Intelligent Diversification of Energy Resources in DC Grids

PI: Ali Davoudi

As the number of inputs energy sources and loads increase, the benefits of the proposed converter over existing topologies becomes more pronounced.

The proposed topology provides
1. Minimum part numbers
2. Only a single inductor
3. High efficiency
4. Improved reliability
5. Power budgeting
6. Voltage regulation

The existing multiple-input multiple-output converters employ several converter stages to process power and supply different loads.

Employment of several converter stages:
- reduces the efficiency of the system,
- is costly,
- requires several inductors which leads to a larger size,
- makes integration of MIMO converters impossible.

NEW INSIGHTS

The proposed single-stage multiple-input multiple-output (SSMIMO) converter is capable of:
- Diversifying energy sources
- Supplying diversified loads
- Processing power by means of a single inductor which makes a compact system
- Budgeting power between different input energy sources

END-OF-PHASE Results

MAINACHIEVEMENT:
- The SSMIMO converter topology is an optimized, ultimately integrated, and cost effective topology that can be used to supply different loads by multiple input sources
- The total required power by the loads can be budgeted between diversified input sources while regulating output voltages.

HOW THE PROPOSED TOPOLOGY WORKS:
- Multiple energy sources and multiple loads are connected to a single inductor and semiconductor switches.
- Employing the proposed switching and control scheme, multiple loads can be supplied while the total required power is budgeted between different input sources.
Ultra-reliable Topology Reconfiguration of Power Electronics for Mission Critical Applications

PI: Ali Davoudi

**Main Achievement:**
- Capability to increase the mean-time-to-failure (MTTF) of the power electronics converters up to ten fold that of existing parallel or standby topologies for mission-critical applications.

**How the Proposed Topology Works:**
- Several converter modules are put in the topology illustrated in the figure above.
- Since the junction temperature of the semiconductor switches determines the MTTF of the converter modules, once the temperature of any module has reached a certain limit, the thermal camera detects the overheating condition.
- Thermal data are processed by FDIR controller and optimized configuration is chosen and applied to the system through RF transmitter/receiver.

**End-of-project objectives:**
- Increase the reliability and the expected lifetime of power electronic converters up to ten fold that of the existing redundant topologies
- Find an optimized FDIR control strategy for managing and controlling faults in such systems

The following thermal image of the prototype hardware with two converter modules shows that the proposed converter topology (b) is less susceptible to faults.
High-fidelity Modeling of Energy Storage Units
PI: Ali Davoudi

STATUS QUO

✓ An equivalent circuit model of super-capacitor is needed for computer simulations to reduce the design time and the cost of energy storage unit.
✓ High-fidelity circuit model of SC relatively shows the highest accuracy in simulations compare to the proposed model, however it is not computationally efficient.

MAINACHIEVEMENT:
• Model Order Reduction theory is used to replace the original high-order state space with a low order space, while preserving the input-output relationship.

HOW THE REDUCTION PROCESS WORKS:

End-of-project objectives:
• Extracting 3rd order differential equation with different techniques (TBR and SPA).
• Presenting a circuit-based reduced model of super capacitors

Present a simple model which can be simulated faster and show acceptable accuracy in a wide range of frequency. This circuit-based component model can be used for system-level studies.

End-of-phase goal

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Fast Response Control of Power Electronics Applications
PI: Ali Davoudi

STATUS QUO:
Power Factor Correction (PFC) converters transfer the electric power to the load with nearly unity input power factor. These converters are widely studied due to their significant impact on power quality.
- Low efficiency of the cascaded topologies
- Second line harmonic in output voltage
- Low dynamic due to large output capacitor
- High accuracy small-signal modeling of the PFC converters is still open to research

NEW INSIGHTS:
- Cuk converter is an inherent power factor corrector when operating in discontinuous capacitor voltage mode (DCVM)
- Small-signal modeling for PFC operation can be somehow related to DC operation of the converter
- Switching frequency can be considered as a control parameter in DCVM operation

MAIN ACHIEVEMENT:
We focus on making the case for the application of the DCVM Cuk converter as a PFC power supply for communication equipment:
- Modeling of the converter for PFC and DC-DC operation
- Fast response controller for the application of supplying sensitive loads such as the high speed processors
- Constant voltage stress on switches which leads to higher efficiency in full load

HOW THE PROPOSED TOPOLOGY WORKS:
An averaged model of the converter for DC-DC operation is developed. Then, the model is used for PFC mode by establishing a correspondence between DC-DC and PFC modes.
The switching frequency is employed as a control parameter and changes in inverse proportion to the effective loading resistance. This technique remarkably improves the dynamic response of the converter to load variations. It also provides a constant voltage stress on semiconductor switches.

QUANTITATIVE IMPACT:
End-of-project objectives:
- Calculating the dynamic model of the converter for DC-DC and PFC operation
- Design a fast response controller and study its performance in reality

The following figure shows the hardware setup for conducting the experiments and a sample of output voltage with no overshoot or undershoot while the output load changes.
Time-invariant Modeling of Switching Converters

PI: Ali Davoudi

**MAIN ACHIEVEMENT:**
This research focuses on developing highly accurate TI and SFD models with the consideration of parasitic effects for fourth order DC-DC converters.

HOW THE PROPOSED MODELING WORKS:
- State variables, switching function, and duty cycle command are represented in time-dependent quasi-Fourier series (QFS).
- In a closed loop system, the coefficients of the duty cycle command are known, which are used to solve for the on-time of the switching function for every switching period. The QFS coefficients of the switching function is a function of on-time.
- The QFS coefficients of state variables are functions of the QFS of the switching function. After solving for the coefficients of the switching function, the values of the state variable can be found for that particular switching period.

**QUALITATIVE IMPACT**

**END-OF-PHASE GOAL**
- Develop TI and SFD models for fourth order DC-DC converters
  - Cuk converter
  - ZETA converter
  - SEPIC
  - Positive Output Luo-Converter
  - Negative Output Luo-Converter
  - Buck converter

**QUANTITATIVE IMPACT**
- TI and SFD Models that are used in stability assessment and controller design.
- The developed model should closely match with the detailed switching model as well as the hardware in both time domain and frequency domains.