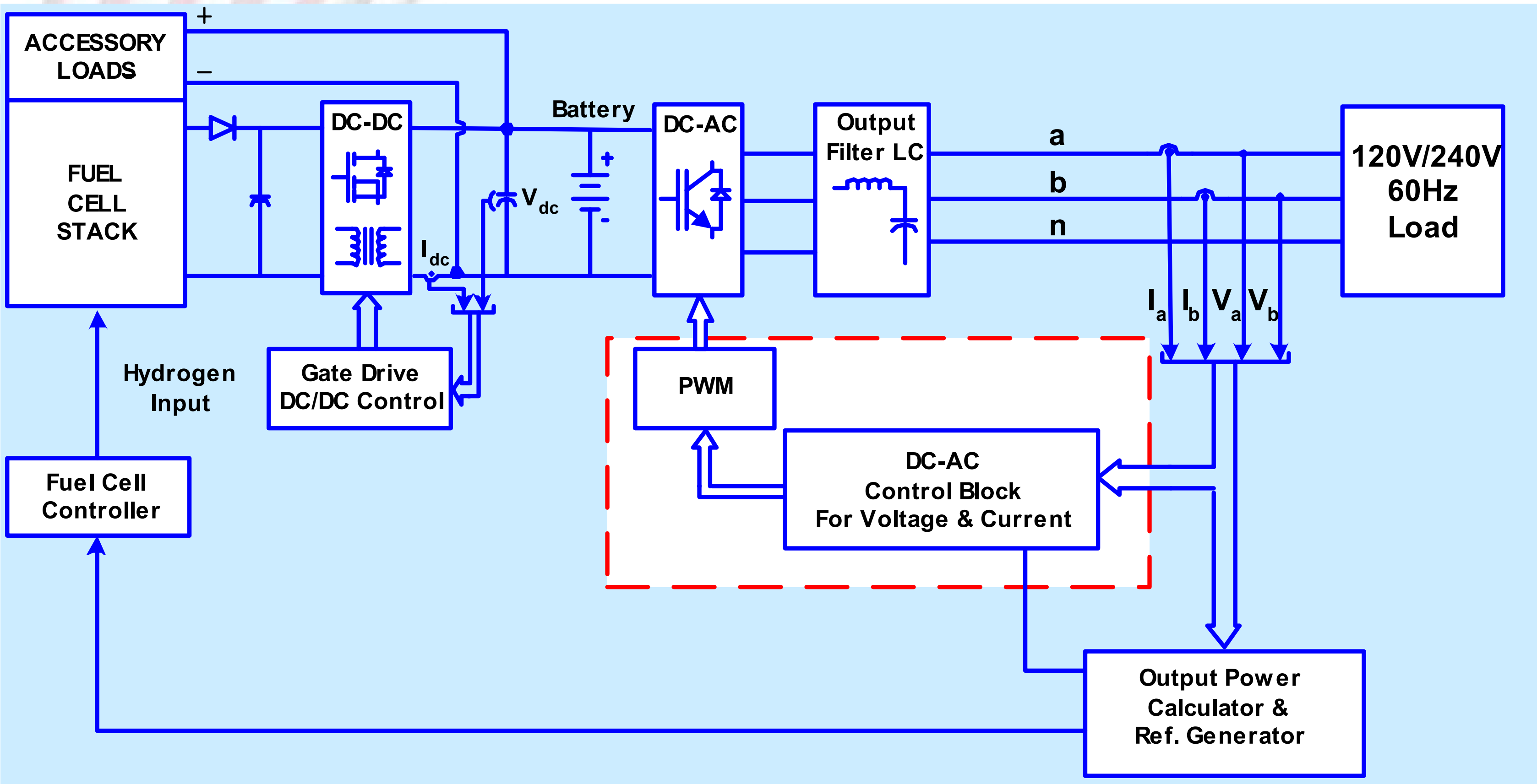
Development of High Frequency Link Direct DC to AC Converters for Solid Oxide Fuel Cells (SOFC)

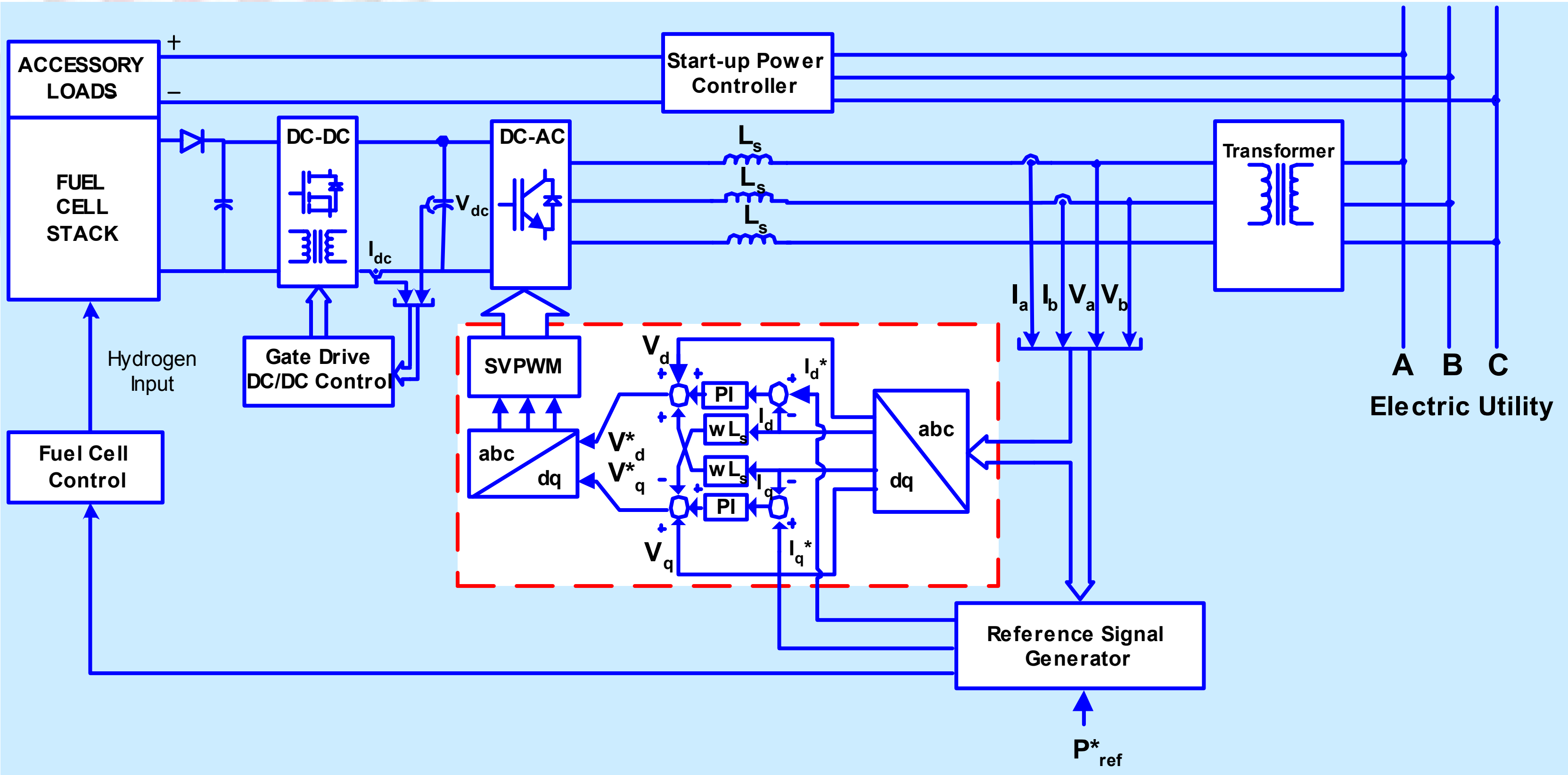
Dr. Prasad Enjeti
Power Electronics Laboratory
Department of Electrical Engineering
Texas A&M University
College Station, TX - 77843

SECA Industrial Partner: Delphi-Auto

Fuel Cell Power Conditioning Stage: Block diagram (dedicated loads)



Fuel Cell Power Conditioning Stage: Block diagram (connected to utility)



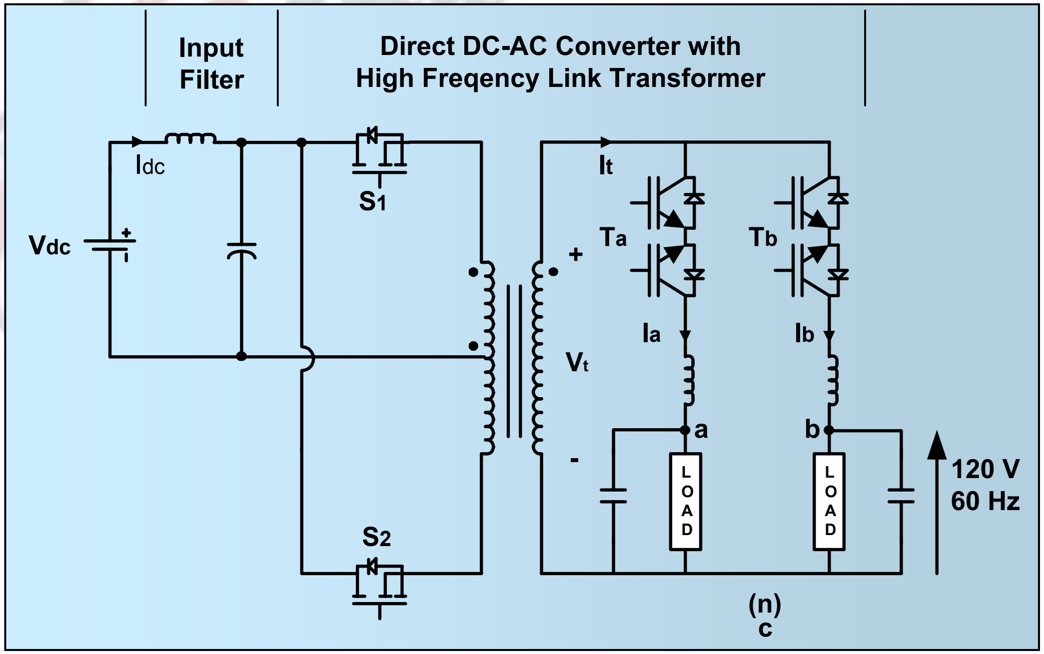
High Frequency Link Direct DC to AC Converters for SOFC

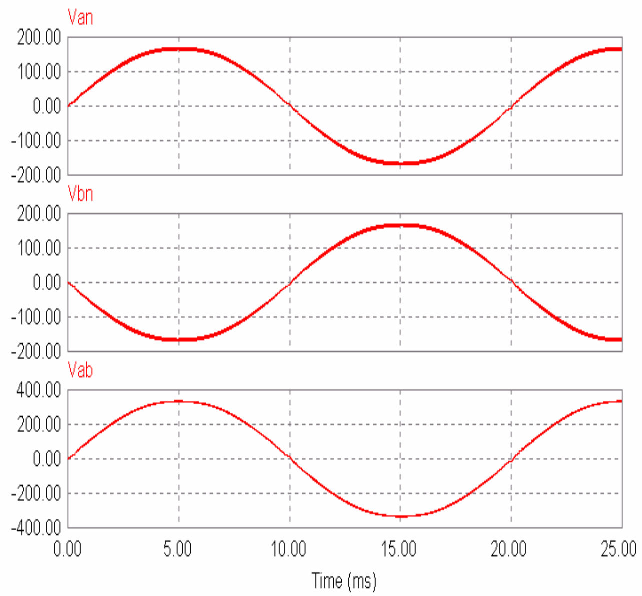
- This project proposes to design and develop high frequency link direct DC to AC converters to improve performance, optimize the size, cost, weight and volume of the DC to AC converter in SOFC systems
- The proposed topologies employ a high frequency link, direct DC to AC conversion approach. The direct DC to AC conversion approach operates without an intermediate dc-link stage
- The absence of the dc-link, results in the elimination of bulky, aluminum electrolytic capacitors, which could result in lower weight/volume/size and cost of the power electronic converter

R&D Objectives & Approach

- The primary objective is to realize cost effective fuel cell converter, which operates under a wide input voltage range, and output load swings with high efficiency and improved reliability
- Employ state of the art power electronic devices & configure two unique topologies to achieve direct conversion of DC power (24-48V) available from a SOFC to AC power (120/240V, 60Hz) suitable for utility interface and powering stand alone loads
- Investigate direct DC to AC conversion

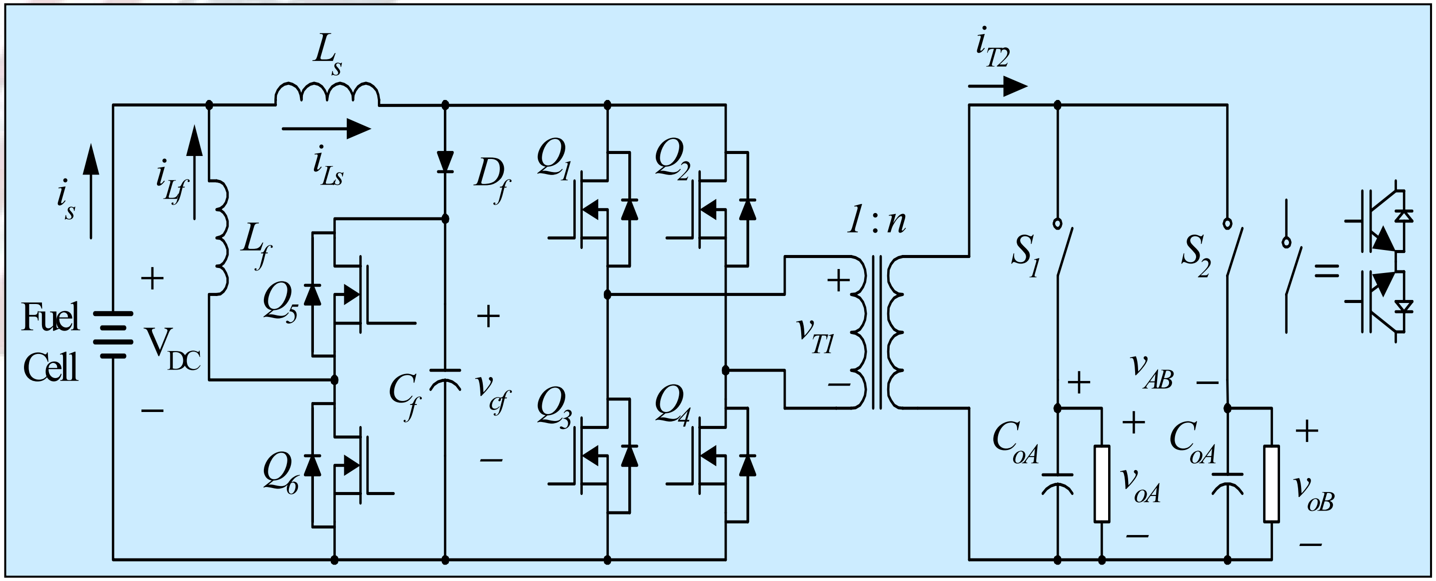
Voltage-fed High Frequency Link Direct DC to AC Converters for SOFC





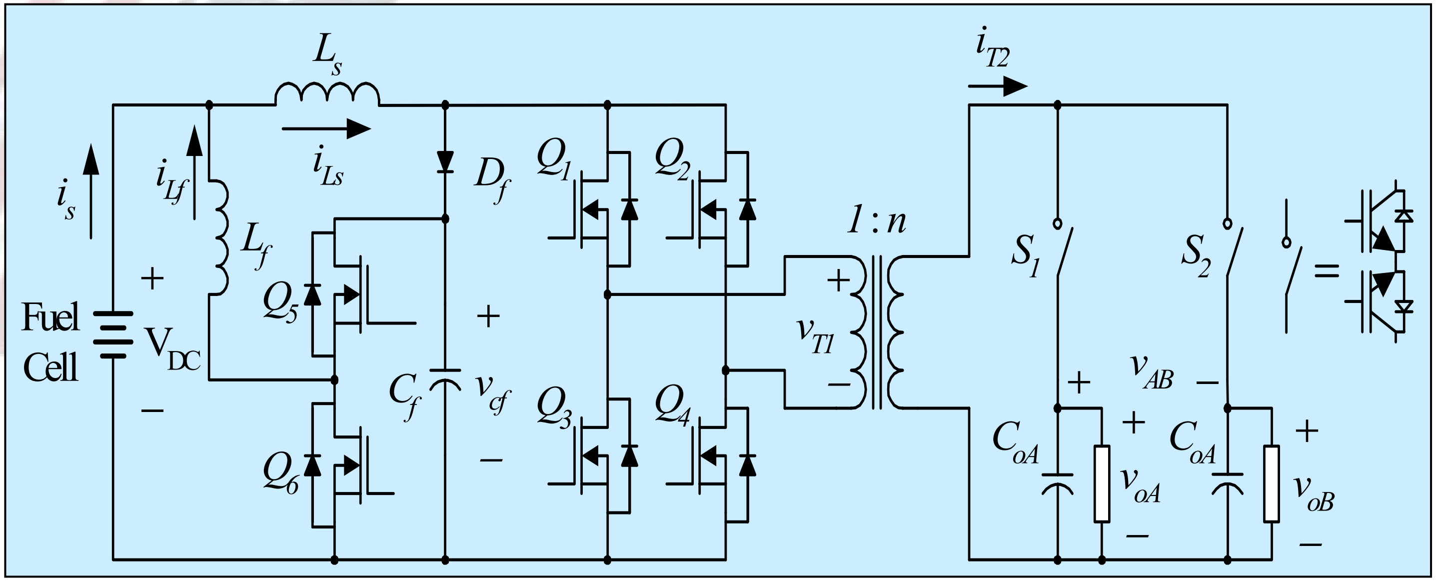
- Direct DC to AC power conversion of fuel cell voltage (22V) to 120/240V AC, 60Hz
- The switches are operated in high frequency (40kHz), zero current switching (ZCS) mode
- ZCS also guarantees transformer volt-second balance

Current-fed High Frequency Link Direct DC to AC Converters for SOFC



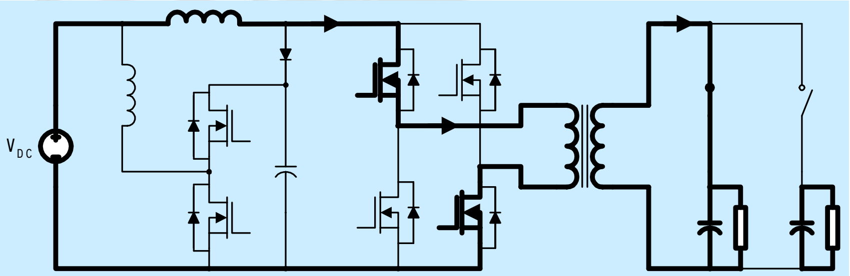
- Current-fed direct DC to AC power conversion of fuel cell voltage (22V) to 120/240V AC, 60Hz
- Consists of full-bridge inverter Q1-Q4, HF transformer, simplified AC-AC converter
- The switches Q5, Q6 (are optional) provide input ripple current (120Hz) cancellation

Current-fed High Frequency Link Direct DC to AC Converters for SOFC

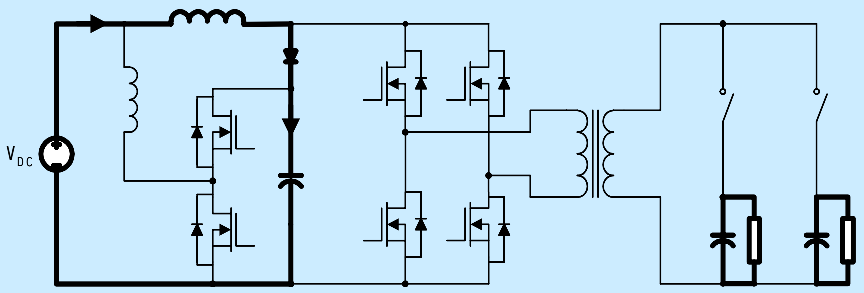


- **Full-bridge inverter offers lower switch stress, simple voltage clamping and transformer flux balance**
- **The switches Q5, Q6, Lf (optional components) provide active filtering function: i.e. cancellation of fuel cell input ripple current**
- **The converter has three operating modes**

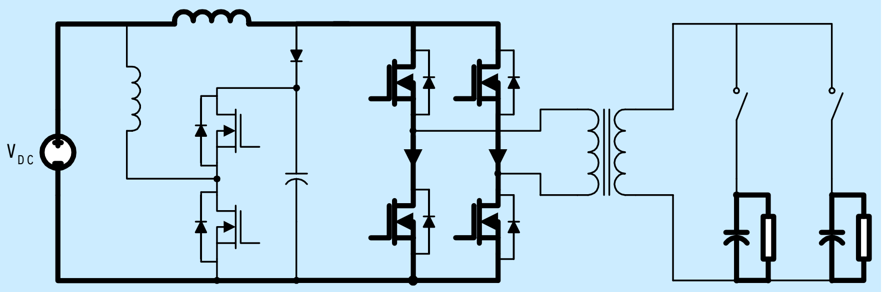
Current-fed Direct DC to AC Converter: Operating Modes



- Powering mode: Diagonal switches Q1, Q4 or Q2, Q3 are turned-on.
- Primary inductor current is transferred to secondary side

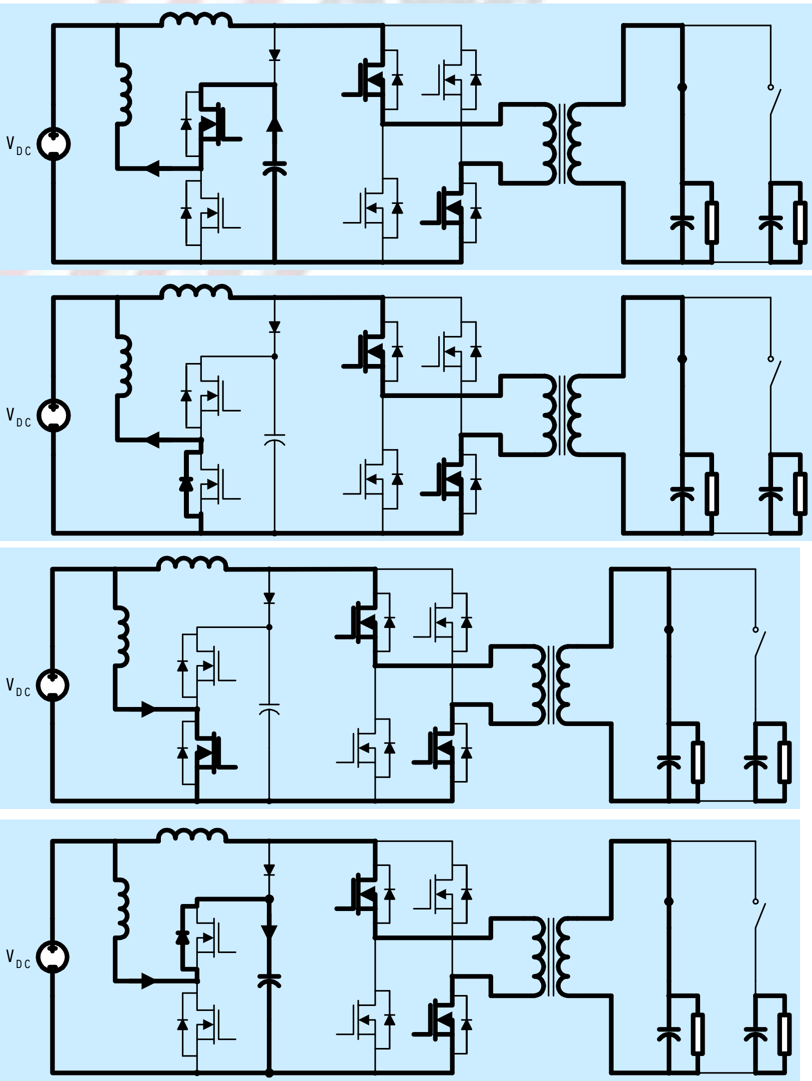


- Restoring mode: switches are turned-off, the inductor current flows via the diode Df and charges the input capacitor
- Capacitor voltage is controlled by Q5, Q6 and is maintained higher than fuel cell voltage



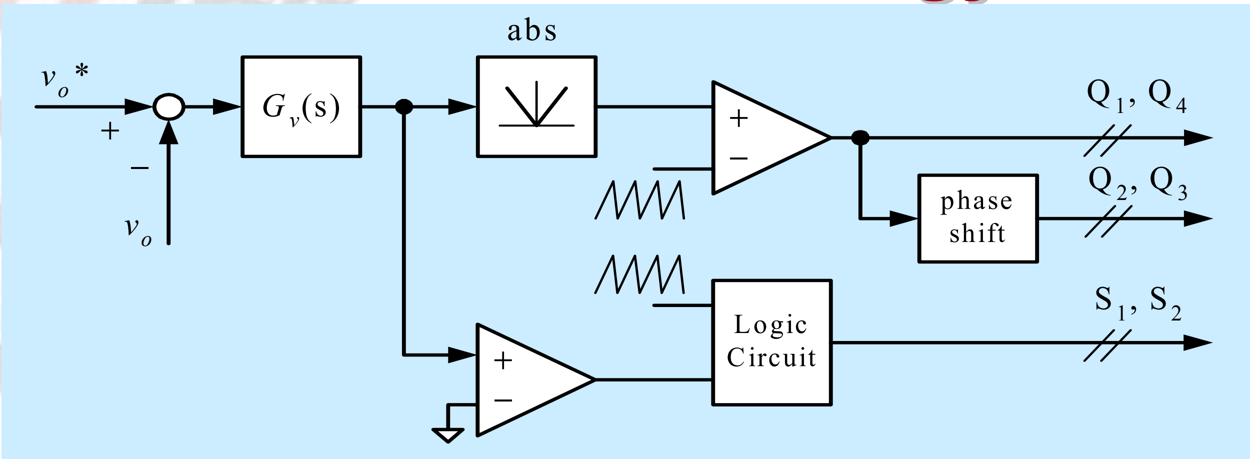
- Restoring mode: switches Q1-Q4 are turned-on
- Primary inductor current increases at the rate of Vdc/Ls

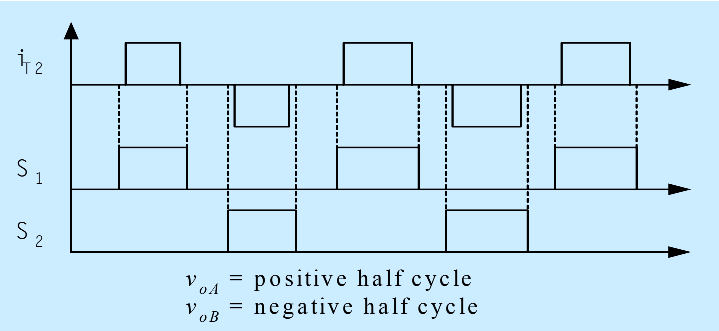
Current-fed Direct DC to AC Converter: Operating Modes

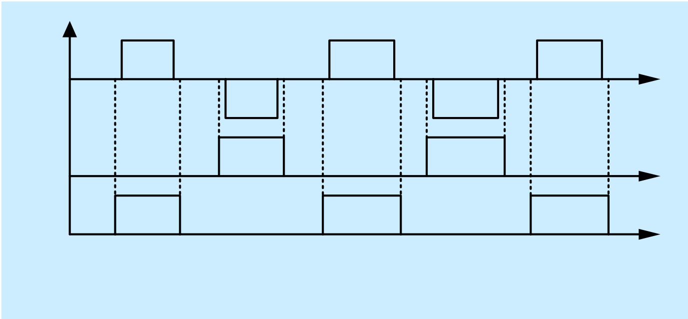


- Input ripple current cancellation modes are shown in this figure
- Capacitor voltage is controlled by Q5, Q6 and is maintained higher than fuel cell voltage

Direct DC to AC Converter Control Strategy

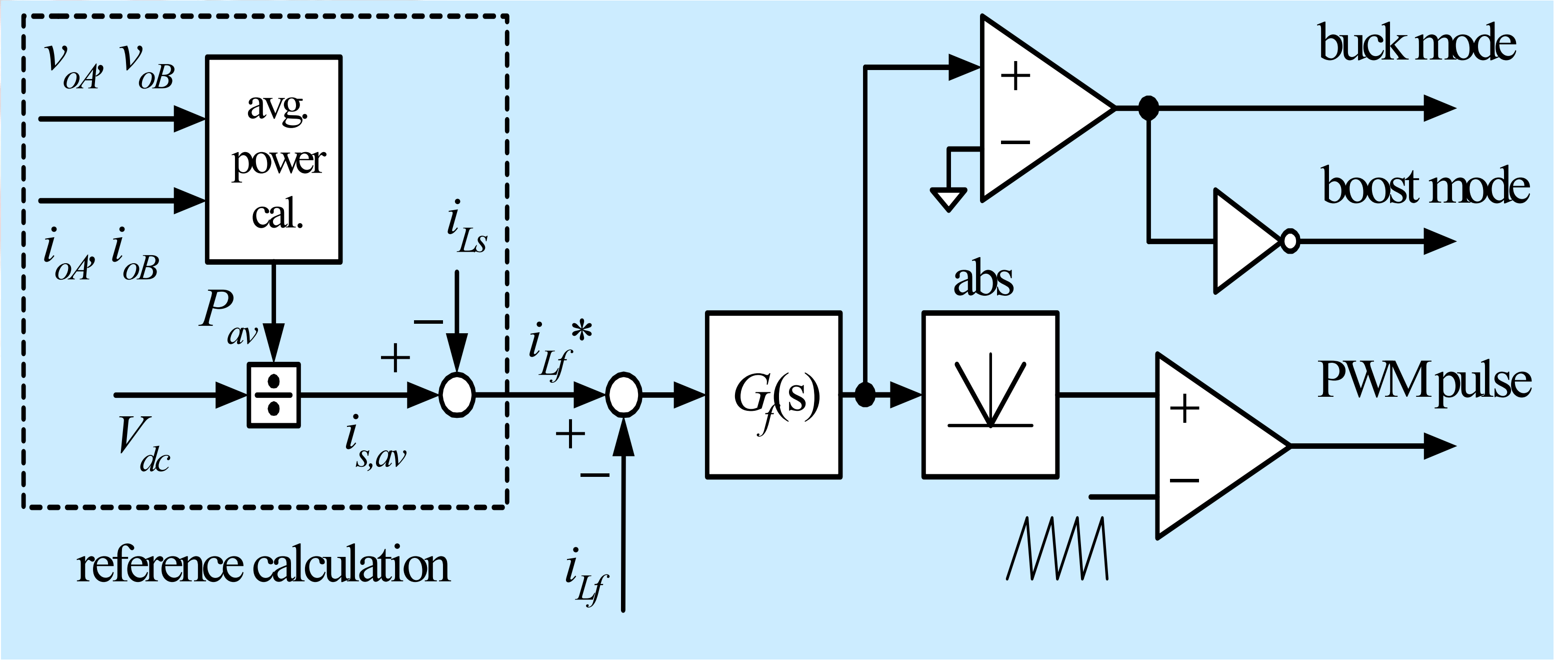






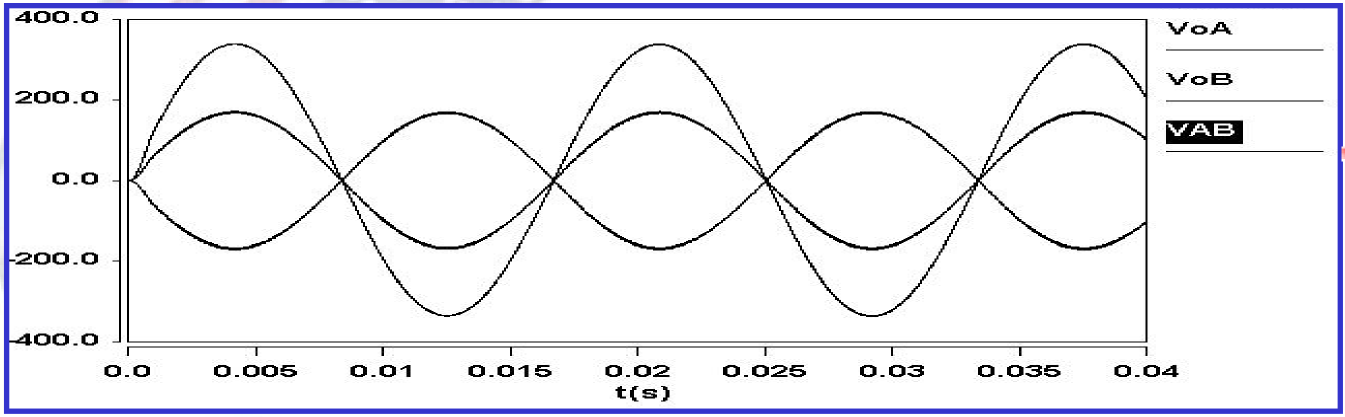
- **Voltage control strategy for the direct DC to AC Converter**
- **A proportional (P) controller is used for Gv(s)**
- **The bi-directional switches S1, S2 are selected based on the input current polarity**

Direct DC to AC Converter Control Strategy

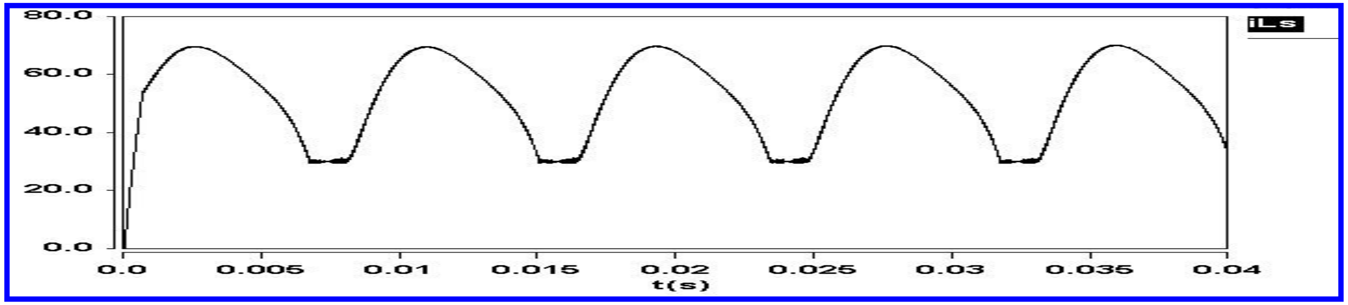


- **The above control block diagram is used to actively cancel the low frequency ripple current from the fuel cell input current**

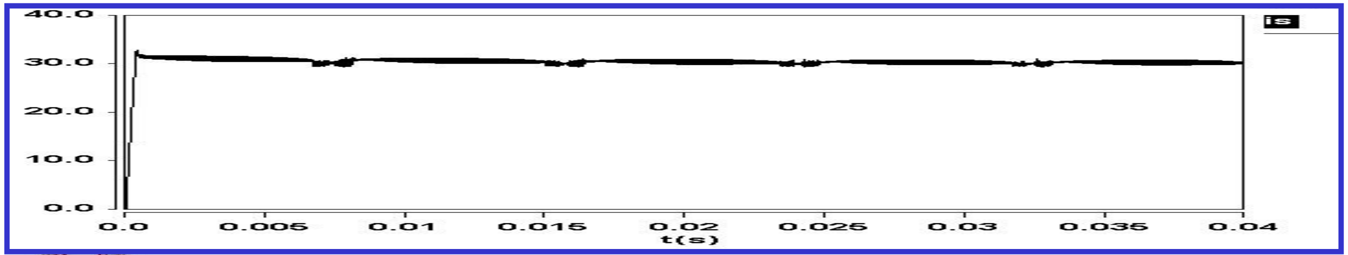
Direct DC to AC Converter Simulation Results



- Output Voltage 120V/240V, 60Hz



- Input inductor current

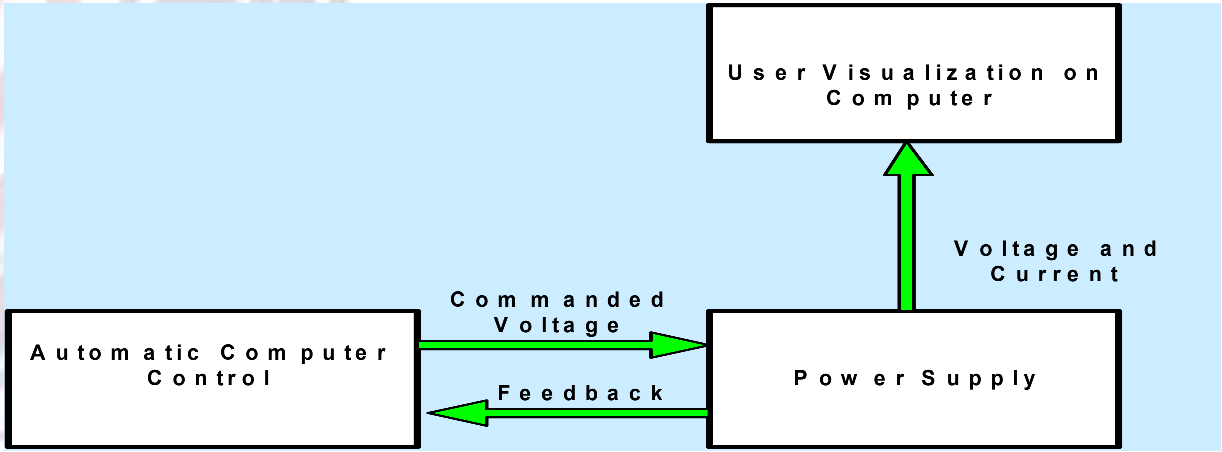


- Fuel cell input current

Activities for the Next 6-12 months

- **Task # 1: Design**: A detailed design of the proposed direct DC to AC converters will be completed: high frequency transformer design, component ratings, protection circuitry, hardware layout will be completed followed by a comprehensive simulation of the FCI systems. The design will be optimized to handle wide input voltage range and output load swings. **Completed**
- **Task # 2: Evaluation of Fuel Cell Ripple Current & Energy Storage**: A trade study will be initiated to study the performance of various types of input filter designs
- **Task # 3: Hardware Construction & Testing**: Hardware components will be procured for the development of the proposed converters and tested with DSP control in open loop
- **Task # 4: Testing & Verification**: The proposed converters will undergo linear & nonlinear load testing on a SOFC fuel cell simulator. These tests will be conducted in coordination with SECA Industrial partner: Delphi-Auto

SOFC Fuel Cell Simulator Development to assist in testing/validation



- The purpose of the fuel cell simulator is to enable testing and validation of power conditioning module performance under various loading conditions
- A programmable DC power supply (0-55V, 10kW) is controlled via Labview to emulate V-I characteristics of a SOFC
- Labview is employed for SOFC V-I curve fitting and emulation