Optimization of Boost Converter Controller Design

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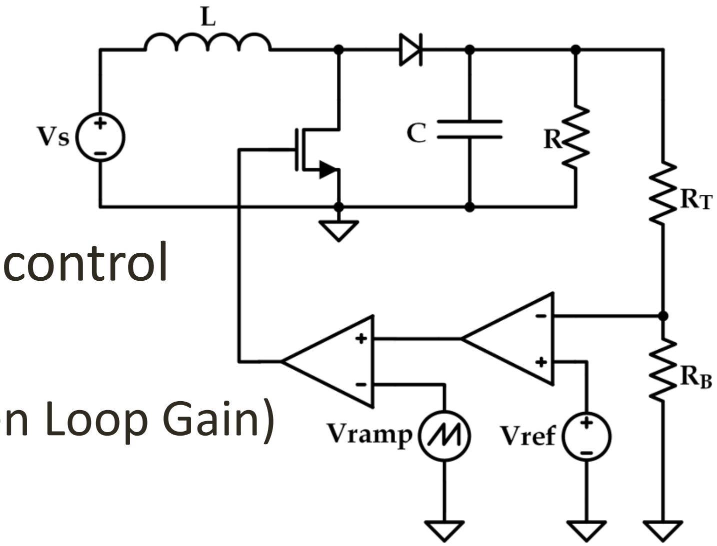
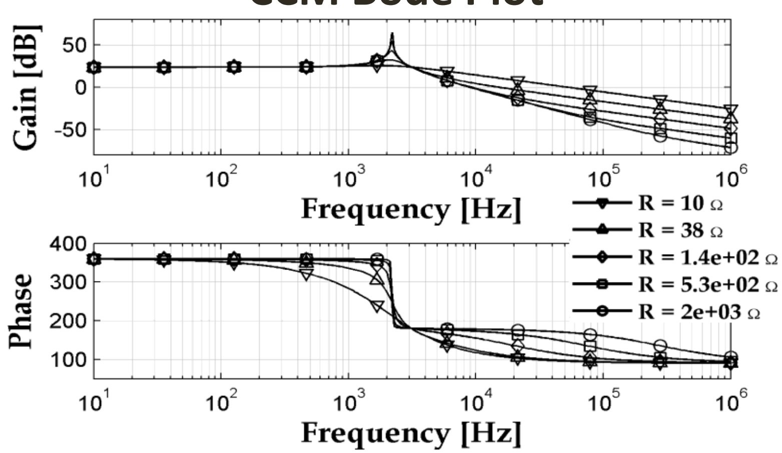
The Problem

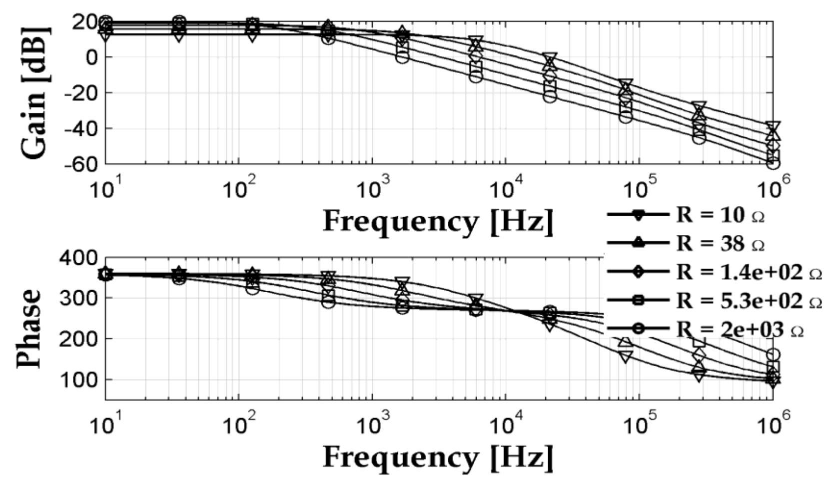
- Boost Converters can be difficult control
  - Need stability (Phase Margin)
  - Need low steady-state error (Open Loop Gain)
  - Need fast response (Bandwidth)
- Two operating modes:
  - CCM (Current always flowing in inductor)
  - DCM (Current in inductor goes to zero within a switching cycle)



CCM Bode Plot



DCM Bode Plot



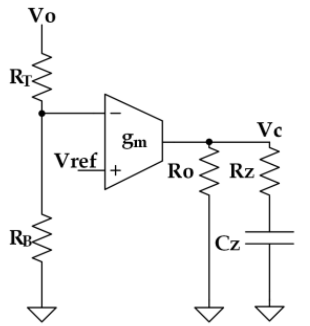
The Problem

Controller Topologies

- Lag Controller

$$\frac{V_c}{V_o} = K\left[\frac{sR_ZC_Z+1}{sR_OC_Z+1}\right]$$

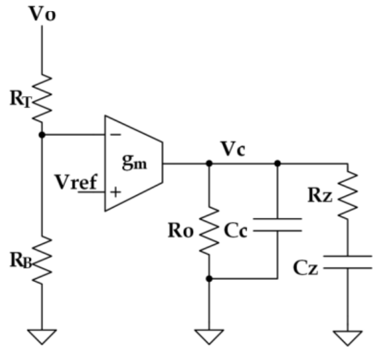
$$K = g_mR_O\frac{R_B}{R_T+R_B}$$



- Lag Plus Pole Controller

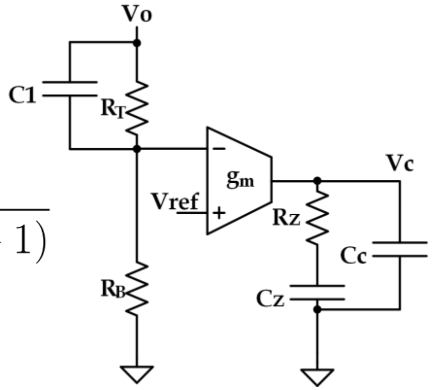
$$\frac{V_c}{V_o} = K\frac{sR_ZC_Z+1}{s^2R_OR_ZC_CC_Z+sR_OC_Z+1}$$

$$K = g_mR_O\frac{R_B}{R_T+R_B}$$



- Lag-Lead Controller (a.k.a. PID)

$$\frac{V_c}{V_o} = \frac{g_mR_B}{s(R_B+R_T)(C_Z+C_C)}\frac{(sR_TC_1+1)(sR_ZC_Z+1)}{(s\frac{R_ZC_ZC_C}{C_Z+C_C}+1)(s(R_T\|R_B)C_1+1)}$$



Proposed Solution

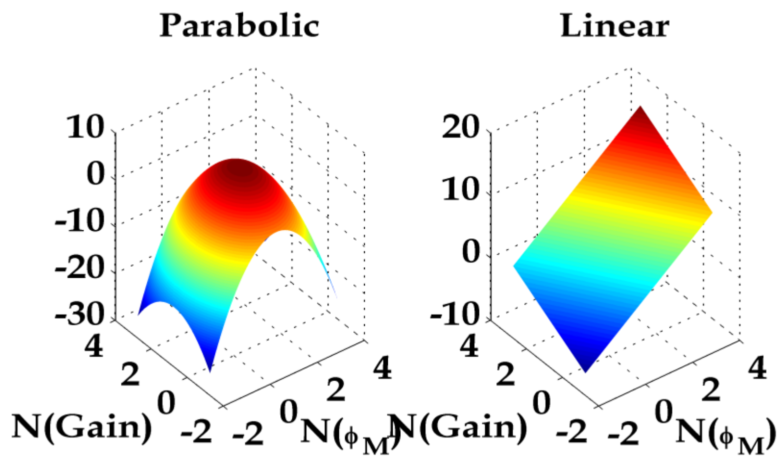
Genetic Algorithms and PSO

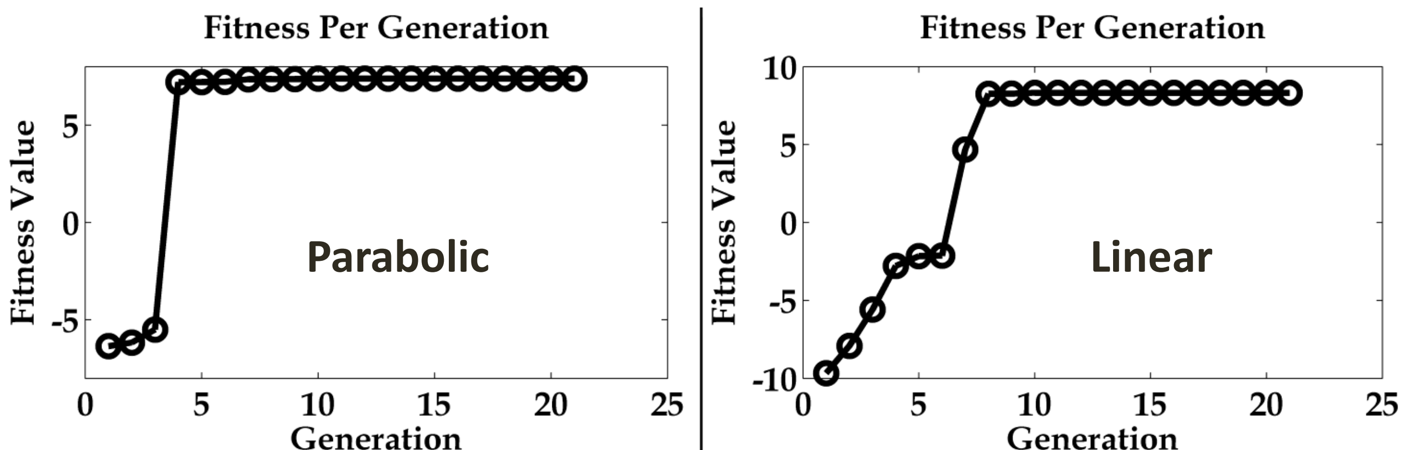
- Controller Design → Dependent on Converter Design
  - Operating mode
  - Desired characteristics
- GAs
  - Good exploration of solution space
  - Large amount of previous work on GAs for Circuit Design Optimization
  - Highly dependent on fitness function, mutation probability, crossover probability
- PSOs
  - Good exploration of solution space
  - Tendency to get "stuck" on local optima

Fitness Function

Implementation Comparisons

- Parameters with large ranges
  - Need to normalize
- Two functions:
  - Linear
  - Parabolic





(a) (b)

Fitness Function

Selected Implementation

- Penalty function added
  - Aids convergence
- Steps:
  - Normalize variable → Calculate penalty → Place in Parabola → Apply weighted constant

Parabola

$$F = \sum_{i=1}^{N} -\alpha_i (N(\theta_i) - 1)^2 + \alpha_i - P(\theta_i)$$

Weight

Normalize

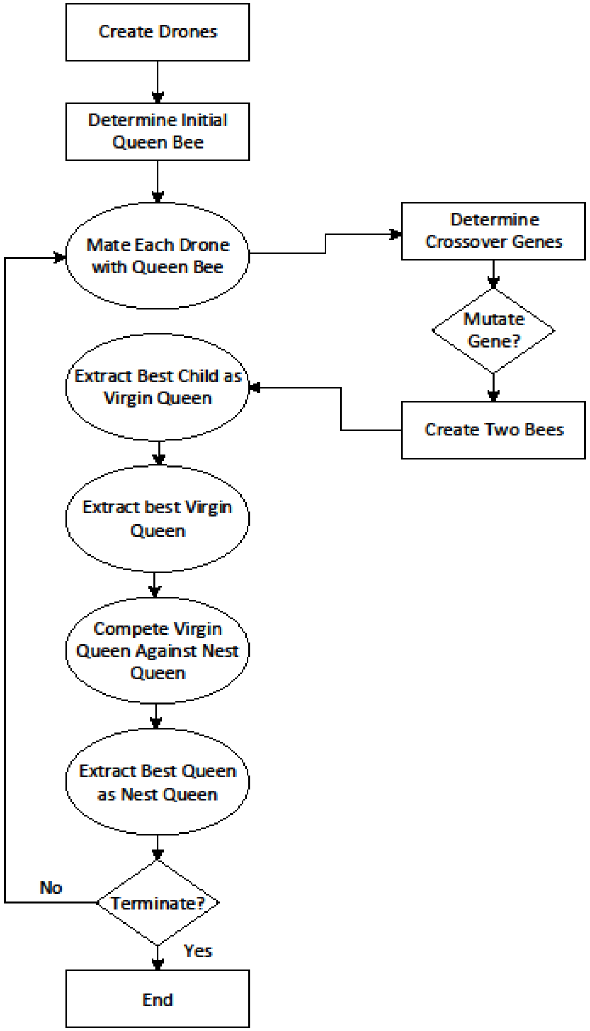
Weight

Penalty

Genetic Algorithm

Queen Bee Architecture

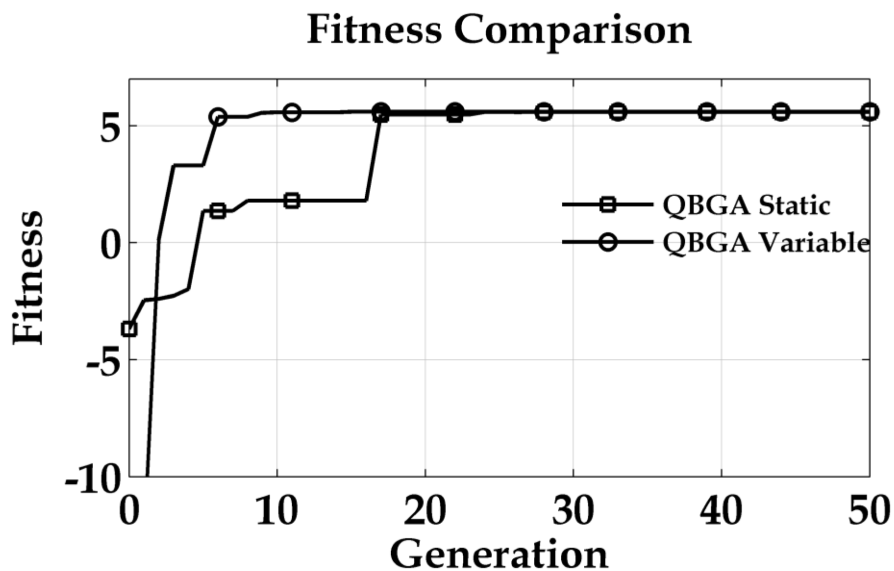
- Queen Bee Implementation
  - Variant on elitism



Genetic Algorithm
Mutation Rate

- Attempt: Mutation rate that varies with Queen age
  - As Queen's age increased, mutation rate probability increased

- Variable rate:
  - Convergence in 11 iterations
- Static rate:
  - Convergence in 25 iterations



Note: 30 drones simulated for DCM Boost

Particle Swarm Optimization
Constriction

- Swarm constricted to smaller solution space over time

$$V_p = \chi(V_p + C_1[U(0,1)\cdot(\beta_p - X_p)] + C_2[U(0,1)\cdot(G - X_p)])$$

$$\phi = C_1 + C_2$$

$$\chi = \frac{2}{2 - \phi - \sqrt{\phi^2 - 4\phi}}$$

Particle Swarm Optimization

Chaotic Inertial Weight

- Inertial Weight with Randomness
  - Limit particle's speed over time
- Chaotic Descending (CDIW)

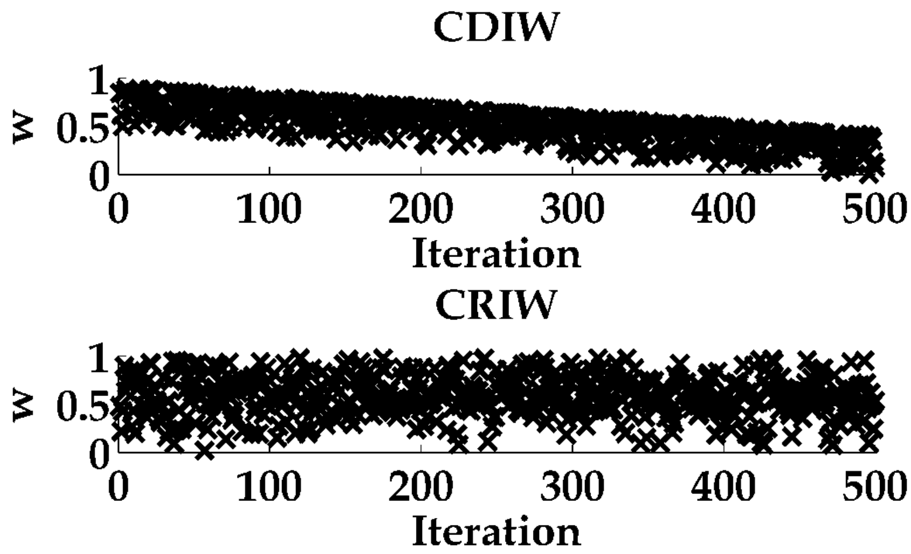
$$z = 4 \cdot z \cdot (1 - z)$$

$$w = \frac{(w_1 - w_2)(i_{max} - i)}{i_{max}} + z \cdot w_2$$

- Chaotic Random (CRIW)

$$z = 4 \cdot z \cdot (1 - z)$$

$$w = \frac{1}{2}[U(0,1) + z]$$

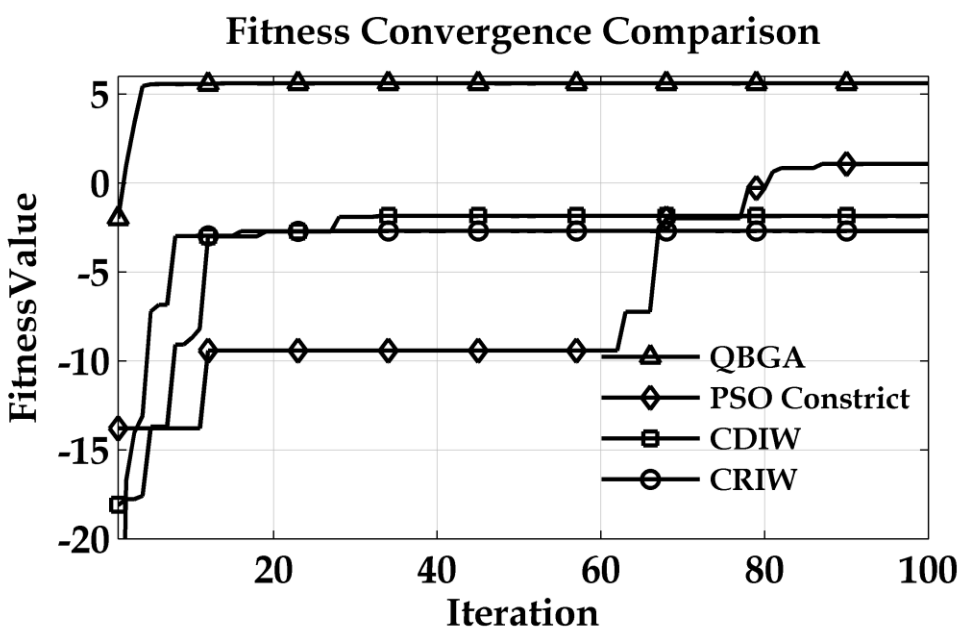


Algorithm Comparisons

Convergence

- GA performed better
- PSO consistently converged on local optima
- Constriction better than Chaotic IW

Algorithm	Error From Expected
QBGA (Static)	0.268%
QBGA (Variable)	0.179%
PSO-CDIW	133.286%
PSO-CRIW	133.036%
PSO-Constrict	73.750%

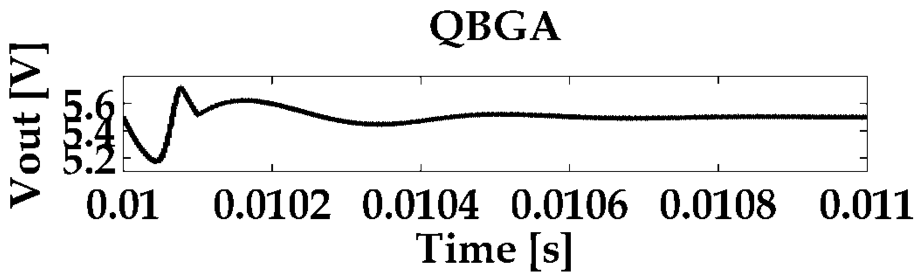


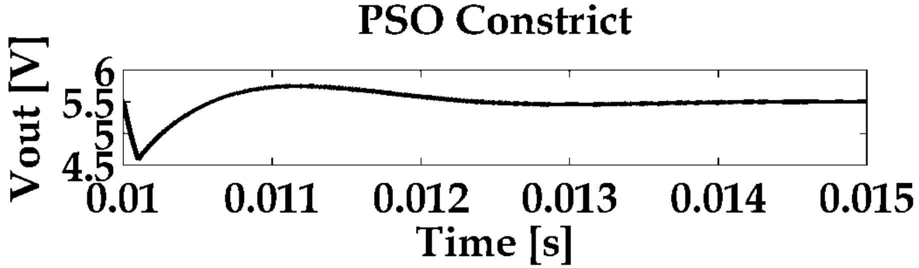
Algorithm Comparisons

DCM Solutions

$$T_{QBGA}(s) = \frac{0.0034s + 159.8}{0.0026s + 1}$$

$$T_{PSO}(s) = \frac{147s^2 + 288.9s + 3.016}{0.196s^3 + 0.0066s^2 + 0.000021s + 0.00002}$$





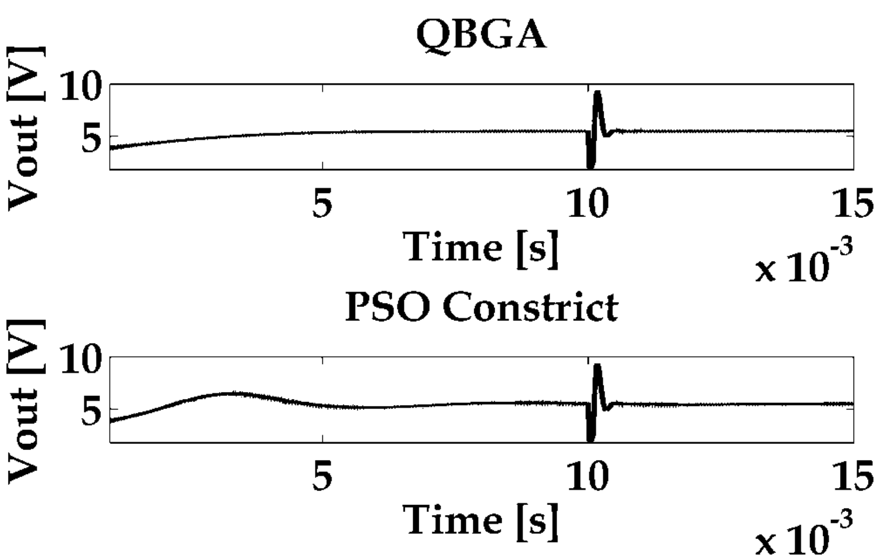
Both valid solutions
- QBGA faster (more ideal)

Algorithm Comparisons

CCM Solutions

$$T_{QBGA}(s) = \frac{348.6s + 348.6}{0.00017s^3 + s^2 + 3.5 \times 10^{-7}s + 1}$$

$$T_{PSO}(s) = \frac{4.2 \times 10^4 s + 2.02 \times 10^4}{0.06s^3 + 48.53s^2 + 0.27s}$$



Both valid solutions

- QBGA better large-signal response

Summary

- Variable mutation rate for QBGA yields better convergence
- Parabolic parameterization aids convergence
- GA better suited for Boost Converter controller design
  - PSO Constrict better than Chaotic Inertial Weight

- Problems encountered:
  - Selection of weighted constants in fitness function = tedious
    - Experimentation and iteration
    - PM → 3; Gain → 2; GM → 0.6
  - CCM solutions harder to find
    - Expected since it's harder to control → requires more iterations than DCM

Thank You

- Comments/Questions?