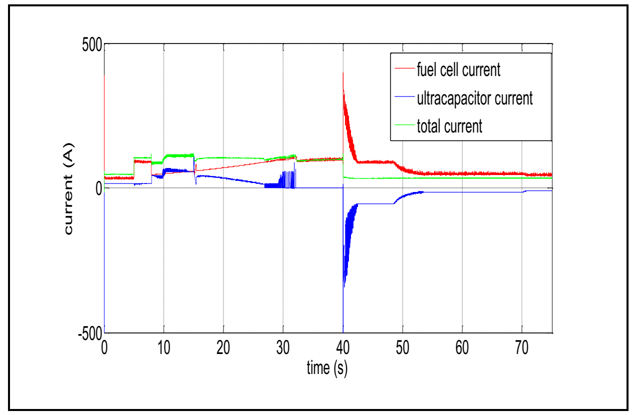

Fig.6. Fuel cell and Ultracapcitor currents at dc bus

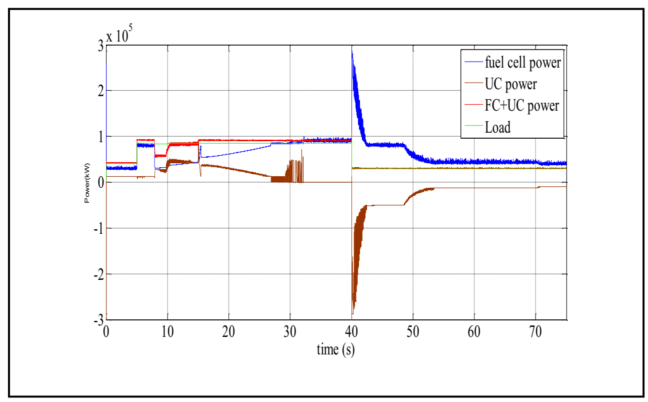

Fig.7.Variation of FC and UC power.

The variation of power at dc- bus is shown in Fig.8. Power drawn from Ultracapacitor decreases slowly as FC power increases. Ultracapcitor stops discharging when FC reaches the required power level. The UC starts charging at 40s as the load is reduced to 30kW. Fig.8. Shows the charging of UC . As the UC charges slowly the power drawn by UC also reduces.

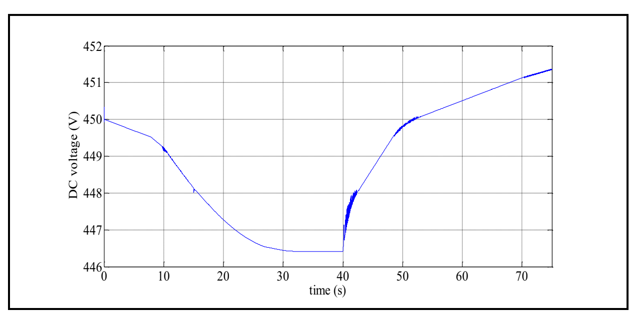

Fig.8. UC bank terminal voltage

The terminal voltage of UC is shown in Fig.9. During the discharging period the voltage reduces slowly and becomes constant when UC stops discharging.

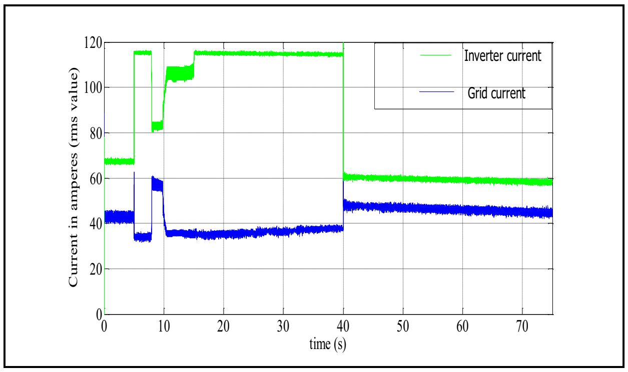

Fig.9. Variation of inverter and grid current as load varies.

When the load changes suddenly the output of inverter also varies. Due to which the power drawn from the gird also varies. Fig.10. shows grid power variations as inverter power output varies. The load transient also reflects on system frequency. Fig.11. shows the frequency variation of the system.

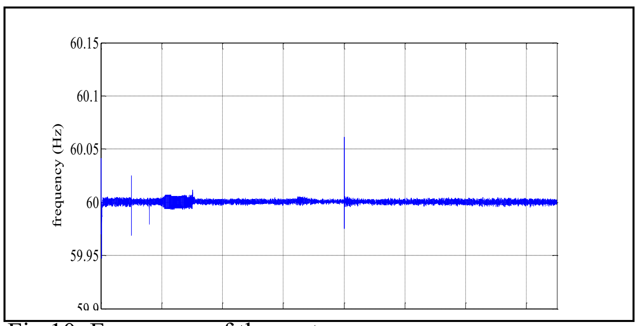

Fig.10. Frequency of the system.

V. CONCLUSION

The UC based energy storage system is interfaced with SOFC using bidirectional converter, in grid connected mode. The simulation results shows that the UC effectively delivers the power during transients. The UC serves instantaneous power requirement. The bidirectional converter effectively manages power flow from UC as per requirement. Without UC the power will drawn from the grid during load transients, which affects other parameters of grid like frequency. Ulatracapcitor usage effectively mitigates load transients and increases system reliability.

VI. REFERENCES

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VII. BIOGRAPHIES

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