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FUEL CELL BASED DG INVOLVING IMPROVED POWER QUALITY CONVERTER FOR VOLTAGE CONTROL

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ABSTRACT
The paper presents a model and controllers of fuel-cell -based distributed generation systems (DG) in a Grid. A dynamic model of the fuel cell is considered. To boost low-output DC voltage of the fuel cell to high DC voltage and to compensate for its slow response during the transient, zeta converter is adopted and their controllers are designed. Voltage control technique was investigated by simulation. Distributed Generation (DG) units are connected to the grid increasing nowadays for several reasons. Most DG units are relatively small and connected to the distribution network. A large part of the DG units connected to the grid via power electronic converters. The main task of the converters is to convert the power that is available from the prime source to the correct voltage and frequency of the grid. The general objective of this paper is to investigate how the power electronic converters can support the grid and solve power quality problems. An IEEE-5 bus system is considered with fuel cell source for this work to validate the power electronic converter using MATLAB/ Simulink.

KEYWORDS: Distributed Generation, Fuel Cell, IEEE – 5 bus system, Voltage control, Zeta converter, power Quality.

INTRODUCTION
Fuel cells produce electric power through an electrochemical process in which hydrogen energy is converted to electricity. The hydrogen fuel can be produced from a variety of sources. The most economic source of hydrogen is steam reforming of natural gas. Several different liquid and solid media can be used to facilitate the fuel cell's electrochemical reactions. These media are phosphoric acid (PA), molten carbonate (MC), solid oxide (SO), and polymer electrolyte membrane (PEM). Each medium consists of a distinct fuel cell technology and unique performance characteristics. Environmentally friendly distributed generation systems (DG) such as fuel cells, wind turbines, hydro turbines or photovoltaic arrays are rapidly increasing around the world because they can meet both the increasing demand for electrical power and environmental regulation of greenhouse gas emissions [1-7].

Outstanding advances in Power Electronics and energy storage devices for transient backup have accelerated the penetration of the DGS into electric power generation plants. These DGS technologies can be used for various applications to a standalone, a grid interconnection, cogeneration, standby, peak shavings, etc., and have many benefits such as environmental friendliness, modular electrical generation, increased reliability, high power quality, uninterruptible power service, cost savings, on-site generation, and expandability, etc. The fuel cells are electrochemical devices that convert chemical energy directly into electrical energy by the reaction of hydrogen from fuel and oxygen from the air without regard to climate conditions, unlike hydro or wind turbines and photovoltaic array. Thus, the fuel cells are among the most attractive DG resources for power delivery. However, batteries need to be placed in parallel or in series with the fuel cells as a temporary energy -storage element to support startup or sudden load changes because fuel cells cannot immediately respond to such abrupt load changes.

In this paper, simulation studies that cover all the slow dynamics of the fuel cell, a zeta power converter and a three-phase inverter are performed for the fuel cell- powered DG in a Grid. Specifically, to boost low output DC voltage of the fuel cell to high DC voltage and to compensate for its slow response during the transient, zeta converters are adopted and a proportional controller (PI) is designed.

FUEL CELL BASED DISTRIBUTED GENERATION

A national electricity grid must always be able to meet the needs of its users. This requires it to be: stable, maintaining the required electrical frequency balanced, continuously matching supply to demand; and adequate, ensuring total generation capacity is never outstripped by demand. Grid supply is split into three tiers: base, intermediate, and peak load. Base load is a permanent minimum amount of electricity that is required at all times and is met by predictable, long-running power sources, usually coal-fired plants. Intermediate power plants are more flexible and can vary output to suit the needs of the grid, but at a cost to the system operator. These include nuclear, hydroelectric and gas/diesel combined cycle turbine plants. Finally, peak power generators are called upon to meet short-term spikes of requirement and as such must be able to start up and provide power instantaneously.
To improve energy security and cut greenhouse gas emissions, governments around the world are supporting the inclusion of renewable sources in the grid energy mix. This is complicated by the fact that the major sources of renewable energy, wind and solar power, are by nature highly variable and to some degree unpredictable. These variations in output are difficult for national grid operators to manage. Increasing the proportion of renewables currently requires an increase in inefficient, carbon-intensive spinning reserve to provide for shortfalls in energy supply. But sudden peaks in the output of wind farms and solar power plants can be just as difficult to manage. The cost was ultimately passed to consumers. Fuel cells can provide stable, predictable base load electricity and if they are fuelled with renewable hydrogen or biogas they can offer the same low-carbon benefits as other sources of renewable energy.
Fuel cells are highly reliable, with minimal downtime & maintenance, and can ensure a consistent electricity supply. They operate with low noise and much less pollution than fossil-fuel power stations, especially if run on hydrogen. This means they can be sited close to population centers, which minimizes transmission losses. Even when fuelled with natural gas, the higher efficiency of fuel cells means the amount of carbon dioxide emitted per kilowatt-hour generated is significantly lower than conventional power generation. As such, fuel cells are eligible for government incentives in a number of countries.
The fuel cell cannot immediately respond to power demand during start-up or sudden load changes due to its slow dynamics. As a result, energy storage elements, such as batteries or flywheels, deliver the remaining power to the load for the transient. Fuel-cell stack voltage, battery position, and the topology of DC -to -DC boost converters can be selected variously according to the designers. Among the several types of fuel cells categorized by the electrolyte used, four are promising for distributed generation systems: The Phosphoric Acid fuel cell (PAFC), Solid Oxide fuel cell (SOFC), Molten Carbonate fuel cell (MCFC), Proton-Exchange-Membrane fuel cell (PEMFC). All of the fuel cells produce electricity by electrochemical reaction of hydrogen and oxygen. Oxygen can be easily obtained from compressing air, whereas hydrogen gas, required to produce DC power, is indirectly gained from the reformer using fuels such as natural gas, propane, methanol, gasoline, or from the electrolysis of water [8-12].

PROTON-EXCHANGE-MEMBRANE FUEL CELL (PEMFC)

Proton-Exchange-Membrane fuel cell (PEMFC) fuel cell considered for this system with range of 50kW and each 625Vdc of two cells. The number of cells per unit of the PEMFC is 900. The proton exchange membrane fuel cell (PEMFC) uses a water-based, acidic polymer membrane as its electrolyte, with platinum-based electrodes. PEMFC cells operate at relatively low temperatures (below 100 degrees Celsius) and can tailor electrical output to meet dynamic power requirements. Due to the relatively low temperatures and the use of precious metal-based electrodes, these cells must operate on pure hydrogen. PEMFC cells are currently the leading technology for light duty vehicles and materials handling vehicles, and to a lesser extent for stationary and other applications. The PEMFC fuel cell is also sometimes called a polymer electrolyte membrane fuel cell (also PEMFC).
Hydrogen fuel is processed at the anode where electrons are separated from protons on the surface of a platinum-based catalyst. The protons pass through the membrane to the cathode side of the cell while the electrons travel in an external circuit, generating the electrical output of the cell. On the cathode side, another precious metal electrode combines the protons and electrons with oxygen to produce water, which is expelled as the only waste product; oxygen can be provided in a purified form, or extracted at the electrode directly from the air. Fig. 1 shows the Simulink representation of Fuel cell based IPQC and Fig. 2 shows the V-I Characteristics of fuel cell.

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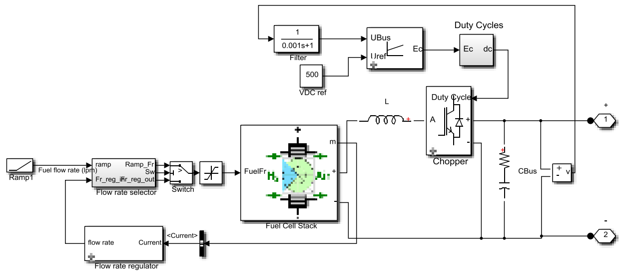
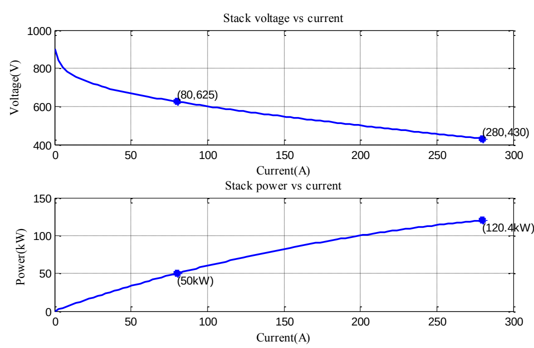
Figure: 1



Simulink representation of Fuel cell based IPQC

Figure: 2



V-I Characteristics of fuel cell

Table 1. Fuel Cell Parameters

Stack Power (Nominal)	50 kW
Stack Power (Maximum)	120 kW
Fuel cell Resistance	0.66 Ω
Nerst Voltage of one cell[En]	1.134 V
Nominal Utilization(Hydrogen,H_2)	99.25 %
Nominal Utilization(Oxidant,O_2)	70.4 %
Nominal Consumption(Fuel)	501.8 slpm
Nominal Consumption(Air)	1194 slpm
Exchange current(i0)	0.916 A
Exchange coefficient(alpha)	0.264
Fuel composition [x_H_2]	99.95 %
Oxidant composition [y_O_2]	21 %
Fuel flow rate at nominal hydrogen utilization (Nominal)	417.3 lpm
Fuel flow rate at nominal hydrogen utilization (Maximum)	1460 lpm
Air flow rate at nominal oxidant utilization(Nominal)	2100 lpm
Air flow rate at nominal oxidant utilization(Maximum)	7350 lpm

System temperature(T)	338 Kelvin
Fuel supply pressure(P_{fuel})	1.5 bar
Air supply pressure(P_{air})	1bar

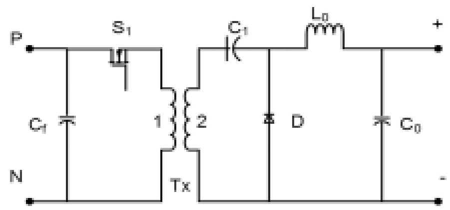
POWER ELECTRONICS INTERFACE

The Power electronic converters play an increasingly important role in modern electrical engineering. They are an essential part of the integration of DG units into the grid. The voltage generated by most DG units cannot be connected to the grid directly. The power electronic interfaces are necessary to match both the voltage level and frequency of the DG unit and the grid [13]. This system consists of a zeta converter as a power quality improved in association with voltage source inverter.

Zeta Converter

Different types of AC-DC converters have been introduced to fulfil the demanded power conversion such as Sepic, Cuk converters, etc. From the available converters, the zeta converters (Buck-Boost type) is incorporated in the proposed work. The zeta converter has advantages such as, safety, flexibility, isolation and output adjustment. Zeta converters usually have high transfer voltage gain and also produce high insulation on both sides. The gain of the Zeta converters always depends on the transformer's turn ratio N, which can be thousand times. The zeta converter is a transformer based converter with a low-pass filter. Its output voltage ripple value is small [14-15]. The circuit diagram of zeta converter is shown in Fig.3.

Figure: 3



Circuit diagram of zeta converter

The output voltage is given by,

Formulae:

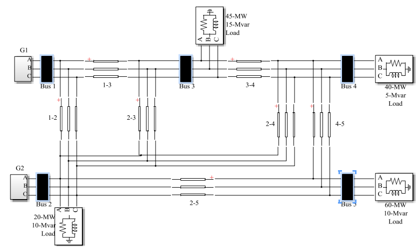
$$V_o = \frac{k}{1-k} N V_{in} \qquad (1)$$

Where N is the turn ratio of transformer, and k is the conduction duty cycle k= ton/T.

Grid

A load of grid connected fuel cell inverters is the utility network. As seen from the inverter, this network looks like an infinite energy sink. The requirements for the grid connected fuel cell system are dictated by the electric utility, and each utility may impose a unique set of requirements. These requirements can be divided into protection, power quality, operation and safety. IEEE- 5 bus, two machine system taken as a system to evaluate the DG performances with a solar panel. Voltage control using DG involving power electronic interface with IEEE 5-bus test system were obtained and discussed in this section. Voltage stability indices are calculated for the IEEE 5 bus system with and without Improved Power Quality Converter (IPQC) and Distributed Generation (DG). Fig.4 shows the IEEE-5 bus system with two generators without IPQC and DG.

Figure: 4

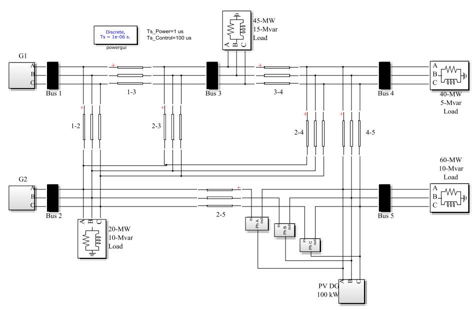


IEEE-5 bus test system

SIMULATION RESULTS

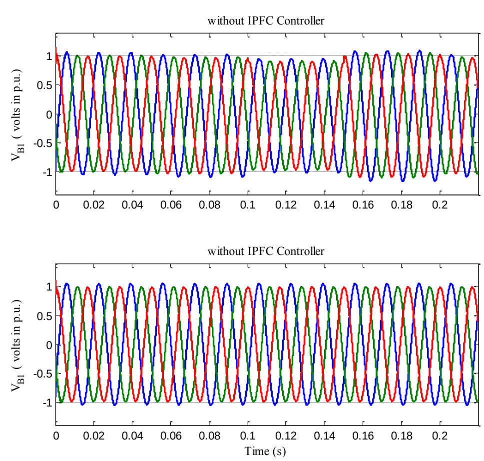
This proposed system consists of a model of an IEEE-5 bus system with two generators for power quality analysis with DG and power electronic interface. Zeta converter chosen as a power quality converter, which boost a maximum output voltage from DE source. fuel cell is considered as a DE source of this proposed system. The proposed system performance has been evaluated with and without IPQC with DG for various voltage disturbances. Fig. 5 shows the Simulink representation of IEEE- 5 bus system with IPQC and DG. Figs. 6-11 show the performance analysis of the 5 bus system for the analysis of PV cell based DG with improved power quality converters.

Figure: 5



IEEE-5 bus test system with IPQC and DG

Figure: 6



Voltage response of bus1 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

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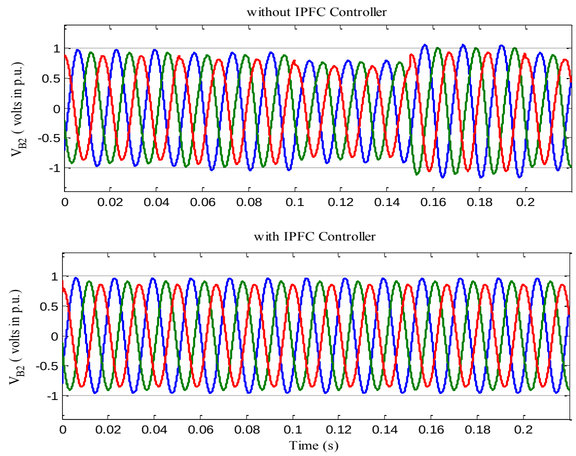
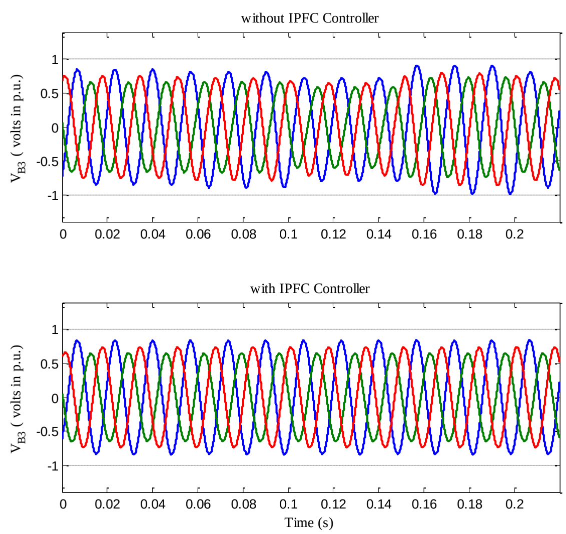
Figure: 7



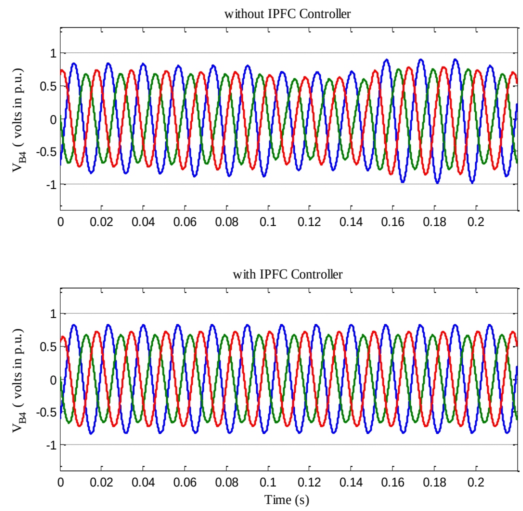
Voltage response of bus2 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

Figure: 8



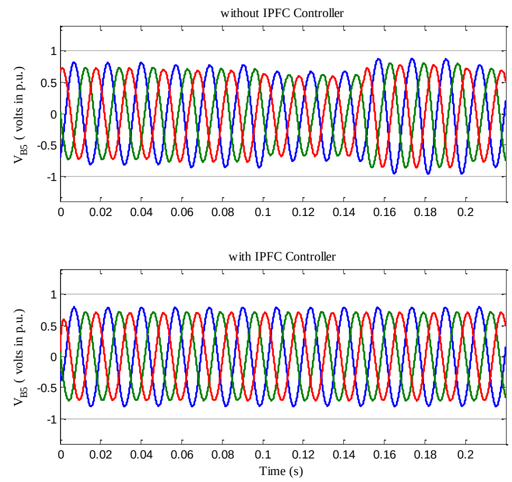
Voltage response of bus3 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

Figure: 9



Voltage response of bus4 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

Figure: 10



Voltage response of bus5 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

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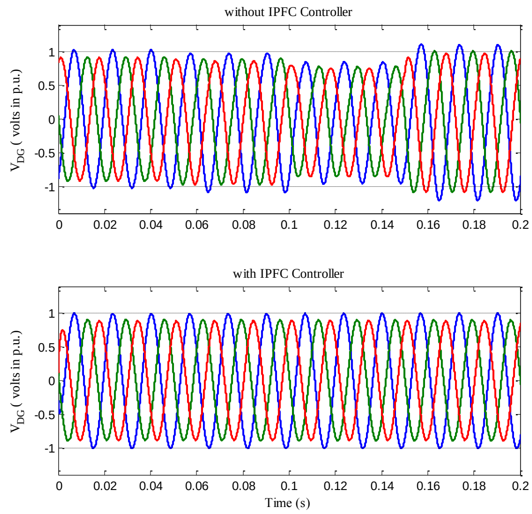
Figure: 11



Voltage response of DG connected with IEEE 5 – Bus system without and with IPFC controller with disturbance introduced at bus 2

Voltage disturbance created in bus 2, the voltage fluctuation has been compensated with implementation of zeta based power electronic converters and improved the power quality of this proposed system. Figure 6 shows the voltage response of bus1 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1, V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 above V=1 p.u. Figure 7 shows the voltage response of bus2 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 8 shows the voltage response of bus3 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 9 shows the voltage response of bus4 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 10 shows the voltage response of bus5 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 11: Voltage response of DG connected with IEEE 5 – Bus system without and with IPFC controller with disturbance introduced at bus 2 (t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u). the overall power quality analysis is tabulated in Table. 1. It is observed that the system produced best power quality with presence of IPQC.

Table 2. Simulated performance evaluation of DG based grid interface with power electronic converters

Bus Number	Voltage in P.u	
	Without IPFC	With IPFC
1	0.89	0.98
2	0.70	0.85
3	0.58	0.64
4	0.62	0.72
5	0.59	0.70

CONCLUSION

Most distribution network operators require the disconnection of DG units when faults occur in the network. One reason for this requirement is that they fear that DG units disturb the classical protection schemes that are applied. It has been shown in this work that disturbance of protection does not necessarily occur when power electronic interfaced DG units are controlled properly. When DG units stay connected during faults, they can support the grid during a voltage dip. For some larger DG units directly connected to the transmission network, this is often required already. Voltage dips occur for a short period only. Overloading of a converter will mostly be possible for this short time. In combination with a variable inductance a significant reduction in the dip, depth can be achieved. It should be noted, however, that in some cases the variable inductance can reduce the short-circuit current that flows in the network, causing blinding of protection. This paper has described the circuit model and controller design of the fuel-cell-powered DG in a grid. A simulation using Matlab/Simulink is presented, which includes the dynamic model of the fuel cell, the Zeta converter and three-phase DC-to-AC inverter. The zeta converter based power quality converter proved the effectiveness of the proposed system.

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