Applications of Operational Transconductance Amplifier In Reconfigurable Power System Emulator

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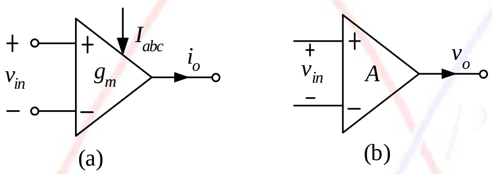
BACKGROUND

OPERATIONAL TRANSCONDUCTANCE AMPLIFIER



OTA

Op-Amp

gm : amplifier gain

i_o: Output current

I_{abc}: amplifier bias current, key parameter to vary gain

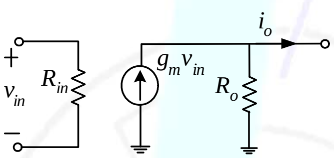
A : amplifier gain

v_o: Output voltage

No reconfigurable gain

MOTIVATION

PRACTICAL OTA PERFORMANCE



OTA equivalent circuit

$$I_{out} = g_m \times V_{in}$$

$$g_m = h \times I_{abc}$$

h : constant (19.2S)

$$I_{out} = hI_{abc}V_{in} = 19.2I_{abc}V_{in}$$

Performance characteristics:

Describe the performance of actual OTAs

- Input/output impedance : ideal R_{in}/R_o = infinite
- Input offset voltage V_{offset} : ideal $V_{offset} = 0$
- Input offset current I_{offset} : ideal $I_{offset} = 0$
- Power consumption : heating can not go beyond a threshold
- Transconductance linearity : decides the reconfigurable range of the generator inertial constant
- Working frequency : related to the emulation speed

OBJECTIVE

Identify, qualify and quantify the accuracy of OTA-based applications a given power system emulator,

Investigate the parameter settings for the reconfigurable OTAs,

Provide feasible OTA applications for power system emulation.

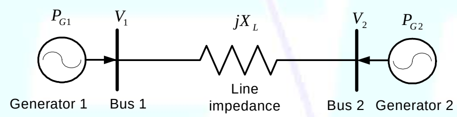
OVERVIEW

The work identifies, qualifies and then quantifies the features of Operational Transconductance Amplifiers (OTAs) that will make them feasible for power system emulation. The unique feature of OTA is its gain is reconfigurable through an external current source, which makes the OTA-based circuits programmable so that the emulator for power system can do multi-scenario analysis. However, the reconfigurable gain also makes the OTA-based circuit more complicated. In this work, the emulator for one-generator infinite-bus power system is used as an example, and the accuracy and sensitivity of OTA-based circuits in the emulator are analyzed so that they are feasible for power system emulation.

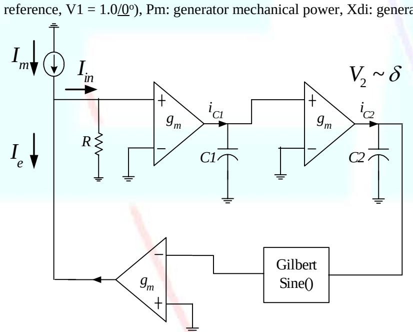
CLASSICAL POWER SYSTEM MODEL

ONE-GENERATOR INFINITE-BUS SYSTEM

Swing equation: $\delta = \dfrac{\pi f_0}{H}\iint (P_m - \dfrac{V_1 V_2 \sin\delta}{X_{d1}+X_{d2}+X_L})dtdt$



H: inertia constant of the generator, fo: nominal frequency, δ: angle between V1 and V2 (V1 is voltage reference, V1 = 1.0/0°), Pm: generator mechanical power, Xdi: generator direct axis reactance



The OTA after Gilbert sine() converts V to I, and Aβ is the overall gain of both circuits

Steady state equivalence:

$$V_2 = V_{02} + \int \frac{g_m}{C_2}\int \frac{I_m - I_e(V_2)}{C_1} dTdT$$

$$V_2 = \frac{g_m}{C_1 C_2}\iint \left(I_m - A\beta\sin(V_2)\right)dTdT$$

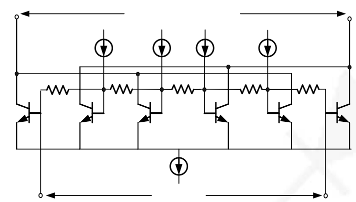
$$P_m = \frac{V_1 V_2 \sin\delta}{X_{d1}+X_{d2}+X_L}$$

$$I_m = A\beta\sin(V_2)$$

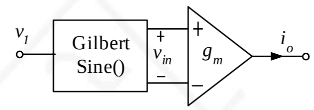
The overall accuracy of the emulation, the solution to the generator angle delta, is dependent on a host of factors including the respective accuracies of components. Here, sine shaper and double integrator are provided with the purpose of identifying qualifying and quantifying certain inaccuracies

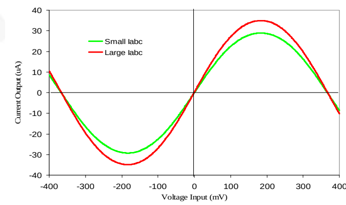
OTA APPLICATIONS IN POWER SYSYEM EMULATOR

OTA-based Sine Shaper:



Gilbert sine() element





OTA-based Gilbert sine()

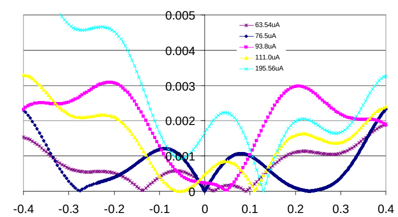
One of the identifiable factors affecting the accuracy of the generator angle is the accuracy of the sine shaper.

Vary I_{abc} value of the OTA to minimize the offset voltage, increase accuracy

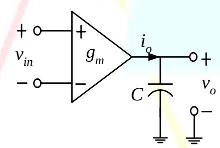
Compare with ideal sine wave, quantify error in case of different I_{abc}

Optimal I_{abc} value exists so that the sine shaper outputs symmetrical wave form with minimum offset voltage.

Absolute Error --- Generator angle V2(mV)



OTA-based Integrator:



Single integrator:

$$v_{C1} = \frac{1}{C_1}\int_0^t i_0(x)dx + v_{C1}(0)$$

$$v_{C1}(t) = \frac{hI_{abc}}{C_1}\int_0^t v_{in}(x)dx + v_{C1}(0)$$

Double integrator: $v_0(t) = v_{C2}(t) = \dfrac{h^2 I_{abc}^2}{C_1 C_2}\int_0^t\int_0^t v_{in}(x)dx$

Double integrator decides the inertia constant of the generator.

Double integrator and hence Iabc determines the region of convergence to the eventual steady state solution (by appropriate initial condition sensitivity evaluation) in addition to emulation speed.

FUTURE WORKS

- Sensitivity evaluation of emulation speed to delay characteristics of individual emulator component circuits
- Error minimization for large scale power system
- Parameter optimization of the OTA applications in large scale power system

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