FUNDAMENTALS, APPLICATIONS AND OPEN PROBLEMS IN TWO CLASSES OF SWITCHING POWER CONVERTERS

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Research Activities  
http://deeeaa.urv.cat/gaei/index.php
OUTLINE

I – CONTEXT

II – EFFICIENT LIGHTING

III – CONTACTLESS POWER SUPPLY

IV – CONSTANT POWER SUPPLY

V – SELF-OSCILLATION FOR SINUSOIDAL GENERATION

VI – CONTROL OF CONSTANT POWER LOADS

VII – CONCLUSIONS
CONTEXT

POWER ELECTRONICS: A BRIEF REVIEW

- DOMAIN

Conversion and Control of Electric Energy for Industrial or Domestic Applications
POWER ELECTRONICS: A BRIEF REVIEW

- INTERDISCIPLINARY SUBJECT

- Power Electronics
  - Computer-Aided Design
  - VLSI Circuits
  - Power Semiconductor Devices
  - Switching Converters
  - Electrical Drives
  - Control Theory
  - Digital Processors
  - Analogue and Digital Electronics
POWER ELECTRONICS: A BRIEF REVIEW

- INTERDISCIPLINARY EXPERTISE

- Power Semiconductor Devices
- Magnetic and Capacitive devices
- Switching Converter
- Modelling and Analysis
- Control
- Microelectronic Integration
- Simulation
POWER ELECTRONICS: A BRIEF REVIEW

- General specifications of a power converter

Extract energy from and external source

- Battery
- PV Panel
- AC-DC Rectifier
- Fuel Cell

Supply energy to the load according to specifications

- Constant consume and strict values of output voltage (Instrumentation)
- Pulsating consume (laser supply)
- Variable consume (motor supply)
POWER ELECTRONICS: A BRIEF REVIEW

- First Reference on DC-DC Switching Power Converters


Where are we now 50 years after one-page Kossov’s publication?
Concern for the global warming is increasing the interest for renewable energies.

Underpinning a sustainable environment implies more efficient devices and better control strategies for electric energy conversion.

Two vectors catalize the new research:

**Technology:**
- Wide-gap power devices
  - Digital processors

**New paradigm in power distribution:**
- Vehicles
  - Smart grids
Three fields have recently emerged:

- Efficient lighting
- Contactless power supply
- Constant power load supply

- Resonant conversion
- Non-linear control
EFFICIENT LIGHTING

- Low Energy Consumption
- Low Maintenance Cost
- Improved Light Quality
- Reduction of CO$_2$ emissions.

- Artificial lighting $\approx 19\%$ worldwide electricity production
## EFFICIENT LIGHTING TYPES

<table>
<thead>
<tr>
<th>Category</th>
<th>IEFL Lamp</th>
<th>Fluorescent Lamp</th>
<th>High Pressure Mercury Vapour</th>
<th>High Pressure Sodium Vapour</th>
<th>Metal Halide Lamp</th>
<th>LED Lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Efficiency (Im/W)</td>
<td>70-80</td>
<td>25-70</td>
<td>30-50</td>
<td>90-110</td>
<td>85</td>
<td>20-80</td>
</tr>
<tr>
<td>Effective Light Efficiency (PLM/W) (lumens measurement for human pupil)</td>
<td>113-130</td>
<td>40-112</td>
<td>26-43</td>
<td>51-63</td>
<td>126</td>
<td>50-100</td>
</tr>
<tr>
<td>Color Rendering index (Ra = CRI)</td>
<td>&gt;80</td>
<td>50-80</td>
<td>30-40</td>
<td>&lt;40</td>
<td>65</td>
<td>70-80</td>
</tr>
<tr>
<td>Power Factor</td>
<td>&gt;0.98</td>
<td>0.35-0.95</td>
<td>0.44-0.67</td>
<td>0.44</td>
<td>0.4-0.6</td>
<td>1</td>
</tr>
<tr>
<td>Cold start time</td>
<td>Instant</td>
<td>&lt;3’</td>
<td>4-10’</td>
<td>4-10’</td>
<td>4-10’</td>
<td>Instant.</td>
</tr>
<tr>
<td>Stroboscopic effect</td>
<td>No</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>No</td>
</tr>
<tr>
<td>Lamplife (hrs.)</td>
<td>80000</td>
<td>5000-10000</td>
<td>3500-6000</td>
<td>8000-14000</td>
<td>10000</td>
<td>50000-80000</td>
</tr>
</tbody>
</table>
EFFICIENT LIGHTING

Example: A two-stage versatile ballast for discharge lamps

EFFICIENT LIGHTING
Example: A two-stage versatile ballast for discharge lamps
EFFICIENT LIGHTING
Example: A two-stage versatile ballast for discharge lamps

Steady-state

Warm-up and steady-state
EFFICIENT LIGHTING

A first question arises:

Can we develop a one-stage efficient balast?
CONTACLESS POWER SUPPLY
Common Application of Contactless Power

Heating generation

Battery charging
CONTACLESS POWER SUPPLY

Principle of Contactless Power Transfer

F. Turki (Vahle GmbH&Co.KG, Kamen, Germany), "An introduction to wireless power transfer: basics, applications and design“ GAEI Seminar, June 20th 2014, Tarragona, Spain
CONTACLESS POWER SUPPLY

Industrial System Components

System overview of a contactless power supply application
CONTACLESS POWER SUPPLY

Vahle 3kW Charging Systems for Electric Vehicles

Location at the bottom of the car

Location under the number plate
CONTACTLESS POWER SUPPLY

Fleet test with Karabag GmbH Hamburg.

Conductive charging (3 kW) also possible.
A second question arises:

Can we develop a simple battery charger either conductive or contactless?
CONSTANT POWER LOAD SUPPLY

Electric vehicle power distribution architecture

CONSTANT POWER LOAD SUPPLY

Electric vehicle CPL operation

- Speed reference
- Controller to maintain constant speed
- Main DC Bus
- DC/DC Converter
- DC/DC Inverter
- M
- Load
- Energy Storage System
- 1st stage: Source Converter
- 2nd stage: Load Converter
- Rotating load with one-to-one torque-speed characteristic

Conditions:
- \( w = \text{Const} \)
- \( T = \text{Const} \)
- \( P = \text{Const} \)
CONSTANT POWER LOAD SUPPLY

A generalized architecture for EV: multiconverter system notion
Medium voltage DC bus for power distribution in ships

CONSTANT POWER LOAD SUPPLY

Medium voltage DC bus for power distribution in ships

Circuit model for CPL supply

Unstable behaviour of the bus voltage

\[
\frac{d^2 V}{dt^2} = - \left( \frac{1}{C_{eq} L_{eq}} \right) V - \left( \frac{1}{T_f} \right) \frac{dV}{dt} + \frac{E_1}{C_{eq} L_{f1}} + \frac{E_2}{C_{eq} L_{f2}} + \frac{E_3}{C_{eq} L_{f3}} + \frac{E_4}{C_{eq} L_{f4}} - \frac{P_{eq}}{C_{eq} T_f V} + \frac{P_{eq}}{C_{eq} V^2 \frac{dV}{dt}}
\]
CONSTANT POWER LOAD SUPPLY

A canonical problem

\[ i_{CPL} = \frac{P}{v_C} \]
CONSTANT POWER LOAD SUPPLY

DC-DC switching converters with CPL are open-loop unstable

On trajectory

Off trajectory

They don’t belong to the family of switched-affine systems
CONSTANT POWER LOAD SUPPLY

How are CPL problems tackled?

- Passive damping
- Active damping: notion of virtual resistor
- Non-linear control
CONSTANT POWER LOAD SUPPLY

How are CPL problems tackled?

Most existing solutions employ a CPL defined mathematically in a simulation frame.

A simple cascade connection of a converter acting as source and a converter behaving as a CPL has been rarely explored and no experiments have been reported.
A third question arises:

Can we tackle the problem of CPL supply in the cascade connection of two real converters?
SELF-OSC. FOR SINUSOIDAL GENERATION

Self-oscillating resonant converters are a possible response to the first two questions:

Can we develop a one-stage efficient balast?

Can we develop a simple battery charger?
RESONANT CONVERTERS

Principle

Resonant Converters

A recent example of resonant conversion

Frequency or phase modulation
A class of self-oscillating resonant converters

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(a) Operating principle of self-oscillating resonant converters with LFR characteristics:
\[ u = 1 \text{ for } i_L > 0 ; \quad u = 0 \text{ for } i_L < 0 \]

(b) Steady-state behavior
Resonant converters for self-oscillating mode
(a) SRC (b) PRC (c) LCC (d) LCL (e) LCLC
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Second order resonant converters
Matlab simulation of the self-oscillation mechanism in a PRC in the phase plane for $C=10.5$ nF, $L=8$ μH, $V_g=20$ V.
SELF-OSC. FOR SINUSOIDAL GENERATION

Second order resonant converters
SELF-OSC. FOR SINUSOIDAL GENERATION
Second order resonant converters
**SELF-OSC. FOR SINUSOIDAL GENERATION**

Second order resonant converters

\[-v_{C2n+2} = (G + Gr + Gr^2 + \ldots + Gr^{n-1}) - v_{C2}r^n\]

\[G = -V_g (1 + e^{-\xi \pi})^2\]

\[r = e^{-2\pi}\]

\[T = \frac{2\pi}{\omega_0}\]

\[\lim_{n \to \infty} v_{C2n+2} = \frac{G}{1 - r} = \frac{-V_g (1 + e^{-\xi \pi})^2}{1 - e^{-2\pi}} = \frac{-V_g (1 + e^{-\xi \pi})}{1 - e^{-\xi \pi}}\]
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Example: 6.78 Mhz self-oscillating parallel resonant converter based on GaN technology

Circuit diagram of a parallel resonant converter

Self-oscillating control provides:
- Simplicity: no external oscillator is required.
- Oscillation at the resonant frequency in spite of uncertainty.

Advantages:
- Closer operation to the resonant frequency regardless of uncertainty of the components and load/line variations.
- Straightforward realization.
- Reduced number of components.
- Inherent behavior as LFR.

Drawbacks:
- No output voltage regulation. Gain depends on the load.
- High impact of the propagation delays on the operation of the converter.
SELF-OSC. FOR SINUSOIDAL GENERATION

Example: 6.78 Mhz self-oscillating parallel resonant converter based on GaN technology

Design procedure

1. Define input and output voltage.
2. Define the desired switching frequency $\omega_0$ and the load $R_L$.
3. Find $Q$.
   \[ Q = \frac{V_{out}}{V_{in}} = 4.1 \]
4. Evaluate if $Q \geq 3.15$.
5. Calculate the value of the parallel capacitor.
   \[ C_p = \frac{Q}{\omega_0 \cdot R} = 1.44 \text{ nF} \]
6. Calculate the value of the inductance.
   \[ L = \frac{1}{\omega_0^2 \cdot C_p} = 382 \text{ nH} \]

AirFuel Alliance standard design parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_g$</td>
<td>12 V</td>
</tr>
<tr>
<td>$R_{L, \text{max}}$</td>
<td>57 $\Omega$</td>
</tr>
<tr>
<td>$f_0$</td>
<td>6.78 MHz ($\pm$ 150 kHz)</td>
</tr>
<tr>
<td>$V_{out}$</td>
<td>30 V</td>
</tr>
<tr>
<td>$P_{out}$</td>
<td>16 W</td>
</tr>
</tbody>
</table>
Limitations of the Implementation

A. The current sensing stage requires large bandwidth and noise rejection.

B. Effect of the propagation delay introduced by control circuit (comparator) and driver.
A. Current Sensor Design

Two different sensing stages may be appropriate:

1. **Current sensing transformer.**
   It requires compensation of the parasitic effects generated between the windings by opposing the magnetic fields.

2. **Shunt resistor sensed over a high-speed differential amplifier.**
   It does not require any special procedure in order to operate at a frequency of 6.78 MHz and presents a reduced size. This technique was selected.
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B. Delay Compensation Networks

1. RL delay compensation network: phase-leading behavior

Properties:
- Delay compensation defined by the time constant $\tau$ ($\tau = \frac{L_D}{R_D}$).
- No drift in case of load changes.
- Capable of processing high bandwidth waveforms.
- Introduces losses and it is not flexible.
- It exhibits a constant compensation, not easy to adapt for different delays in case of load changes.
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B. Delay Compensation Networks

2. Hysteresis delay compensation network: switching instants different from zero

Properties:
+ Delay compensation controlled by $V_{ih}$.
+ High flexibility in its adjustment.
+ Low latency, accuracy and capability of compensating high delays.
+ Facilitates ZVS if an AND gate is applied (delays lower than half-cycle).

- Range of admissible loads: [37, 57] $\Omega$.
- Requires a startup-ramp in the hysteresis level for auto-starting.

- AND gate: can compensate only a maximum delay of half-semicycle.
- NAND gate: can compensate only delays between half-semicycle and a full semicycle.
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B. Delay Compensation Networks

2. Hysteresis delay compensation network: switching instants different from zero

Effect of delay compensation in case of load changes

Response obtained with NAND gate (circles: switching instants)

Response obtained with AND gate (circles: switching instants)
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Experimental Prototype

Circuit Diagram
SELF-OSC. FOR SINUSOIDAL GENERATION

Experimental Prototype

Summary of components

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Code or value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$</td>
<td>300 nH</td>
</tr>
<tr>
<td>$C$</td>
<td>1.2 nF (C0G)</td>
</tr>
<tr>
<td>$V_s$</td>
<td>12 V</td>
</tr>
<tr>
<td>$C_m$</td>
<td>22.1 µF</td>
</tr>
<tr>
<td>Differential amplifier</td>
<td>THS 4151</td>
</tr>
<tr>
<td>eGaN FET (S)</td>
<td>EPC 8004</td>
</tr>
<tr>
<td>Driver</td>
<td>LM 5113</td>
</tr>
<tr>
<td>$R_{2200}$</td>
<td>0.3 Ω</td>
</tr>
<tr>
<td>$R_a, R_f$</td>
<td>402 Ω</td>
</tr>
<tr>
<td>$R_b, R_g$</td>
<td>2010 Ω</td>
</tr>
<tr>
<td>$R_1, R_2, R_3, R_4$</td>
<td>100 kΩ</td>
</tr>
<tr>
<td>$R_{324}$</td>
<td>4 kΩ</td>
</tr>
<tr>
<td>$R_{220}, R_9$</td>
<td>100 kΩ</td>
</tr>
<tr>
<td>$C_3$</td>
<td>250 pF</td>
</tr>
<tr>
<td>NAND gate</td>
<td>NC7808</td>
</tr>
<tr>
<td>JK monostable</td>
<td>SN74F109DR</td>
</tr>
<tr>
<td>Comparator</td>
<td>LT 1116</td>
</tr>
<tr>
<td>Diodes (Rect.)</td>
<td>PMEG10020ELRX</td>
</tr>
<tr>
<td>$L_f$</td>
<td>1 µH</td>
</tr>
<tr>
<td>$C_f$</td>
<td>0.47 µF</td>
</tr>
<tr>
<td>$R_c$</td>
<td>57 Ω</td>
</tr>
</tbody>
</table>

Experimental realization of the self-oscillating resonant converter based on GaN FETs.
SELF-OSC. FOR SINUSOIDAL GENERATION

Experimental Results

As Inverter

- Self-oscillating response of desired amplitude and period is obtained.
- Fulfillment of the AirFuel Alliance Class 3 standard is verified.

Operation in nominal conditions (near ZVS operation):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$</td>
<td>6.70 MHz</td>
</tr>
<tr>
<td>$P_{out}$</td>
<td>16 W</td>
</tr>
<tr>
<td>Efficiency</td>
<td>96 %</td>
</tr>
</tbody>
</table>

ZVS can be obtained within tolerance limits:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$</td>
<td>6.85 MHz</td>
</tr>
<tr>
<td>$P_{out}$</td>
<td>16 W</td>
</tr>
<tr>
<td>Efficiency</td>
<td>98 %</td>
</tr>
</tbody>
</table>
SELF-OSC. FOR SINUSOIDAL GENERATION

Experimental Results

With Rectifier

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_o$</td>
<td>6.83 MHz</td>
</tr>
<tr>
<td>$P_{out}$</td>
<td>7 W</td>
</tr>
<tr>
<td>Efficiency</td>
<td>83 %</td>
</tr>
</tbody>
</table>

Operation as HF self-oscillating wired battery charger is validated.
SELF-OSC. FOR SINUSOIDAL GENERATION

Third order resonant converters

Matlab simulation of the self-oscillating mechanism in the LCC resonant converter
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Third order resonant converters

Projection in the phase – plane $i_L-v_{Cp}$
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Third order resonant converters

Projection in the phase-plane $i_L$-$v_{Cs}$
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Third order resonant converters

Stability analysis

i) recurrence

\[
\begin{pmatrix} \nu_{Cs}(k+1) \\ \nu_{Cp}(k+1) \end{pmatrix} = \begin{pmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{pmatrix} \begin{pmatrix} \nu_{Cs}(k) \\ \nu_{Cp}(k) \end{pmatrix} + \begin{pmatrix} \gamma_1 \\ \gamma_2 \end{pmatrix} V_g
\]

ii) Characteristic equation

\[ Q(\lambda) = \lambda^2 + b\lambda + c \]

\[
b = -K_c^2 + 2K_c + 2 + 2K_c \ e^{-\xi\pi} \ - \ (K_c + 2)^2 \ e^{-2\xi\pi} \ \frac{ \ (1 + K_c )^2 }{ (1 + K_c )^2 } \]

\[
c = \frac{ (1 - K_c \ e^{-\xi\pi} )^2 }{ (1 + K_c )^2 } \]

\[
K_c = \frac{ C_s }{ C_p }
\]

The system is stable because the eigenvalues are always located within the unit circle
SELF-OSC. FOR SINUSOIDAL GENERATION
Third order resonant converters

Circuit scheme of the implemented self-oscillating LCC converter.
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Third order resonant converters

Experimental limit-cycle generation in the phase-plane $v_{Cp}-i_L$ of the self-oscillating LCC converter
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Example: LCC self-oscillating ballast for IEFL lamps

Ignition and slow warm-up for Osram Endura 150 W
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Example: LCC self-oscillating ballast for IEFL lamps

Ignition detail for Osram Endura 150 W
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Example: LCC self-oscillating ballast for IEFL lamps

Steady-state waveforms for Osram Endura 150W
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Fourth order resonant converters

Power stage of a LCLC resonant converter.
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Fourth order resonant converters

The transient-state associated to each pole position is used as a conjecture to predict which poles will be determinant in the generation of the limit cycle.

Pole-zero diagram of the proposed LCLC converter with:
(a) \( \omega_0^2 = \omega_0^1 = \omega_0 \), (b) \( \omega_0^2 >> \omega_0^1 \).

(a) \( - \xi_2 \omega_0 \) \( - \xi_1 \omega_0 \) \( \omega_0 \)

(b) \( - \xi_2 \omega_0^2 \) \( - \xi_1 \omega_0^1 \) \( \omega_0^2 \) \( \omega_0^1 \)
SELF-OSC. FOR SINUSOIDAL GENERATION

Fourth order resonant converters

Time-domain waveforms of a step-down LCLC with $V_g=12\,\text{V}$, $f_0=160\,\text{kHz}$, $\kappa=10$, $R=100\,\Omega$, $L_s=1\,\text{mH}$, $L_p=0.1\,\text{mH}$, $C_s=1\,\text{nF}$, $C_p=10\,\text{nF}$
SELF-OSC. FOR SINUSOIDAL GENERATION

Fourth order resonant converters

Simulated compacted representation of the limit cycle generation in the SRC-like LCLC converter.
SELF-OSC. FOR SINUSOIDAL GENERATION
Fourth order resonant converters

Time-domain waveforms of a step-up LCLC with $V_g=12$ V, $f_0=500$ kHz, $K_l=66$ and $R=36$ kΩ.
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Self-oscillating low-frequency sinusoidal generation

How can we generate low-frequency sinusoidal oscillations without an external reference?
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-OSCILLATING LOW-FREQUENCY SINUSOIDAL GENERATION

Power stage equations

\[ i_L = i_C + i_R = C \frac{dv_C}{dt} + \frac{1}{R} v_C \]
\[ L \frac{di_L}{dt} + v_C = v_g u \]
\[ LC \frac{d^2v_C}{dt^2} + \frac{L}{R} \frac{dv_C}{dt} + v_C = v_g u \]

Control signal

\[ u = \{-1, 1\} \]
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-Oscillating low-frequency sinusoidal generation

Switching surface

\[ S(x) = \frac{(\frac{dv_c}{dt})^2}{\omega} + \omega v_c - \omega A^2 \]

Control signal

\[ u = -sgn(S \frac{dv_c}{dt}) \]

Conditions for existence of sliding-mode

\[ S \frac{dS}{dt} < 0 \]

\[ \frac{1}{LC} \gg \omega^2 \]

\[ v_g > A + LwA / R \]
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-OSCILLATING LOW-FREQUENCY SINUSOIDAL GENERATION

\[ S(x) = 0 \quad \Rightarrow \quad v_c(t) = A\sin\omega t \]
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-Oscillating LOW-FREQUENCY SINUSOIDAL GENERATION

Block diagram of the SM-based sinusoidal inverter
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-Oscillating Low-Frequency Sinusoidal Generation

PSIM Simulation

860 Hz sinusoidal waveform delivering 100 W
It is not possible to use an electric signal for the square of the derivative in a real prototype. FPGA can be used.
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-Oscillating Low-frequency Sinusoidal Generation

Circuit scheme
SELF-OSC. FOR SINUSOIDAL GENERATION

Digital design of the control strategy
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-Oscillating Low-Frequency Sinusoidal Generation

MAX10_FPGA

Elements for FPGA programming
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-OSCILLATING LOW- FREQUENCY SINUSOIDAL GENERATION

Workbench
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-Oscillating low-frequency sinusoidal generation

Experimental results
SELF-OSC. FOR SINUSOIDAL GENERATION

SELF-Oscillating Low-Frequency Sinusoidal Generation

Spectrum analysis
Control of constant power loads
CONTROL OF CONSTANT POWER LOADS

Sliding-mode control of a boost converter supplying a CPL

\[ i_{CPL} = \frac{P}{v_C} \]
CONTROL OF CONSTANT POWER LOADS

Sliding-mode control of a boost converter supplying a CPL

Converter equations

\[
\frac{di_L}{dt} = -\frac{v_C}{L} (1 - u) + \frac{V_g}{L}
\]

\[
\frac{dv_C}{dt} = \frac{i_L}{C} (1 - u) - \frac{P}{Cv_C}
\]

Switching surface

\[
s := K_C (v_C - V_{REF}) + K_i (i_L - I_{REF})
\]

Control law

\[
u = 0 \quad \text{when} \quad s > 0
\]

\[
u = 1 \quad \text{when} \quad s < 0
\]
CONTROL OF CONSTANT POWER LOADS

Start-up from different initial conditions
CONTROL OF CONSTANT POWER LOADS
Start-up for different values of control parameters
CONTROL OF CONSTANT POWER LOADS

Steady-state response (P = 1kW)

PSIM Simulation

Experiment
Transient response for step-type changes in the CPL: 1kW-0.5kW-1kW

\[ s := K_C (v_C - V_{REF}) + K_i \left( i_L - \frac{v_c}{v_g} i_{CPL} \right) \]

PSIM Simulation

CPL emulated by electronic load EL 9000 from Elektro-Automatik
CONTROL OF CONSTANT POWER LOADS

INSTANTANEOUS CPL BASED ON A BUCK CONVERTER

Buck converter -based CPL employing two possible sliding-mode controllers

\[ S_1(x) = K_v (v_{C2} - V_{REF2}) + K_i \frac{d}{dt} (v_{C2} - V_{REF2}) \]

\[ S_2(x) = v_{C2} i_{L2} - P \]
CONTROL OF CONSTANT POWER LOADS

Experimental transient response for load changes in the reference P profile: 1kW - 500W - 1kW

The buck converter is controlled through $S_2(x)$
The implementation of $S_2(x)$ suggest that this type of switching surfaces could be use to emulate the behaviour of CPLs using DC-DC switching converters.

Does it make sense to build a CPL emulator?
SYNTHESIS OF CONSTANT POWER LOADS

Sea and undersea vehicle DC distribution test bed

Ship service inverter module

Load bank

Motor controller

Generic CPL

SYNTHESIS OF CONSTANT POWER LOADS

Generic DC-DC converter acting as instantaneous CPL
SYNTHESIS OF CONSTANT POWER LOADS

CPL Candidates

Boost

Cuk

SEPIC
Start-up and steady-state

PSIM simulations

Change in $P_{\text{ref}}$ from 1kW to 500W
CONCLUSIONS

Two classes of SPC have been presented:

- Self-oscillating resonant converters
- DC-DC switching converters loaded by CPL

The first family can be competitive in battery conductive charge and efficient lighting. It’s application to contactless charge is still open.

Demonstrating the stability of the self-oscillating mechanism in 4th order converters is an open subject.

Low-frequency self-oscillation involves a complex implementation. More practical research is needed.

Sliding-mode control shows promising results in the control of converters with CPL. More research has to be performed dealing with power uncertainty or power estimation.
REFERENCES


