Lecture Series on

Intelligent Control

Lecture 22

Genetic Algorithms:
Applications

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GENETIC ALGORITHM APPLICATIONS

- **Power Plant Controller Design**
- **Reactive Power and Voltage Control**
- **Unit Commitment and Generation Scheduling**
- **Economic Dispatch**
- **Power System Planning**
- **Hybrid GA/Neural Networks**
- **Hybrid GA/Fuzzy Systems**

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Fossil-Fuel Power Plant Control

- Boiler-Turbine Model
  - 160 MW oil fired drum-type unit
  - a third order MIMO nonlinear system
  - The inputs:
    - the mass flow rates of fuel (u_1 in pu),
    - steam to the turbine (u_2 in pu), and
    - feedwater to the drum (u_3 in pu).
  - The outputs:
    - electric power (E in MW),
    - drum steam pressure (P in kg/cm^2), and
    - drum water level deviation (L in m).

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Boiler-Turbine System

A MIMO nonlinear Model of a Boiler-Turbine System:

$$\dot{x}_1 = -0.0018 u_2 x_1^{9/8} + 0.9 u_1 - 0.15 u_3$$
$$\dot{x}_2 = [(0.73 u_2 - 0.16) x_1^{9/8} - x_2]/10$$
$$\dot{x}_3 = [141 u_3 - (1.1 u_2 - 0.19) x_1]/85$$
$$L = 0.05(0.13073 x_3 + 100 \alpha_{cs} + q_e/9 - 67.975)$$

where

$$\alpha_{cs} = \frac{(1 - 0.001538 \rho_f)(0.8p - 25.6)}{\rho_f (1.0394 - 0.0012304 p)}$$

$$q_e = (0.854 u_2 - 0.147) p + 45.59 u_1 - 2.514 u_3 - 2.096$$

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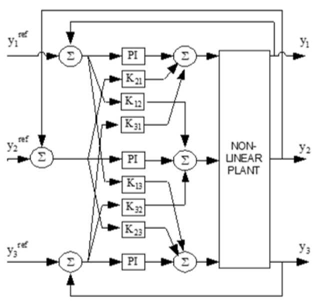
GA-based PI Controller

Coupled PI Controller Structure



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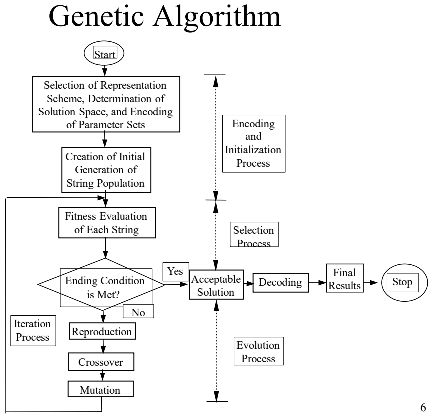
Genetic Algorithm



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Fitness Evaluation

$$f = \frac{1}{1 + J}$$

$$J = J_0 + J_{ss}$$

$$J_0 = \int_{t_0}^{t_f} \left((y - y^{ref})^T Q (y - y^{ref}) + u^T R u \right) dt$$

$$J_{ss} = \sum_{i=1}^{3} e_i(t_f)$$

$$e_i(t) = y_i(t) - y_i^{ref}(t)$$

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GA Parameters

- Population size: 64
- Crossover rate: 0.9
- Mutation rate: 0.001
- Parameter resolution: 9 bits per substring
- Stopping criteria: 30 generations or 95% convergence has been achieved

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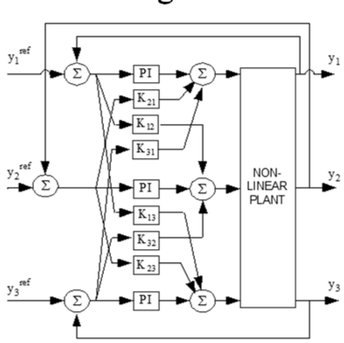
Training Schedule



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Training Schedule

Stage	Gains to Train
I	K_{p1}, K_{p2}, K_{p3}
II	K_{i1}, K_{i2}, K_{i3}
III	K_{12}, K_{13}
IV	K_{21}, K_{23}
V	K_{31}, K_{32}

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Gains at Each Training Stage

	I
K_{p1}	11.3883
K_{p2}	0.0793
K_{p3}	1.2051
K_{i1}	-
K_{i2}	-
K_{i3}	-
K_{12}	-
K_{13}	-
K_{21}	-
K_{23}	-
K_{31}	-
K_{32}	-

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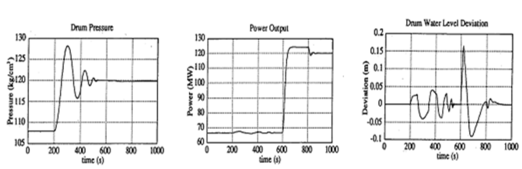
GA/PI Performance



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GA/LQR Controller

Feedback Gain:

$$K = \begin{bmatrix} 0.0354 & 0.2236 & -0.1451 \\ -0.0430 & 0.0588 & 0.0039 \\ 0.1609 & -0.6316 & 0.4275 \end{bmatrix}$$

Feedforward Gain:

$$F = \begin{bmatrix} 0.0341 & 0.0018 & 0.6567 \\ -0.0051 & 0.0903 & -1.3537 \\ -0.4234 & -0.4088 & 94.3416 \end{bmatrix}$$

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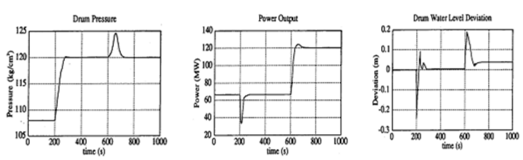
GA/LQR Performance



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Nuclear Power Plant Control

- Advanced Controls:
  - Linearized SISO models
  - Operating point - nominal power level
  - Frequency domain design techniques
  - Controls are too complex, high order
- PID Controls:
  - Not flexible for a wide range operation

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Steam Generator Control

- OTSG is a critical component and provides a dynamic link between the primary system and turbo-generator set in a pressurized water reactor (PWR) power plant
- The safe operation of OTSG plays a very important role in the overall safety of the PWR power plant
- Highly nonlinear and complex system

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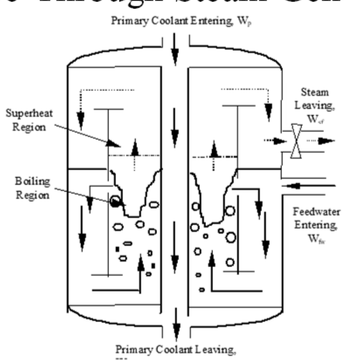
Once-Through Steam Generator



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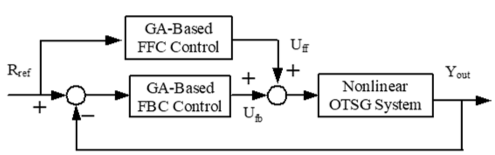
GA-Based Hybrid FFC/FBC



Configuration of Hybrid Feedforward/Feedback Control

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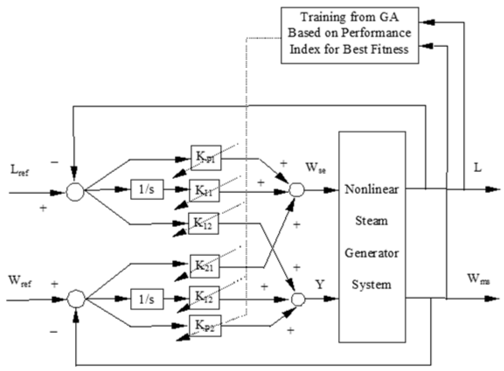
GA Based FBC Control



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Training of Gains with GA

- The six parameters are trained by the GA by adding additional parameters sequentially in four stages:
- First training stage: K_{p1} and $K_{p2.}$
- Secondary training stage: K_{I1} and $K_{I2.}$
- Third training stage: $K_{12.}$
- Fourth training stage: $K_{21.}$

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Fitness Evaluation

The performance objective function:

$$J = \int_{T_o}^{T_{ref}} \left\{ 100\,(L - L_{ref})^2 + 0.2\,(W_{sf} - W_{ref}(t))^2 \right\} dt$$

Fitness function:

$$f = \frac{1}{(1+J)}$$

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Feedforward Control

Training of the reference u_{ref} through the following ramp function:

$$u_{ff}(t) = u_0 + \frac{(u_{ref} - u_0)}{T_{ref} - T_0} t$$

where

T_0 : initial time at which the simulation starts,

T_{ref} : final time of the ramp function,

$u_{0,,}$: initial FFC control (u_{ff}):

feedwater flow rate (W_{fw}), and

steam controlling valve position (Y).

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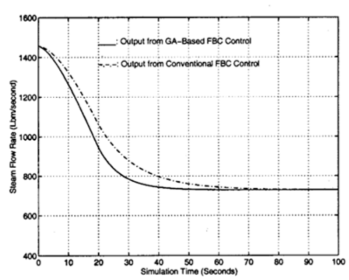
Feedback Control



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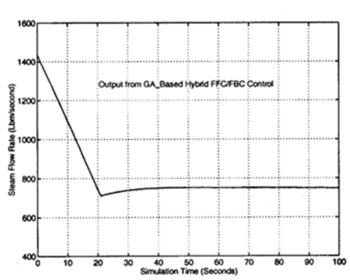
Hybrid FFC/FBC



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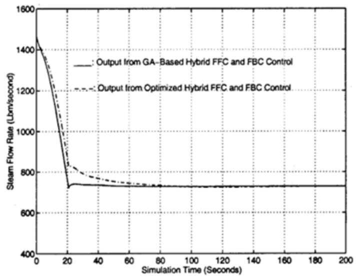
Hybrid FFC/FBC for MMS Model – Steam Flow Rate



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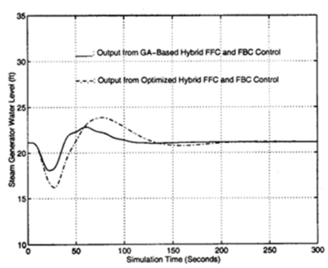
Hybrid FFC/FBC for MMS Model – Water Level



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Conclusions

- MIMO GA-based hybrid control system, consisting of FFC/FBC, is presented for boiler-turbine and a nuclear steam generator system over a wide range of operations.
- The FFC control is obtained by the global GA optimization technique and the FBC control is an optimal design of the PI-based control system.
- Good simulation results are achieved which manifest the efficiency and effectiveness of the GA-based Hybrid FFC/FBC control system.
- This approach can be expanded to overall operation of a nonlinear complex system.

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