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A Case Study on Fuel Cell Cogeneration System and DC-DC (ZETA) Converter

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Abstract - The cogeneration plants contribute to the reduction in primary energy consumption. this makes an essential change by not only lowering emissions to the atmosphere but also in reduction of production costs by improving the total efficiency of conversion of fuel to the heat and electricity used by many number of industries. In the recent days, the energy crisis forces industries to look for new innovative ways to meet the need of peak electrical demand. There are numerous ways to save energy, which when planned and integrated in a proper way could bring a lot of benefits to the industries as well as to the society. one among those would be Cogeneration i.e., Combined Heat and Power(CHP) system. This paper will review the basic system of CHP and then discuss the fuel cell-based CHP system along with the power conditioning circuit (ZETA converter: DC-DC converter) used for it.

Keywords: Combined heat and power, save energy, Zeta Converter

I. INTRODUCTION

Combined heat and power (CHP) energy systems produce electricity and heat at the same time simultaneously nearby to the area of consumption, as shown in Fig1 [7]. When CHP systems are effectively used in a distributed manner, lower loss of transmission and heat causes minimized primary energy consumption.

Usage of a CHP system is expected to minimize cost of operation and avoid greenhouse gas emission. In the past 10 years, CHPs of various efficiencies have been integrated into different sectors across many countries .

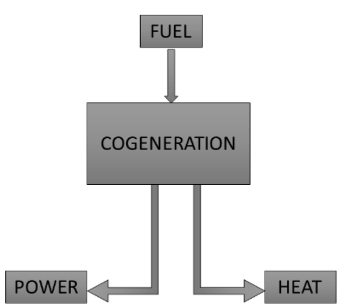

Fig1. Principle Functioning of Cogeneration

There have been several choices for power generation equipment (prime mover) of a CHP system. One among those is fuel cell CHP system ,which has advantages such as : high electrical efficiency, reduced emission, noiseless operation, and lesser maintenance as the mechanical components are absent.

In CHP systems, we basically make use of natural gas irrespective of the prime mover type, and in the case of FC-based CHP systems, natural gas is reformed to hydrogen and is sent to the cell/stack as fuel.

II.OPERATION OF FUEL CELLS

The hydrogen from the fuel that is inserted in the cell oxidizes, releasing two electrons and the ion H+, according to Equation 1. In the cathode, the oxygen is received, through an external circuit, the electrons generated in the oxidation of the hydrogen, combines with O2 being reduced to O2 2- ions, following Equation 2. The H+ ions then cross the electrolyte and combine with O2 2- to form water, according to Equation 3. This process then generates heat, water, and electricity[1].

$$H_2 \rightarrow 2\,H^+ + 2e^- \quad (1)$$

$$O_2 + 2e^- \rightarrow O_2^{2-} \quad (2)$$

$$2H^+ + \tfrac{1}{2}\,O_2^{2-} \rightarrow H_2O + \text{heat} \quad (3)$$

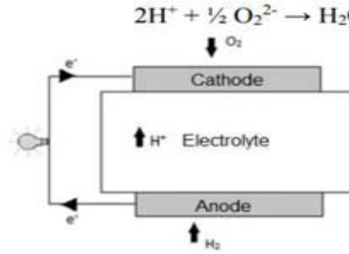

Fig2. Basic Configuration of Fuel Cell

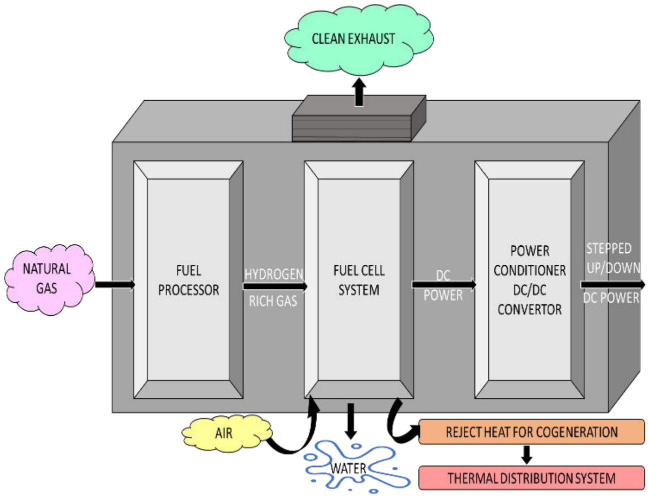

Fig3. Fuel Cell Cogeneration System

III.WORKING

So here as observed from the above ,we see that natural gas is given as input to the system, which then gets reformed into hydrogen rich gas by fuel processor block. This hydrogen rich gas is then given as the input to our fuel cell system, which then processes it to water, heat and generates DC electricity. This generated DC output electricity from the fuel cell system, is then conditioned by the power conditioning circuits such as DC/DC converters or DC/AC converters and once it is done it is either stored in a battery or sent to the grid. The process heat (reject heat) from the fuel cell system is used for cogeneration and then distributed by thermal distribution system for other applications.

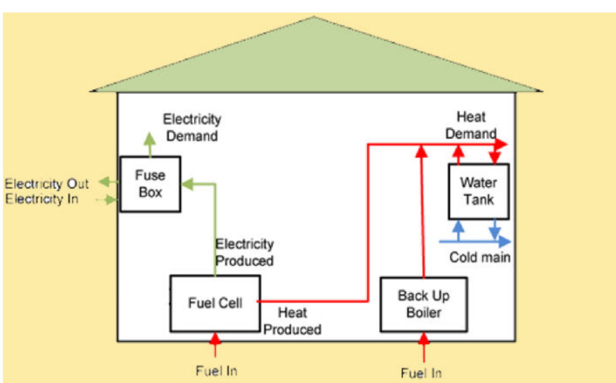

Fig4. Domestic Usage of Fuel Cell Cogeneration System

IV.POWER ELECTRONICS ZETA CONVERTER

A ZETA converter is a Nonlinear system of 4^{th} order. Based on the output energy, it works as boost buck boost converter. Based on the input energy, it works as buck boost buck converter. We can see the ZETA converter basic configuration circuit as below [2].

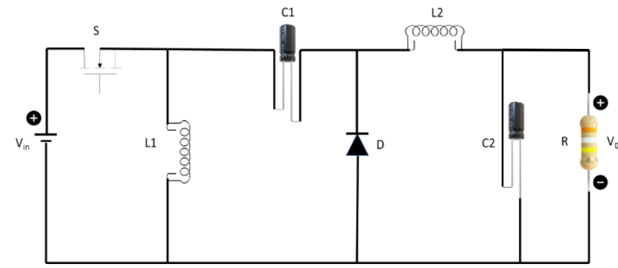

Fig5. ZETA Converter [DC-DC Converter]

When the switch of the ZETA converter is turned ON, the diode D turns OFF. The current passing through the inductor L1 and L2 are obtained from the source voltage Vin. The circuit is then said to be in charging position.

When the switch of the ZETA converter is turned OFF, the diode D turns ON state. The circuit is then said to be in discharging position and the total energy in L2 will be directed to the R which is the load.

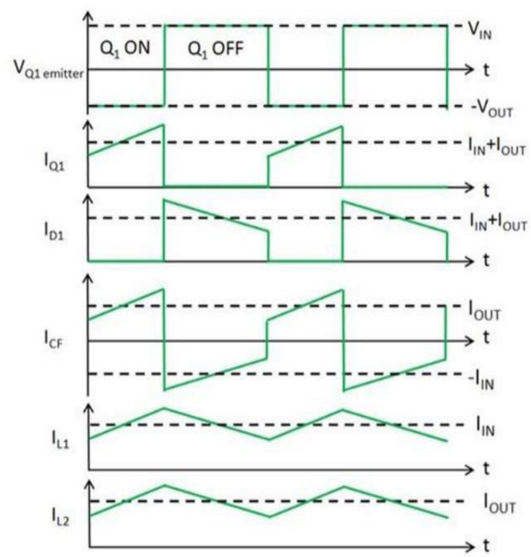

Fig6. Waveforms of elements in the ZETA Converter circuit [6]

V.DESIGN ASPECTS AND SPECIFICATIONS OF ZETA CONVERTER

A. Design Aspect of ZETA Converter

The ZETA converter design equations are as given below:

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1. Calculation of Duty Cycle: $D = \frac{V_o}{V_o + V_{in}}$

2. Value of Inductor: $L = \frac{V_{in} D}{f_s \Delta I}$

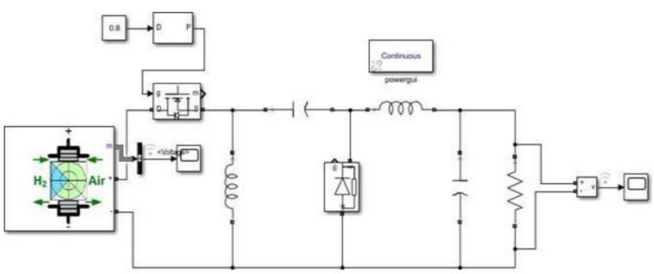
3. Value of Capacitor: $C_1 = \frac{V_o D}{f_s R \Delta V}$; $C_2 = \frac{V_o (1-D)}{8 f_s \Delta V}$

Where Vin - Input Voltage Vo – Output Voltage R – Load resistance fs – Switching frequency ΔV – Capacitor ripple voltage ΔI – Inductor ripple current

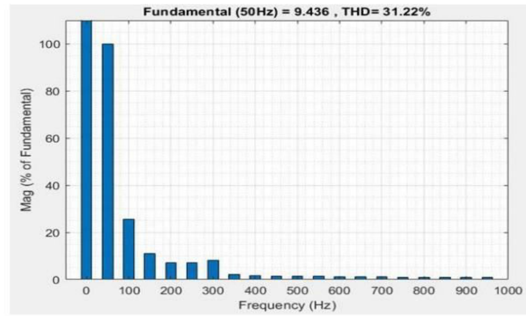
B. Specifications of ZETA Converter [2]

SPECIFICATIONS	VALUE
Duty cycle(%)	80
Output Voltage	48 Volts
Input Voltage	12 Volts
Switching frequency(kHz)	50
Resistive load	100 ohms
Inductor 1&2(mH)	0.16
Capacitor 1,2	16 μF, 312.5 mF

VI.SIMULATION OF ZETA CONVERTER



Simulation model of ZETA converter with Fuel cell



Voltage THD analysis waveform of ZETA converter

The low Total Harmonic Distortion (THD) value of ZETA converter implies that there is room for improving the efficiency of the converter, when compared to converters of high THD values.

VII.LITERATURE SURVEY

There is an immense increase in research and development of fuel cell cogeneration system in the past 5 years. The mostly used fuel cells for cogeneration system are PEMFCs and SOFCs, these can be furthermore developed in future for usage in cogeneration systems. Steady-state and linear models will be used for the modelling process of the system. A decent number of studies have focused on the control and energy management strategies for the cogeneration system.

The studies conducted on the hybrid configurations of renewable energy devices and fuel cells are scarce. Many researches show that the only prime mover in the cogeneration system is the fuel cell. The two types of fuel cell (PEMFC and SOFC) were mostly paid attention to and the analysis was made on the integration of conversion of energy elements used for the storage with the fuel cells[4].

When it comes to real time applications, these systems were mainly used for domestic use. the system of cogeneration for providing cooling, hydrogen, treated water, oxygen, etc., are still limited.

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A.Companies and fuel cell cycles with cogeneration [1]:

Fuel cell	Company	Type of co-generation	Efficiency without co-generation	Efficiency with co-generation
MCFC	Fuel Cell Energy	MTG	40%	60%
MCFC	Fuel Cell Energy	DUHW	42%	80%
MCFC	Ansaldo Fuel Cells	MTG	45%-50%	75%
MCFC	CFC Solutions	DUHW	50%	70%
PAFC	Doosan fuel Cell America	DUHW	37%	87%
PAFC	Fuji Electric	DUHW	42%	91%
SOFC	Kyocera	DUHW	45%	75%
SOFC	Siemens Westinghou se	With MTG	52%	65%
SOFC	Solidia	With MTG	50-55%	60-75%

VIII.CONCLUSION

Fuel cells generate electricity at large scale without pollution. In the current scenario, two important features are high efficiency and eco-friendly. The fuel cells meet this need. The fuel cells have several uses such as: vehicles, constant power generation, cell phones and domestic use. The recent technology is the microbial fuel cell that is not yet into market [1]. The reason is power generation is very small, which would make it necessary for an external source.

However, PAFC, MCFC and SOFC cells have been improved more as we started using it along with combined cycles of heat and power. FC's which have a high operating temperature are used in cogeneration, which makes use of the exhaust hot water, making the system more efficient. Several investments are being done in the development of this type of technology, so in the upcoming years, it is expected that the fuel cells will play a major role in power generation. By doing more research on each fuel cell i.e., by discussing it's working, applications and characteristics etc., we can further develop this technology in the future.

Fuel cell cogeneration is a cost-effective and energy-efficient method for providing electricity and heat. As we move to a more reliable future of energy , constant availability of inexpensive natural gas is critical. Recent technologies such as fuel cells which have small-scale applications, play a key role in cogeneration's future.

As more organizations invest in cogeneration, we will be able to meet the need of the peak electrical demand. Utility providers benefit by this as it decreases infrastructure costs and upward pressure on electricity costs become less severe. As greenhouse gases become a growing global issue affecting the climate, the CHP helps in reducing this in significant amounts and contributes for a much better world.

The ZETA converter used in this process is a converter topology which provides a regulated output voltage ,as input voltage varies above and below the output voltage. Some of the advantages of the ZETA converter are lower output-voltage ripple and easier compensation [5]. By adding more filters to the ZETA converter, we can improve its performance further.

IX.FUTURE SCOPE AND ADVANCEMENTS

The PEMFC and SOFC are the fuel cells which are mostly used in cogeneration systems, finding its commercial products is easy. But, finding commercial products for other types of fuel cells is a bit of a difficult task, thus research studies regarding other types of fuel cell is highly beneficial.

The issue of cost regarding development of fuel cell can be solved by identifying technologies for using different types of fuel and reforming those. There are different areas in fuel cells that can be improved for example we can use different hydrocarbon fuels or make use of a different electrolyte in the cell. These aspects can help to improve the life cycle and cause reduction in the investment cost [4].

The strategy of energy management along with system predictions and optimal operation parameters help in controlling the primary energy consumption, which brings down the greenhouse gases and reduces the working expense. The loss of energy in the system is minimized and there will be an increment of dependability on the system. There is an enormous ability for additional advancement of fuel cell cogeneration system, in the domain pertaining to the conversion of waste-to-energy.

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