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A Family of New Multiport Power Sharing Converter Topologies for Large Grid Connected Fuel Cells

Sreeranjini C nair[1], Annie P Oommen[2], Neena Mani[3]

M.Tech Student, M. A. College of Engineering, Kothamangalam, Kerala, India[1]

Professor, M. A. College of Engineering, Kothamangalam, Kerala, India[2,3]

ABSTRACT: **-** In recent years, there has been growing interest in generating electricity from renewable resources. It is necessary to connect multiple sources in order to achieve the desired capacity to a power grid or load. A new family of bidirectional multiport power sharing converters can be used for high-power clean and renewable energy technologies with utility-scale energy storage and medium voltage grid interface. This topology allows for multiple dc-voltage distributed energy resources to be individually referenced to ground and connected via high-frequency isolation to a single multilevel inverter with utility interface. This system connects multiple FC sources to a medium- voltage grid via a single multilevel neutral point clamp (NPC) inverter interface with high frequency isolation. High-voltage series-connected inputs are achieved, despite safely referencing each source to ground. Also, unique power-sharing technology decouples series-connected source currents and enables control of each FCs individual power level. The two primary architectures of power sharing converters are there such as LV-PSC and MV-PSC. The MATLAB/SIMULINK model verifies the performance of PSC topology.

KEYWORDS: Fuel cell (FC), medium voltage (MV), multilevel, multiport, neutral point clamp (NPC) power sharing, utility grid.

I. INTRODUCTION

In recent years, there has been growing interest in generating electricity from renewable resources. Fuel cells are electrochemical devices that process hydrogen and oxygen to generate electrical power, having water vapour as their only by-product. The voltage resulting from the reaction of the fuel and oxygen varies with the load and ranges from 0.8V at no load and 0.4V for full load. So it is necessary to connect multiple sources in order to achieve the desired capacity to a power grid or load. For low power applications, the number of cells that are needed to be connected in series is small, but as power demand increases, the number of cell required in the stack also increases rapidly. These stack voltages are limited by their electrostatic potential with respect to ground. Currently, utility-scale fuel cell voltages range from 300 V to 1,000 V. In order to achieve increased DC-link voltages, centre point grounding is applied by tying the mid-point of two cells stacked in series to ground. Because fuel cell voltages have a wide variation in output voltages, conventional fuel cell power conditioning systems generally consist of three stages 1) DC-DC converter to boost the voltage level. 2) DC-AC Neutral Point Clamp (NPC) inverter. 3) 60 Hz isolation transformer interface to electric utility grid. This conventional approach has the following disadvantages 1) Excessive component count. 2) Each fuel cell stack requires its own set of converters and low frequency (60Hz) transformer to interface with the utility grid, resulting in excess weight, volume, and cost. The power-sharing converter (PSC) technology presents a series-connected MPC solution which: 1) Reduces input converter count 2) Integrates into isolated system topologies and 3) Nullifies and/or mitigates the aforementioned short-comings associated series connected sources.

II. POWER SHARING CONVERTER (PSC)

Multiport converters, a promising concept for hybrid power sources, have attracted increasing research interest recently. The use of a single power processing stage to interface multiple power inputs integrates power conversion for a hybrid power source. This structure removes redundant power stages that would exist in the conventional approach

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that uses multiple converters. The multiport structure is promising from the view points of centralized control and compact packaging. Series-connected MPCs are desirable because higher input voltages translate into lower conduction losses and less stress from voltage boosting. However, there are some negative tradeoffs to consider. Namely, the coupling of source currents $I_1 = I_2$ and an increase in electrostatic stress across the sources. Fortunately, PSC technology addresses both concerns by decoupling source currents and grounding each input with centre point grounding (CPG).

A fully integrated PSC system can realize the following aspects: 1) Power Sharing: Source-currents are decoupled, such that each input can operate independently at any desired power level, allowing for thermal balancing. 2) Center Point Grounding: DC-link voltages are doubled, whereas electrostatic potentials per input remain safely minimized. 3) HF Isolation DCDC Conversion Stage: Two small HF transformers replace four bulky 60 Hz transformers; this stage strategically tolerates the voltage drooping of naturally saggy FC VI curves and series-connected MPC technology. 4) Inherent MPC Benefits: Decreased grid stress and increased operational fexibility, availability, source utilization, and cost effectiveness. There are two types of power sharing converters available.

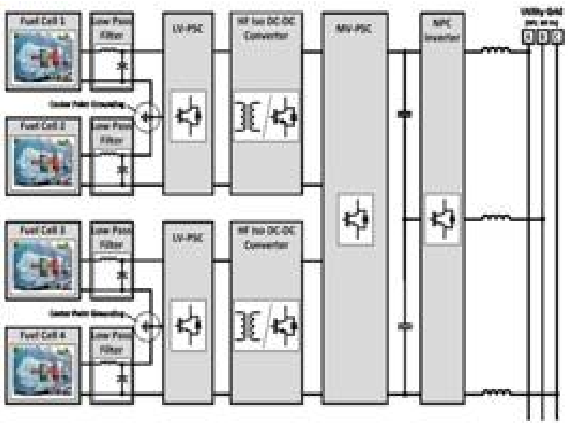

Figure 1: FC Power Conditioning Architecture Implements with Both LV/MV PSC Topologies

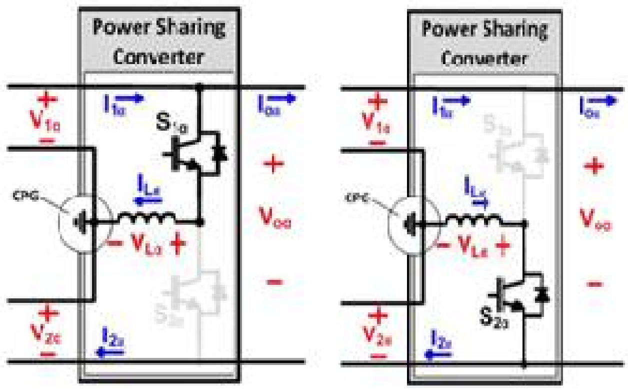

Figure 2: Low Voltage Power Sharing Converter

Low Voltage Power Sharing Converter (LV-PSC): The LV-PSC creates power-sharing zone α by interfacing two input sources with a single output via a half-bridge leg and a zonal inductor $L_α$. When switch $S_{1α}$ is activated, the zonal inductor sees $V_{1α}$. Similarly when $S_{2α}$ is activated, the zonal inductor sees $V_{2α}$. This will induce an excess dc-current $I_{Lα}$ to flow through the zonal inductor when the power delivered by the first source $P_{1α}$ is not equivalent to the power delivered by the second $P_{2α}$.

When $S_{1α}$ is activated:

$$V_{1α} + V_{Lα} = 0 \qquad (1)$$

When $S_{2α}$ is activated:

$$V_{2α} - V_{Lα} = 0 \qquad (2)$$

Let $D_{1α}$ be the duty ratio of $S_{1α}$ and $D_{2α}$ be the duty ratio of $S_{2α}$

$$D_{1α} = V_{1α} /(V_{1α} + V_{2α}) \qquad (3)$$
$$D_{2α} = 1 - D_{1α}$$

Medium Voltage Power Sharing Converter (MV-PSC): During higher voltage operation, the two half-bridge switches used in the LV-PSC may not be sufficiently rated. In such cases, the MV-PSC can be implemented. Unlike an NPC

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chopper, the MV-PSC has a four-switch leg with diodes clamping each top and bottom switch-set to a neutral point. This effectively doubles the voltage tolerance from that of the LV-PSC by balancing the voltage stress across two inactive switches during either switching state. A significant addition to the NPC topology is the placement of a zonal power-sharing inductor between the mid-leg zero voltage ac-output terminal and the neutral point. Similar to the LV-PSC, this inductor decouples the output currents of both HF Isolated dc-dc converters ($I_{1\gamma}$ and $I_{2\gamma}$). In the MV-PSC, two switching states are used. In State 1, $S_{1\gamma}$ and $S_{2\gamma}$ are turned on, allowing the top HFI dc-dc converters output voltage to be seen across the zonal inductor, such that $V_{L\gamma} = V_{1\gamma}$. In State 2, $S_{3\gamma}$ and $S_{4\gamma}$ are turned on, allowing the bottom HFI dc-dc converters output voltage to be seen across the zonal inductor, such that $V_{L\gamma} = V_{2\gamma}$. The duty cycle and overall ideal operational characteristics mirror that of the LV-PSC. However, it is mandatory to note that $V_{1\gamma} = V_{2\gamma}$ at all times, lest a voltage stress imbalance be introduced among inactive switches. This constraint is tolerable since HFI dc-dc converters precede the MV-PSC in the grid-level connection and can equalize the MV-PSCs input voltages.

The following are the advantages of power sharing converter 1) Centre-point grounding of fuel cell zones helps in achieving a higher DC link voltage and safe operation resulting from lower electrostatic potentials to ground for each fuel cell stack. 2) The FC-PSC provides each fuel cell stack with complete power operation flexibility. This means that each fuel cell can operate at separate power levels. 3) The use of fewer converter stages reduces overall power conditioning system cost, while allowing for a series connection of DC sources to a medium voltage utility grid. 4) The introduction of high-frequency (HF) isolation transformers in the DC-DC converter stage eliminates bulky line frequency 60 Hz transformers. 5) Increased efficiency of power converters with higher utilization of power devices. 6) The drooping characteristics of a fuel cell stack's voltage maintains sufficient input voltages at the DC bus of the inverter, even at lower powers.

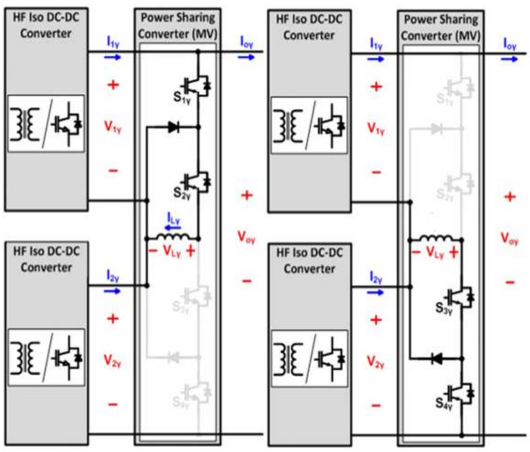

Figure 3: Medium Voltage Power Sharing Converter

Case I: The power shared by both fuel cell is assumed as its 100% of output power. Here the source voltages are equivalent, such that $V_{1\alpha}$= 12 V and $V_{2\alpha}$ = 12 V

Case II: The power output of first fuel cell is 100% of its full output power and the second fuel cell is 50% of its full output power. Here the source voltages are not equivalent, such that $V_{1\alpha}$ = 12 V and $V_{2\alpha}$ = 18 V

Case III: The power output of first fuel cell is 20% of its output power and the second fuel cell is 80% of its full output power. Here, the source voltages are not equivalent, such that $V_{1\alpha}$ = 21.6 V and $V_{2\alpha}$ = 14.4V

$$L_\alpha = (D_{1L\alpha}\, V_{1L\alpha})/(f_{sw}\, \Delta I_{L\alpha}) \quad \text{......................................(4)}$$

$$D_{1L\alpha} = 50\% \quad V_{1L\alpha} = 12V \quad f_{sw} = 20\ kH \quad \Delta I_L = 3A$$

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$$L_{\alpha} = (0.5*12)/(20*1000 * 3) = 100\mu H$$

The power sharing converter was simulated using MATLAB/SIMULINK. The Figure 4 is the SIMULINK model of a low voltage power sharing converter.

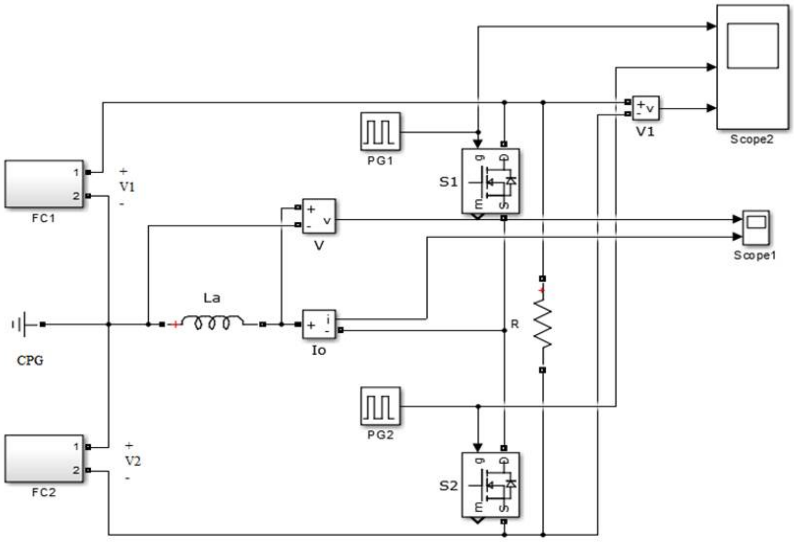

Figure 4: Simulink Model of LV-PSC

III. SIMULATION RESULTS

Case I: Here, the source voltages are equivalent, such that $V_{1\alpha}$ = 12 V and $V_{2\alpha}$ = 12 V. The average current flowing through the zonal inductor is zero, which shows that both source powers are equal as no power is shared between them. The average current owing through the zonal inductor is zero, which shows that both source powers are equal as no power is shared between them. The Figure 5 shows the switching pattern of switches $S_{1\alpha}$, $S_{2\alpha}$ and also the output voltage. Also Figure 6 shows the zonal inductor voltage and current. The duty ratio can be taken as 50%.

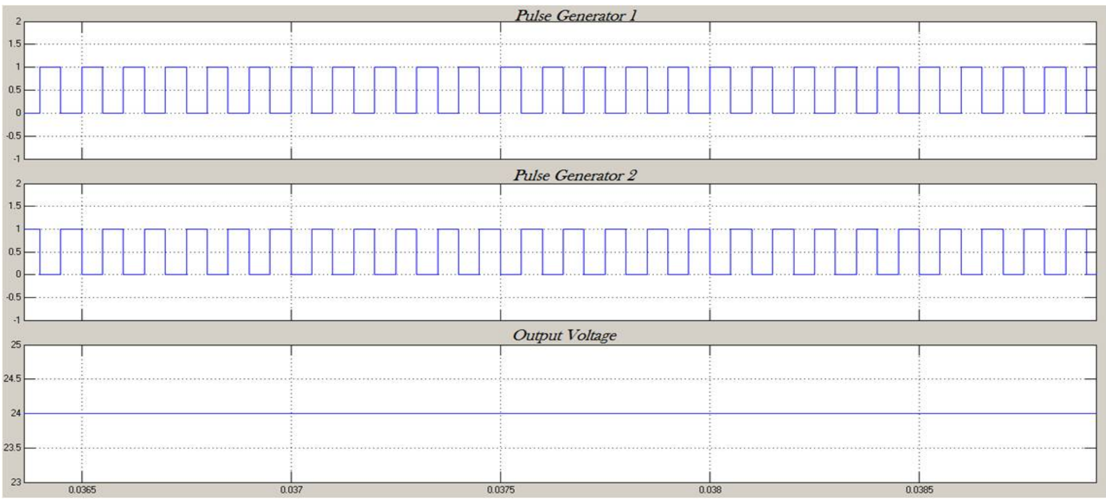

Figure 5: Gating Signals of Switches $S_{1\alpha}$, $S_{2\alpha}$ & Output Voltage.

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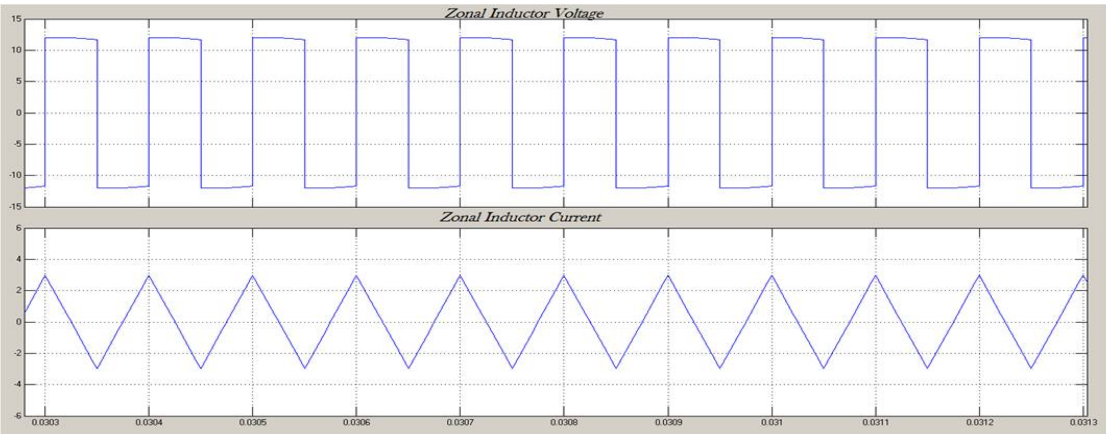

Figure 6: Zonal Inductor Voltage & Current.

Case II: Here, the source voltages are not equivalent, such that $V_{1\alpha}$ = 12 V and $V_{2\alpha}$ = 18 V. The average current owing through the zonal inductor is positive, which shows that there is a power sharing between two sources. The Figure 7 shows the switching pattern of switches $S_{1\alpha}$, $S_{2\alpha}$ and also the output voltage. Also Figure 8 shows the zonal inductor voltage and current. $D_{1\alpha}$ is taken as 60% and $D_{2\alpha}$ is taken as 40%.

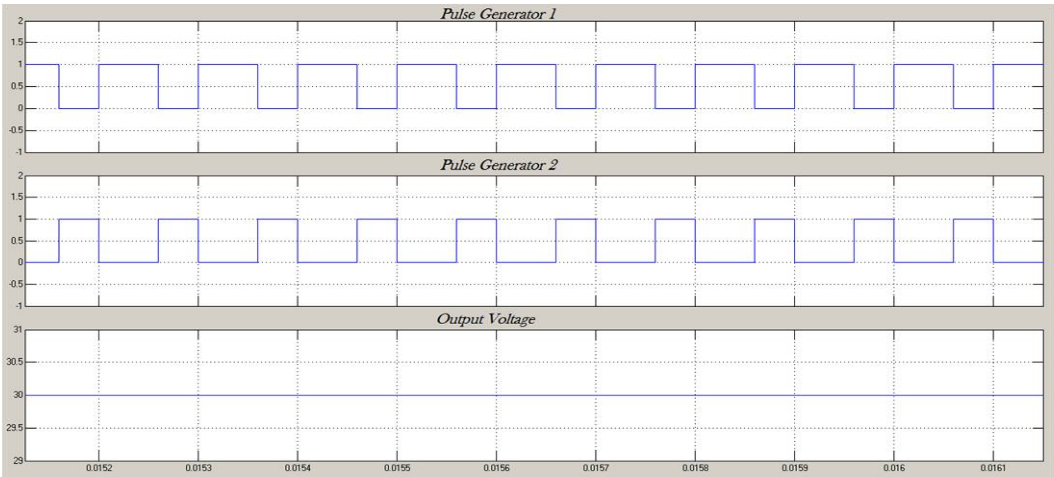

Figure 7: Gating Signals of Switches $S_{1\alpha}$, $S_{2\alpha}$ & Output Voltage.

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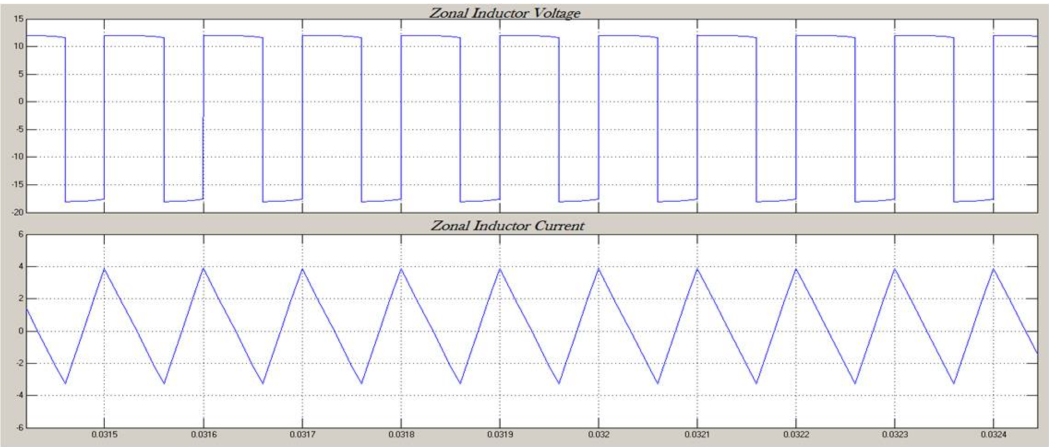

Figure 8: Zonal Inductor Voltage & Current.

Case III: Here, the source voltages are not equivalent, such that $V_{1\alpha}$ = 21.6 V and $V_{2\alpha}$ = 14.4 V. The average current owing through the zonal inductor is negative, which shows that there is a power sharing between two sources. The Figure 9 shows the switching pattern of switches $S_{1\alpha}$, $S_{2\alpha}$ and also the output voltage. Also Figure 10 shows the zonal inductor voltage and current. $D_{1\alpha}$ is taken as 40% and $D_{2\alpha}$ is taken as 60%.

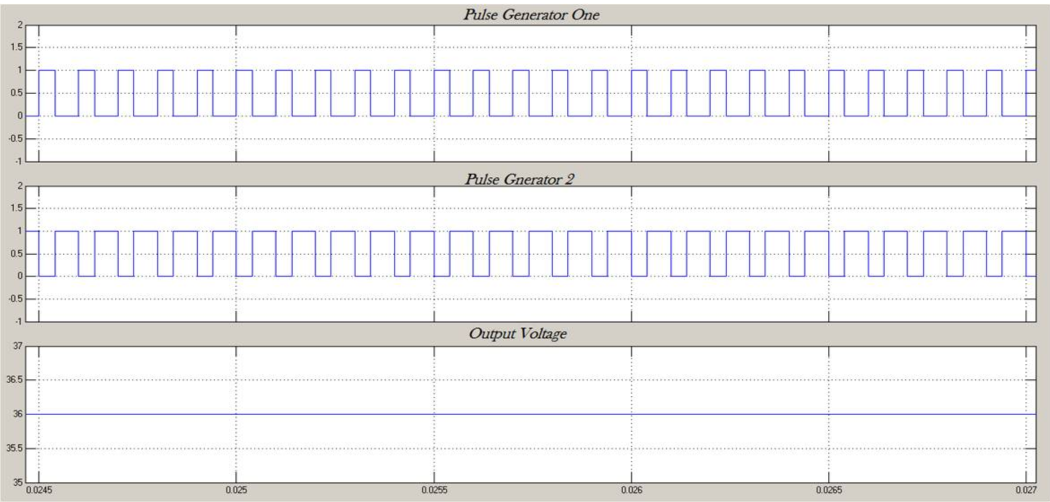

Figure 9: Gating Signals of Switches $S_{1\alpha}$, $S_{2\alpha}$ & Output Voltage.

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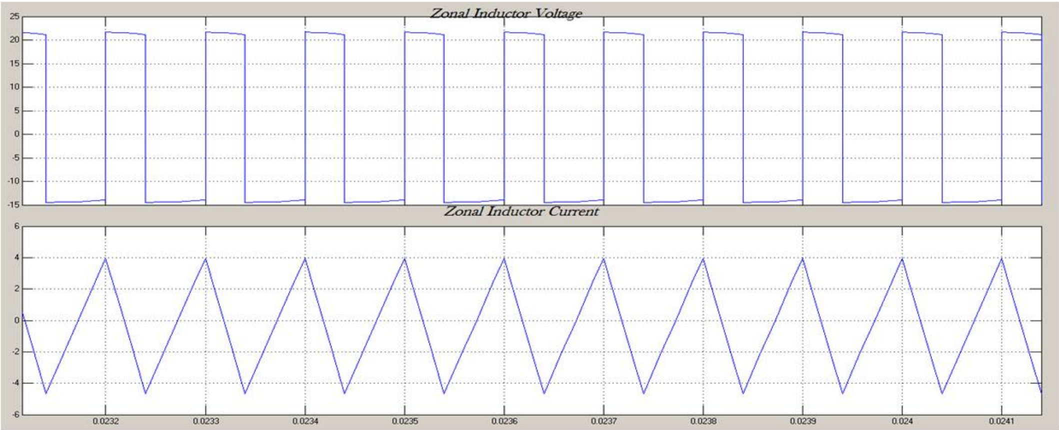

Figure 10: Zonal Inductor Voltage & Current.

IV. CONCLUSION

A family of new multiport power sharing converter topologies is used for utility scale FC power generation. Multiple FC sources is connected to a medium voltage grid via a single multilevel neutral point clamped (NPC) inverter, interfaced with high-frequency isolation. The concept enables each FC source to be electrically grounded, thereby eliminating the rise in electrostatic potential and contributing to increased safety. A unique family of power-sharing technology has been shown to decouple series-connected source currents and enable control of each fuel cells individual power level. There are two types of power sharing converter used, one is low voltage power sharing converter and other is medium voltage power sharing converter. For case I, the average current owing through the zonal inductor is zero, which shows that both source powers are equal as no power is shared between them. For case II, the source voltages are not equivalent and the average current owing through the zonal inductor is positive, which shows that there is a power sharing between two sources. For case III, the source voltages are not equivalent and the average current flowing through the zonal inductor is negative, which shows that there is a power sharing between two sources.

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