Perfect tracking feedforward control of output voltage for boost converters based on noncausal nonlinear stable inversion

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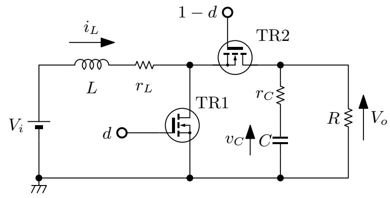
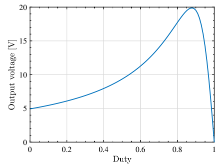
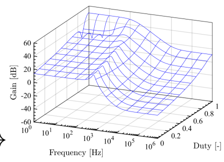
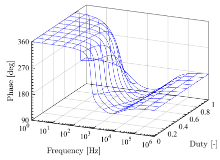
Background and objective

Boost converter



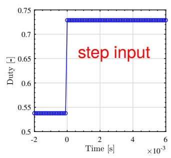


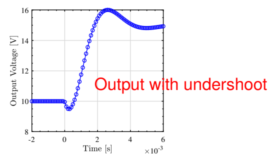




Difficult to change output voltage smoothly

- Nonlinear steady state characteristic ↗
- Linear parameter-varying frequency characteristic →
- Nonminimum phase characteristic ↓





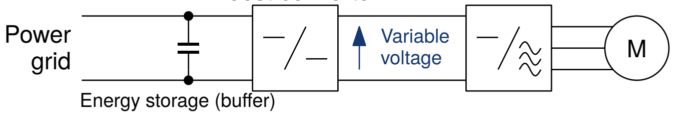
This study realizes

Voltage change according to an arbitrary trajectory

Possible applications

Voltage optimization of motor drive systems fed by energy storage

Energy and power saving servo drive



Modelling

State-space averaging

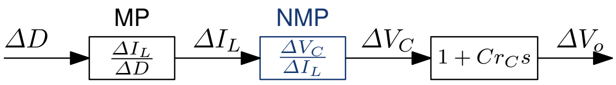
State 1: TR1 = ON and TR2 = OFF
State 2: TR1 = OFF and TR2 = ON
} Average by duty cycle d

Averaged state-space

$$\begin{pmatrix} \dot{i}_L \\ \dot{v}_C \end{pmatrix} = \begin{pmatrix} -\frac{r_L}{L} - \frac{(1-d)r_C R}{L(r_C+R)} & -\frac{(1-d)R}{L(r_C+R)} \\ \frac{(1-d)R}{C(r_C+R)} & -\frac{1}{C(r_C+R)} \end{pmatrix} \begin{pmatrix} i_L \\ v_C \end{pmatrix} + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} V_i,$$

$$\begin{pmatrix} i_L \\ v_o \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{(1-d)r_C R}{r_C+R} & \frac{R}{r_C+R} \end{pmatrix} \begin{pmatrix} i_L \\ v_C \end{pmatrix}$$

Structure of small signal transfer characteristics from the state-space



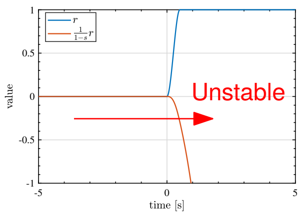
Stable inversion

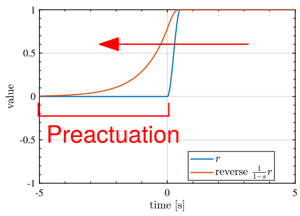
Feedforward control technique

Normal feedforward → Controller as the inverse of plant P^{-1}

For nonminimum phase plant P (unstable P^{-1})

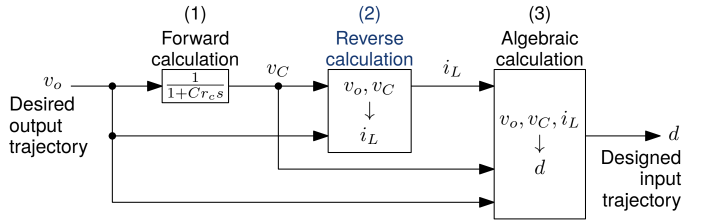
Time axis reversal of the unstable P^{-1} → stable





LPV stable inversion is difficult.... → but realized!

Proposed Method



Feedforward equations to solve numerically

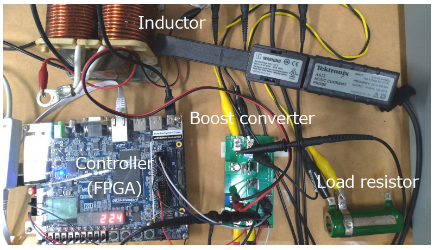
$$Cr_C \dot{v}_C + v_C = v_o \quad (1)$$

$$\dot{i}_L = \frac{1}{L}\left(-r_L i_L + V_i + \left(-v_o + \frac{R}{r_C+R}v_C\right)\cdot\left(1 + \frac{v_C}{r_C i_L}\right)\right) \quad (2)$$

$$d = 1 - \frac{r_C+R}{r_C R i_L}\left(v_o - \frac{R}{r_C+R}v_C\right) \quad (3)$$

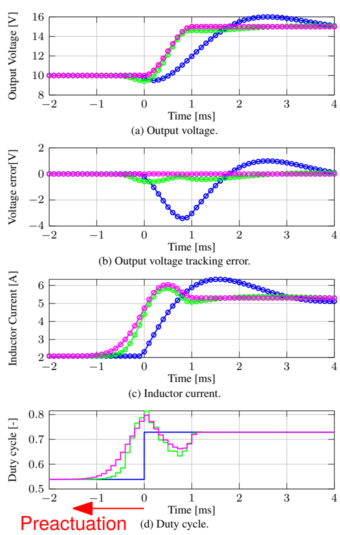
Simulation and experiment

Experimental setup

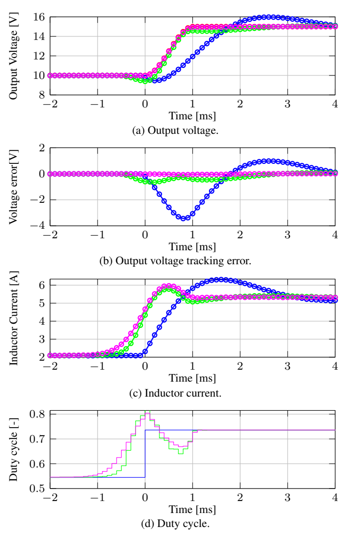


Input voltage = 5 V
Output voltage = 10 V to 15 V
PWM cycle = 0.1 ms (10 kHz)
Rising time = 1 ms (10 PWM cycles)

Simulation

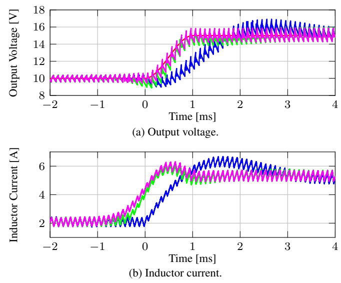


Experiment (moving averaged)



— Reference trajectory
— Step input
— Author's former method
— Proposed method
○ PWM sampling points

Raw experimental waveform



- Achieved designing exact feedforward input with preactuation
- No overshoot, undershoot, and output delay for LPV systems

Conclusion

Novelty → Exact stable inversion for the boost converters

Usefulness → Operating the boost converters freely (if the trajectory is given before starting varying)

Future work Feedforward design considering time-varying load $R(t)$ for practical use

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