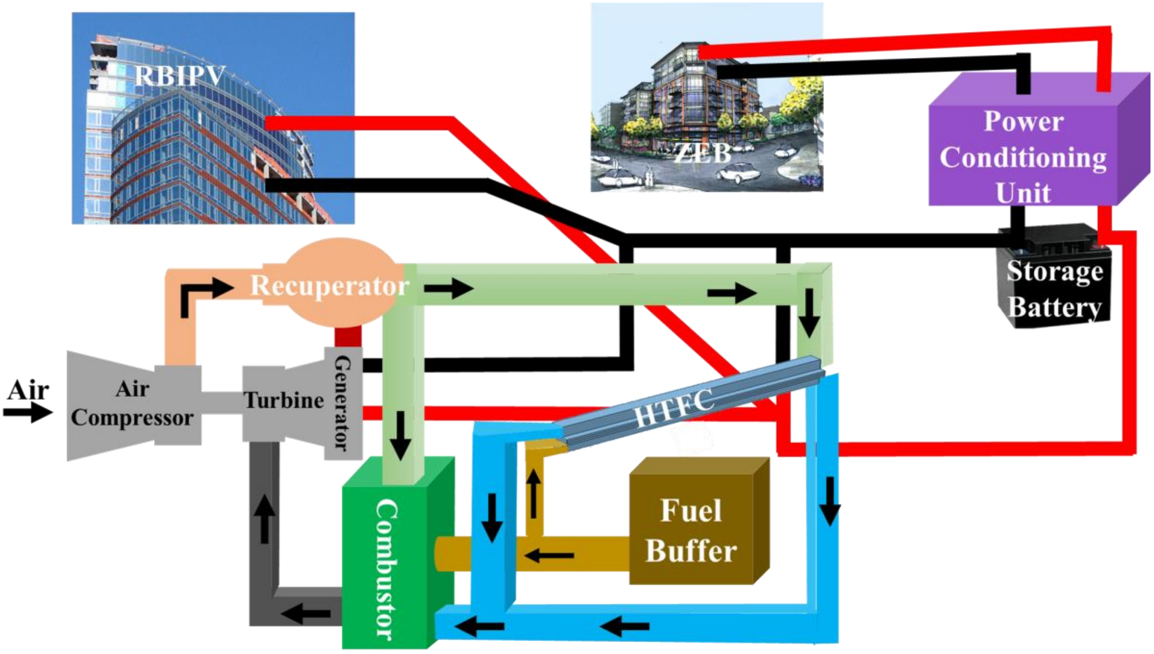

Fig. 2 Schematic of the proposed HCGPGS

2 System Configuration

The schematic of the system we are proposing as a Hybrid Captive Green Power Generation System (HCGPGS) for the ZEB is shown in Fig. 2.

The components of the HCGPGS are:

i. RBIPV
ii. Multi Fuel option driven Hybrid Fuel Cell System (MFODFCS): -
  - Fuel Cell
  - Gas Turbine
iii. Smart Storage and Power Conditioning Unit (SSPCU)
iv. ZEB (load)

3.1 *RBIPV*

The SPV modules are mounted on motorized towers so that they are able to track the sun throughout the day.

Fig. 3 (a) Traditional SPV rooftop installations, (b) RBIPV installation scheme using flexible PV module

These modules trap the solar energy to produce electricity and being eco-friendly.

These occupy large areas and need clear area so that there is no shading effect on the modules as it would affect the performance. Also, they are bulky and need special structural modifications so as to set them up over a rooftop as shown in Fig. 3 (a).

Instead of this a RBIPV [1 – 3] can be incorporated in any structure by using flexible PV modules so that they can be covered over the contoured rooftops as well as shown in Fig. 3 (b). These RBIPV installations range from few kW’s to MW’s.

3.2 MFODFCS

The MFODFCS is a combination of gas turbine generator connected to a Fuel Cell which helps in achieving higher efficiencies [4 – 6]. Using COMSOL Multiphysics®, efficiency comparison between the two major fuel cell technologies, viz. Low Temperature Fuel Cell (LTFC) [7 - 9] and High Temperature Fuel Cell (HTFC) [10 - 12] have been simulated as shown in Fig. 4.

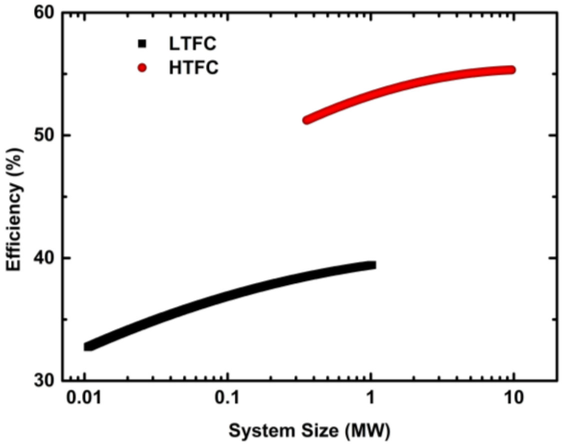

Fig. 4 Higher efficiency is seen in HTFC

As seen from Fig. 4, a second order dependence is observed for both LTFC and HTFC as a function of efficiency to the system size. The change is observed due to the uniformity of ion transport across the electrolyte area [13] and also due to the stacking of multiple cells to boost the performance. The HTFC technology has a higher efficiency and thus suitable for having a ZEB as seen from Fig. 4.

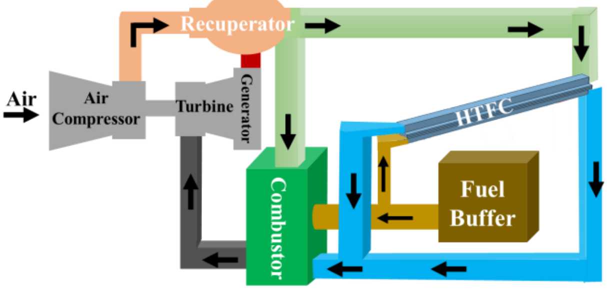

Fig. 5 Schematic of a MFODFCS

The schematic of the proposed MFODFCS is shown in Fig. 5. The fuel options used for running this system are (i) Hydrogen (ii) Landfill Methane, (iii) CNG, and (iv) LPG. These fuels are easily available and can be used as per the availability. HTFC performance dependence is modelled and explained in [9, 10, 12, 14]. The HTFC will be a stack of HTFC's connected in a series and parallel combination to deliver the desired power requirements. The schematic of this combinational connection is shown in Fig. 6. These stacks range from few tens of kW's to hundreds of MW's.

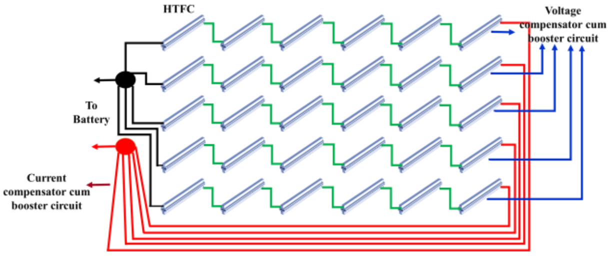

Fig. 6 Schematic of a combinational connection of HTFC stack

Recuperator uses the exhaust of this system to provide the necessary heat for the HTFC stack to function.

3.3 SSPCU

The power generated by HCGPGS is stored in fast discharge batteries by conditioning to meet the power rating of the ZEB.

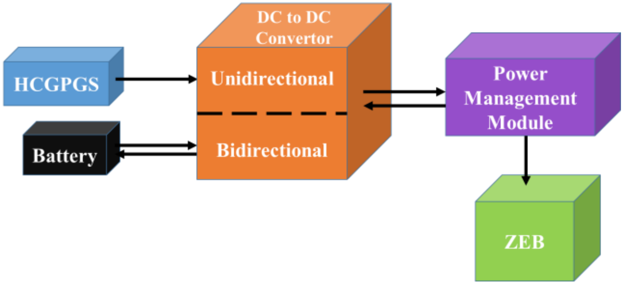

Fig. 7 Schematic of the HPS

Due to the unstable environmental conditions, the HCGPGS terminal voltage varies, therefore HCGPGS voltage needs to be regulated, and boosted with power converters. Energy storage units (ESU), such as a fast discharge battery are used. The schematic of HCGPGS fed power source (HPS) for testing dynamic load profiles (Fig. 7). HPS consists of a HCGPGS, fast discharge battery, power converter, power controller and HCGPGS controller. The power controller will generate a reference signal for flow control based on the load power and HCGPGS current requirement.

The ESU is connected to the dc-link capacitor in parallel through the bidirectional converter for maximum HCGPGS utilization as shown in Fig. 8.

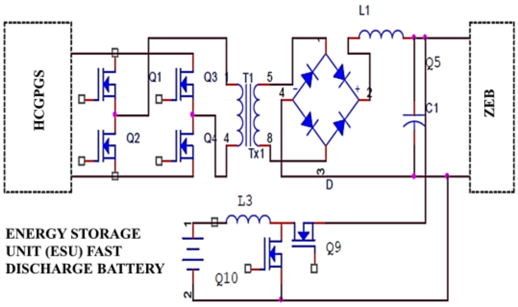

Fig. 8 Power converter configuration with bidirectional converter for HCGPGS - Battery interface

The response to the load requirement of HCGPGS–ESU system has been modeled and is shown in Fig. 9. As seen from Fig. 9, the ESU gets charged by the HCGPGS when the power requirement by the ZEB is low and the HCGPGS slowly meets the full power requirement when the transient power requirement arises.

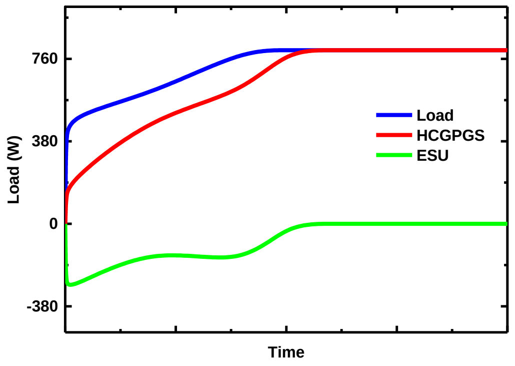

Fig. 9 HGPGS – ESU response to the transient power requirements of the GDC (Load)

4 Conclusion

Thus, a HCGPGS is proposed which would be able to generate self-sustainable power to meet the power requirements of a ZEB. The fuel cell technology is modeled for this application with multi fuel option so as to be functional as per the fuel availability alongwith the modeling of the response of the power conditioning unit. Thus, the power system will be a captive power generation facility and will be locally generated near the ZEB. This HCGPGS can be scaled from few kW to MW as per the requirement of ZEB.

References:

[1] Nguyen D, Lehman B. An adaptive solar photovoltaic array using model-based reconfiguration algorithm. IEEE Transactions on Industrial Electronics. 2008 Jun 24; 55(7):2644-54.

[2] Al-Janahi SA, Ellabban O, Al-Ghamdi SG. A Novel BIPV reconfiguration algorithm for maximum power generation under partial shading. Energies. 2020 Jan; 13(17):4470.

[3] Yang RJ. Overcoming technical barriers and risks in the application of building integrated photovoltaics (BIPV): hardware and software strategies. Automation in Construction. 2015 Mar 1; 51:92-102.

[4] J Palsson, A Selimovic, and L Sjunnesson, "Combined solid oxide fuel cell and gas turbine systems for efficient power and heat generation," Journal of Power Sources, Vol. 86, Issues 1–2, March 2000, Pages 442-448, ISSN 0378-7753

[5] Chan SH, Ho HK, Tian Y. Modelling of simple hybrid solid oxide fuel cell and gas turbine power plant. Journal of power sources. 2002 Jun 15;109(1):111-20.

[6] Singhal SC. Advances in solid oxide fuel cell technology. Solid state ionics. 2000 Nov 1;135(1-4):305-13.

[7] Shao Y, Yin G, Wang Z, Gao Y. Proton exchange membrane fuel cell from low temperature to high temperature: material challenges. Journal of Power Sources. 2007 May 15; 167(2):235-42.

[8] Lv H, Mu S. Nano-ceramic support materials for low temperature fuel cell catalysts. Nanoscale. 2014; 6(10):5063-74.

[9] Patil, T. Micro/Nano–Fuel Cell for Portable Applications: A Multi–Fuel Solution. PhD dissertation, Indian Institute of Technology Bombay, 2015.

[10] Patil TC, Kulkarni SG, Duttagupta SP, Phatak GJ. Multi-fuel modeling of oxygen ion transport in solid oxide fuel cell. Recent Advances in Energy and Environmental Management. 2013 Jul 16 ISBN: 978-960-474-312-4.

[11] Patil TC, Duttagupta SP, Kulkarni SG, Phatak GJ. Oxygen ion transport through the electrolyte in solid oxide fuel cell. In2013 International Conference on Renewable Energy Research and Applications (ICRERA) 2013 Oct 20 (pp. 70-72). IEEE.

[12] Patil TC, Mahajani SM, Duttagupta SP. Direct Biomass Fuel Micro–Solid Oxide Fuel Cell. Int. J. Electrochem. Sci. 2014 Dec 1; 9:8458-64.

[13] Schmidt SA, "Mathematical models of ion transport through nafion membranes in modified electrodes and fuel cells without electroneutrality." dissertation, University of Iowa, 2010

[14] Patil TC, Duttagupta SP. Micro-Solid Oxide Fuel Cell: A multi-fuel approach for portable applications. Applied Energy. 2016 Apr 15; 168:534-43.