Modeling and Simulation Aspects of Topological Design of Distributed Resource Islands

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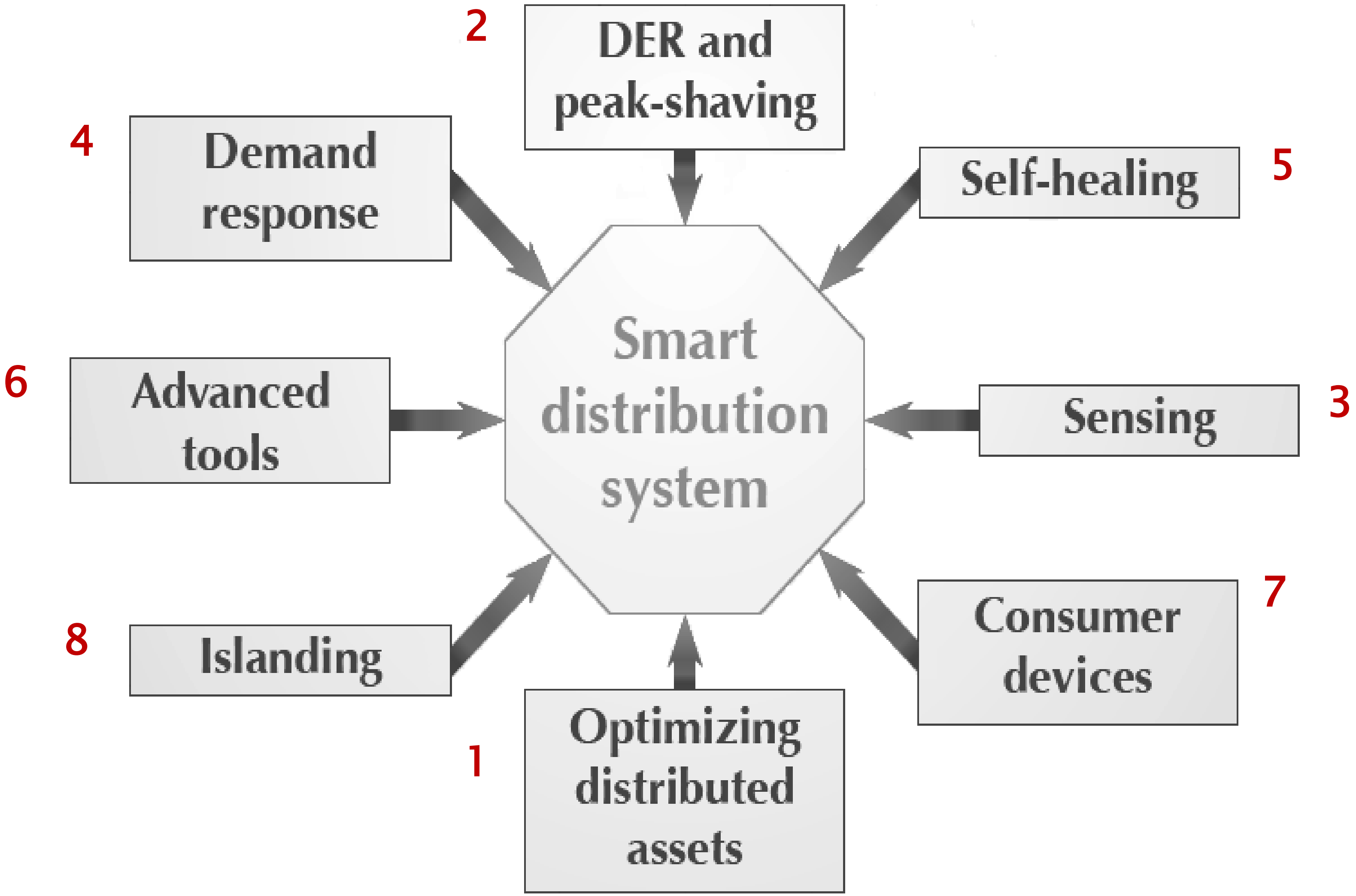
JISEA Joint Institute for Strategic Energy Analysis

Outline of presentation

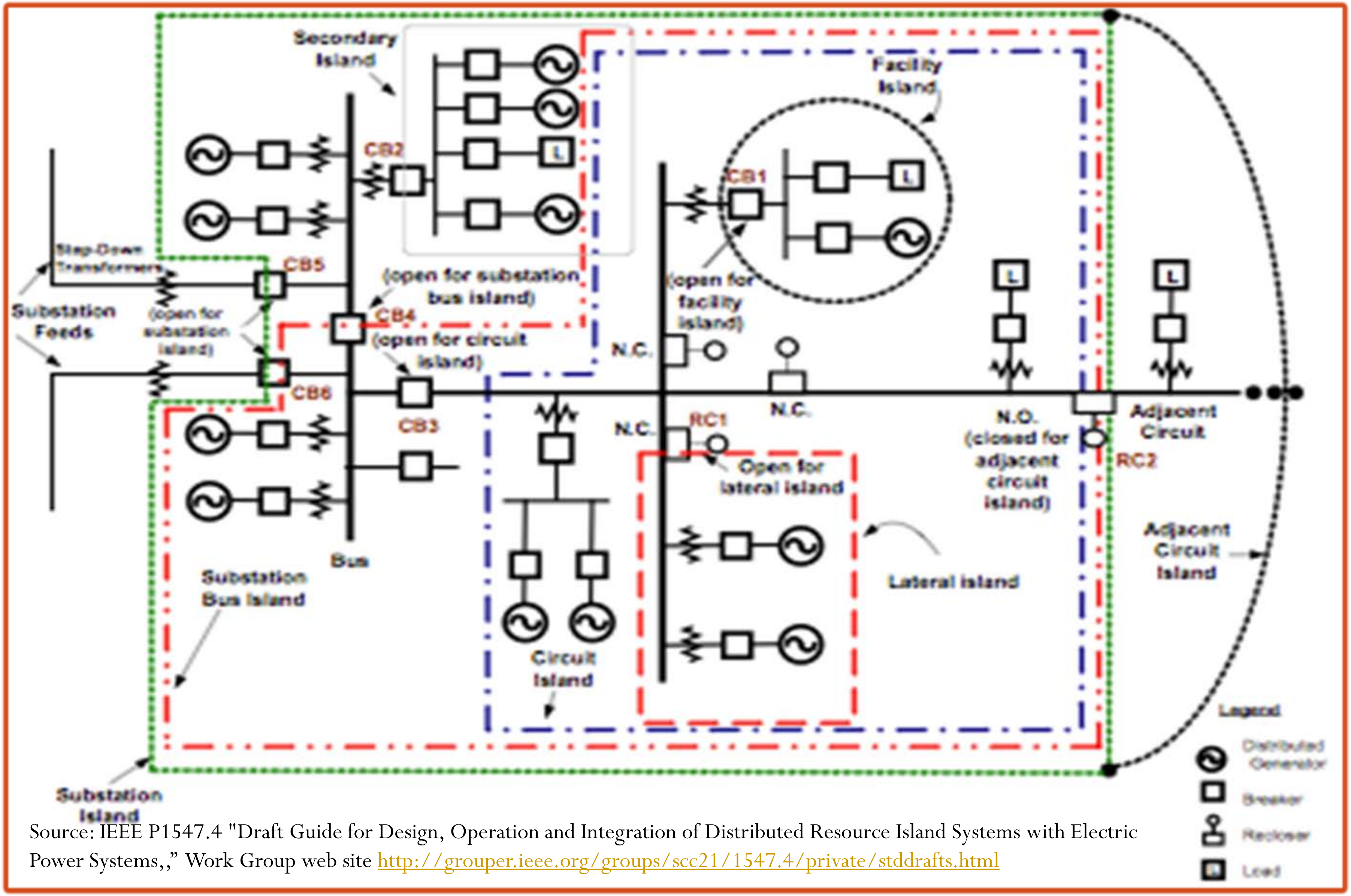
- Introduction
- Microgrids
- Intentional islanded distribution systems -design issues
- Optimization problem
- A GA approach including a test system
- Challenges
- Machine learning

A smart distribution system



Source:H. E. Brown, S. Suryanarayanan, G. T. Heydt, “Some characteristics of emerging distribution systems under the Smart Grid Initiative,” *Elsevier The Electricity Journal*, vol. 23, no. 5, pp. 64-75, Jun 2010.

What is a microgrid?



Source: IEEE P1547.4 "Draft Guide for Design, Operation and Integration of Distributed Resource Island Systems with Electric Power Systems,," Work Group web site http://grouper.ieee.org/groups/scc21/1547.4/private/stddrafts.html

Some characteristics of the microgrid

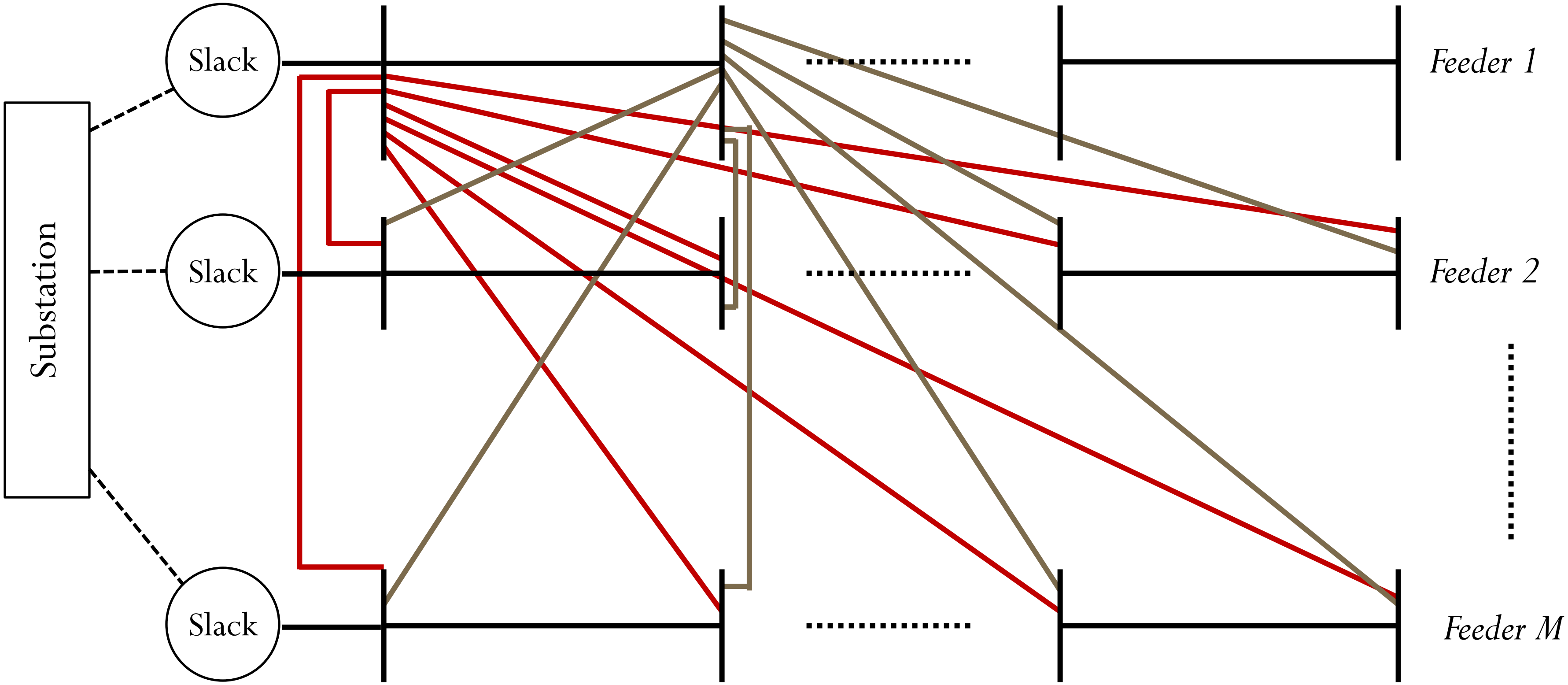
- Designed to enhance reliability to loads
- Possible provision of ancillary services
- Potential for <u>economic incentives</u>
- May incorporate renewable energy sources
  - Avenue for meeting renewable portfolio standards (RPS)
- Applications in civilian and military milieus
- Types: remote, utility-owned, industrial, *customer-driven*

Introduction to the *feeder addition problem*

- From a utility perspective…
  - Can connections be made between feeders to increase reliability?
  - Where do we make those connections?
- *Feeder addition problem*
  - Given a distribution system with distributed generation (DG) sources, add networked connections such that the cost of the addition is feasible while improving the reliability and satisfying power flow constraints.

Mathematical formulation of optimization

- What does the “feeder addition problem” *look* like?



Mathematical formulation of optimization

- Mathematical formulation

$$Q(x) = \begin{bmatrix} f(x) \\ h(x) \end{bmatrix} \begin{matrix} \longleftarrow \text{Cost} \\ \longleftarrow \text{Reliability} \end{matrix}$$

min { Q(x), such that (1)–(4) are satisfied}

(1) $f(x) \le f_{max}$

(2) $h(x) < h_o$

$$\left.\begin{array}{l} (3)\ \ 0.95 \le V_a \le 1.05 \\ (4)\ \ S_{ab} \le 1.00 \end{array}\right\}$$

These are part of the power flow equations, which are another well-known application of optimization in power systems

Opt

- Number

$$\eta = n_1($$

$$\mathcal{N} = \prod_{j=}^{R}$$

↑

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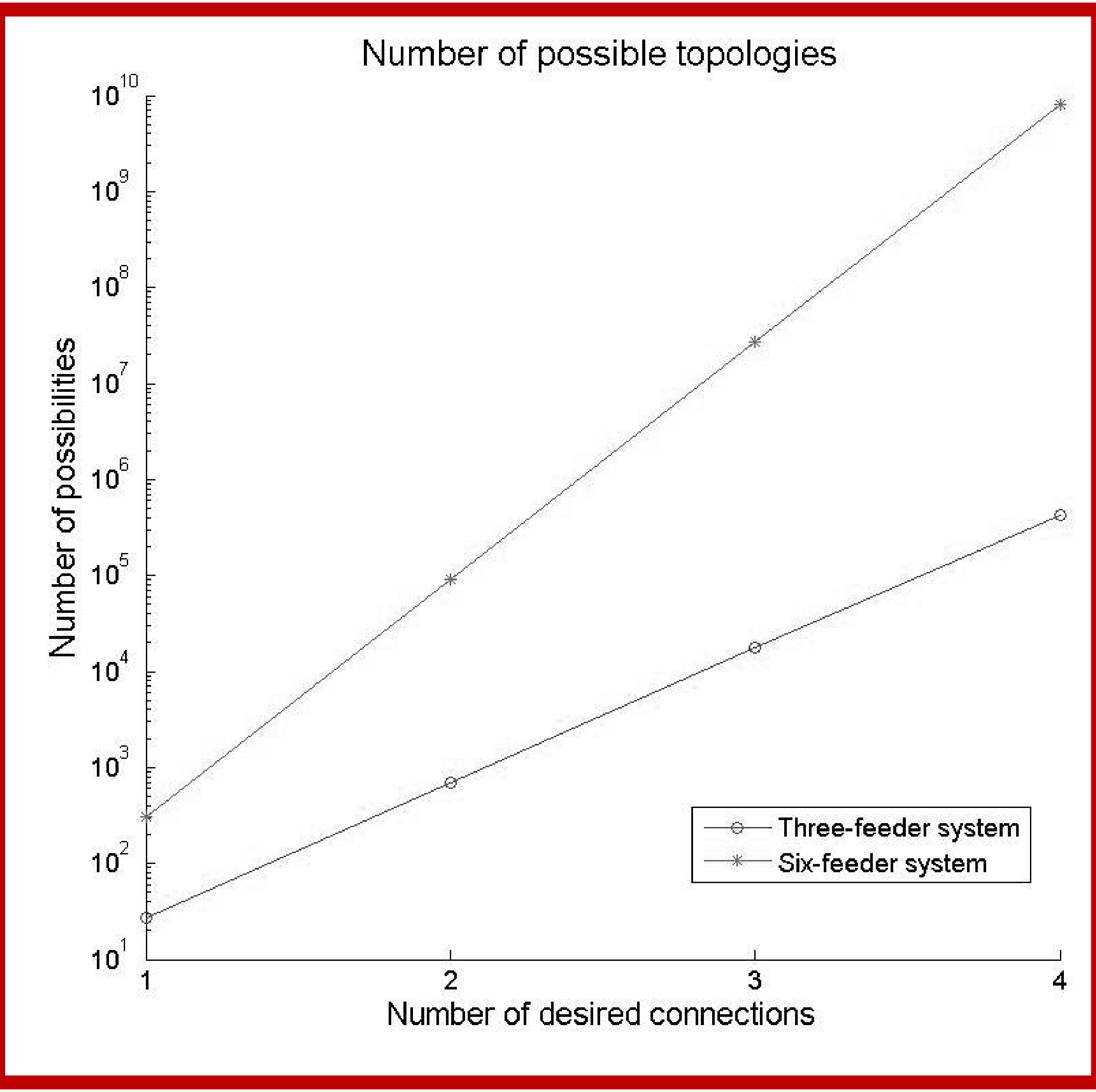

ogy has
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n feeders

$M\text{-}1$

$, n_M$

Mathematical formulation of optimization

- Characteristics of the feeder addition problem
  - Non-linear
  - Non-convex
  - Discontinuous objective function values
  - Discrete variables

•Optimization problem

Mathematical formulation

- Objective functions: Cost

$$f_1(x) = \sum_{i=1}^{Nc} C^c l_i^c x_i^c + \sum_{j=1}^{Ng} C^g P_j^g (x_j^g)$$

C^C :Cost of conductor includes transformer costs [\$/km]

l_i : Length of connection *i [km]*

C^g: Cost of DG [\$/MW]

P_g: Power Output of generator *j* [MW]

Mathematical formulation of optimization

- Quantify **reliability** using “energy not supplied” (ENS)
- A system is more reliable as the ENS decreases
- The ENS is defined as

$$ENS = \sum L_i U_i \quad \longleftarrow \quad \text{Traditional}$$

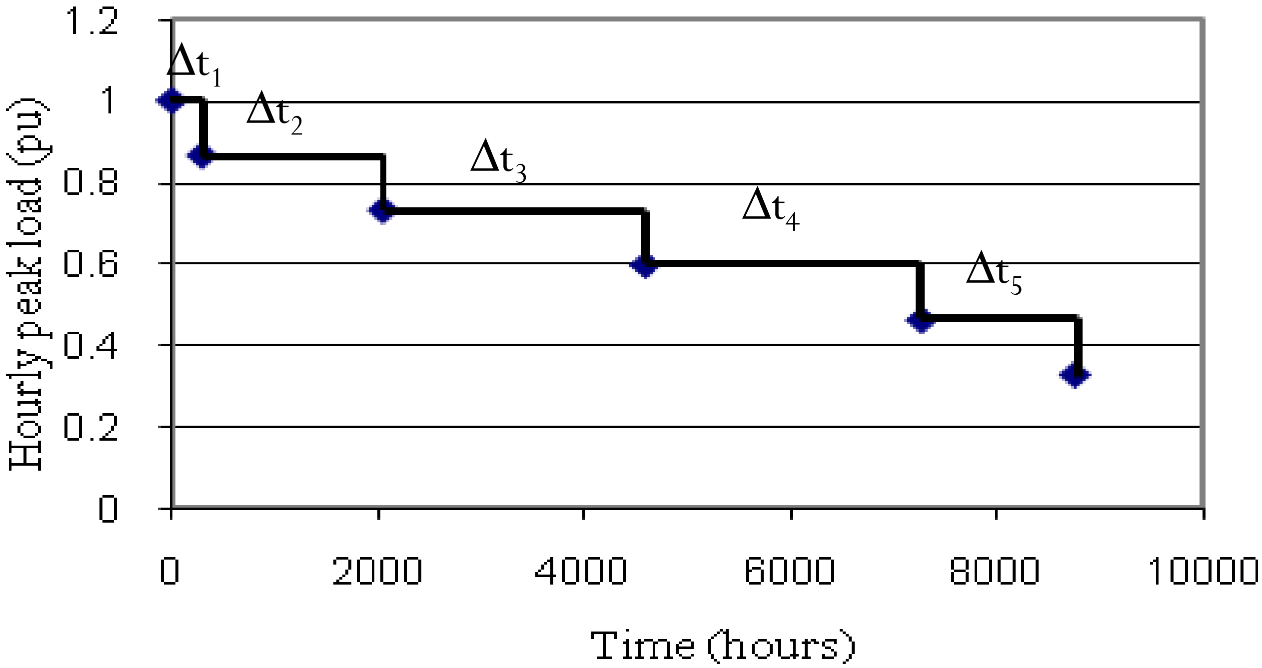
$$ENS = 8760 * (1 - ASAI) \sum L_i \quad \longleftarrow \quad \text{Base case}$$

$$h(x) = T \sum_{j=1}^{M} P_j \;, \forall\, P_j \geq 0 \quad \longleftarrow \quad \text{Modified}$$

•Modeling of a Distribution System

Loads

- Demand: two ways of modeling the loads
  - **Fixed Load**: we use the Annual Average Load values
  - **Time Dependent Load**: reorder the Peak Loads by increasing power levels



•Optimization problem

Mathematical formulation

- Objective functions: Reliability Index
  - Energy Not Supplied (ENS):

$$ENS = f_2(x) = AnnualOutageTime \times \sum_{h=1}^{8760} PNS(h)$$

    - Fixed Average Loads :

$$f_{2,Average\_Loads}(x) = 8760 * U * PNS$$

    - Time Dependent Annual Peak Loads :

$$f_{2,Load(t)} = U * \sum_{i=1}^{5} PNS(L_{\Delta t_i}) * \Delta t_i, with \sum_{i} \Delta t_i = 8760h$$

•Modeling of a Distribution System

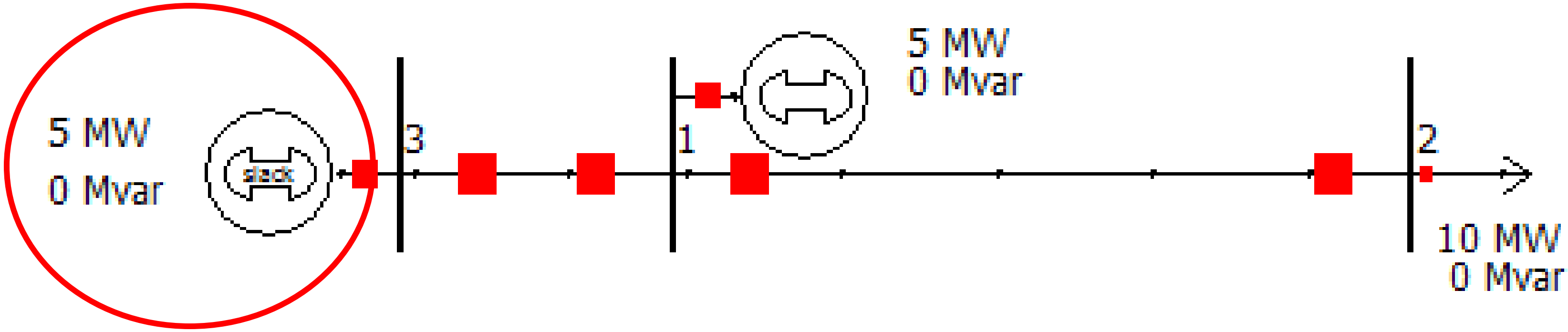
Slack Bus

- Power Systems Simulation Tool (Power World):

Slack bus: slack bus is modeled as a generator that absorbs or supplies generation in order to balance the load and generation

~ Power Not Supplied~

Solve Power Flow: Steady State conditions



•Modeling of a Distribution System

DGs

- Distributed Generation [5]:
  - $$P_{out} = CDG + RE + DS$$

$$P_{out} = R_{CDG} * CF_{CDG} + R_{RE} * CF_{RE} + (1 - CF_{RE}) * 0.15 * L_i$$

- **Capacity Factor**: ratio of the actual output of a power source and its output if it had operated at full capacity
- Total DG rating $R = R_{RE} + R_{CDG}$
- P_{out} is aggregated to known points throughout the test system

Source:H. E. Brown, **S. Suryanarayanan**, G. T. Heydt, "Some characteristics of emerging distribution systems under the Smart Grid Initiative," *Elsevier The Electricity Journal*, vol. 23, no. 5, pp. 64-75, Jun 2010.

•Optimization problem

- Mathematical formulation
  - Variables:

X (binary)	
x^c	x^g
Possible Connections	Possible location of DG
0001001 ………..... N_c	0101000 ……… N_g

•Possible networked connections to add

•Possible DG location

•Difference from previous work – co-location and co-optimization

•Genetic Algorithm

Concept

- Has successfully approximated the Pareto front for power system applications *
- A ***population*** *is comprised of* ***individuals*** *or chromosomes, each of which encodes a* ***potential solution*** *to the optimization problem*
- ***Evolutionary operators*** *are used to create individuals which may move to a higher level of fitness and include mutation, recombination, and selection operators an example of which is crossover*
- The ***fitness function*** *determines how likely an individual is to survive to the next generation*

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*A. M. Berry, D. J. Cornforth, and G. Platt, "An Introduction to Multi-objective Optimization Methods for Decentralized Power Planning," in IEEE Power and Energy Society General Meeting 2009 Calgary, Canada, July 26-30, 2009.

*D. Salazar, C. M. Rocco, and B. J. Galvan, "Optimization of constrained multiple-objective reliability problems using evolutionary algorithms," *Reliability Engineering and System Safety, vol. 91, pp. 1057-1070, 2006.*

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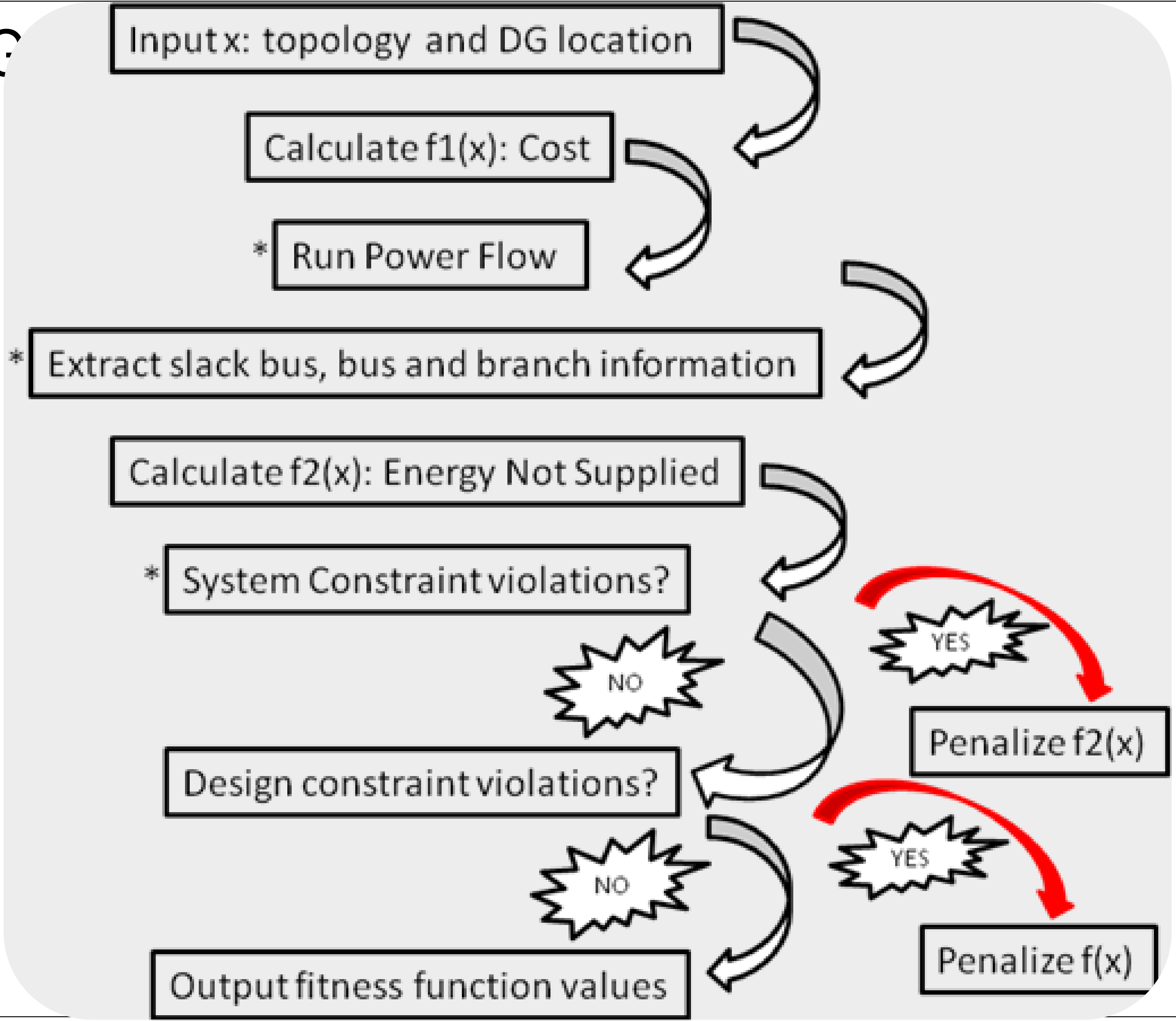
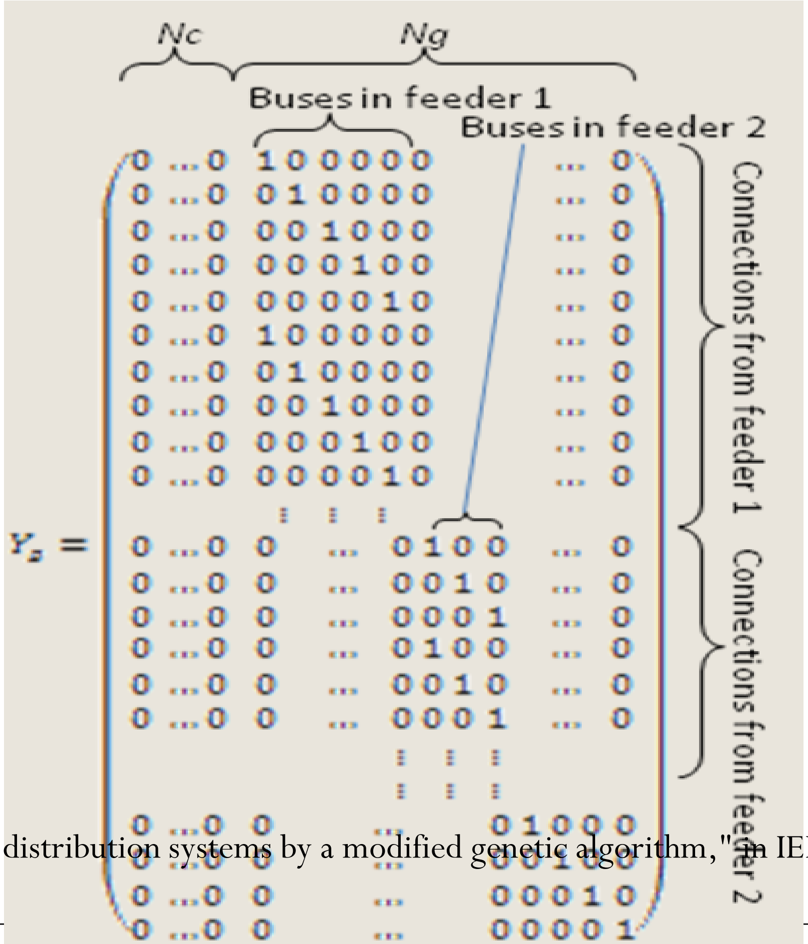

Input x: topology and DG location
Calculate f1(x): Cost
* Run Power Flow
* Extract slack bus, bus and branch information
Calculate f2(x): Energy Not Supplied
* System Constraint violations?
YES
Penalize f2(x)
NO
Design constraint violations?
YES
Penalize f(x)
NO
Output fitness function values

•Genetic Algorithm

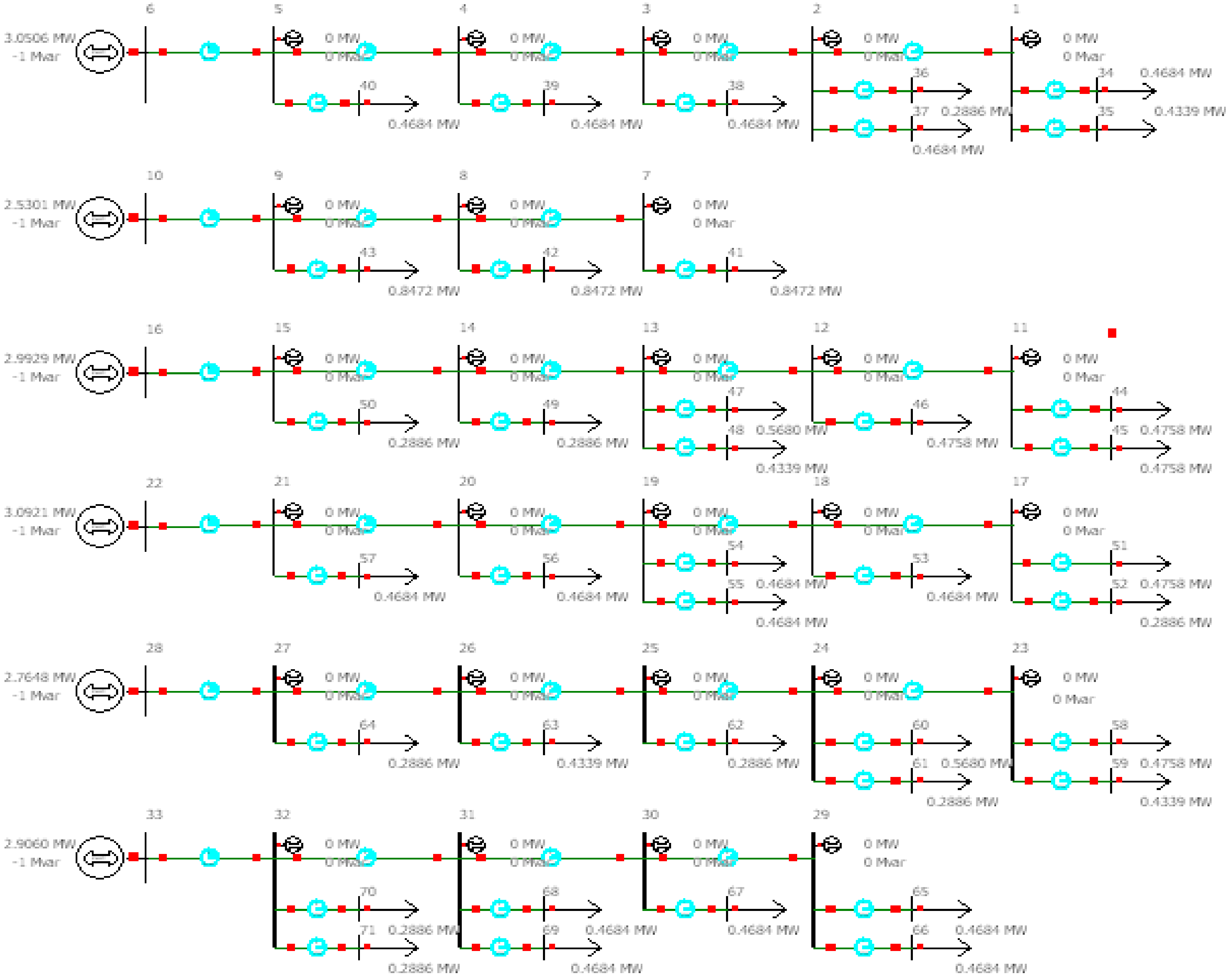
Initial Population

- Picking the initial population can have strong effect on convergence characteristics [†]
- Initial population: $Y = Yc + Yg$ [Nc x Nc+Ng]

$$Y_c = \begin{pmatrix} \overbrace{\begin{matrix}1 & \dots & 0\\ \vdots & \ddots & \vdots\\ 0 & 0 & 1\end{matrix}}^{Nc} & \overbrace{\begin{matrix}0 & \dots & 0\\ \vdots & \ddots & \vdots\\ 0 & \dots & 0\end{matrix}}^{Ng}\end{pmatrix}$$



[†] M. A. N. Guimaraes, C. A. Castro, and R. Romero, "Reconfiguration of distribution systems by a modified genetic algorithm," in IEEE PowerTech 2007, pp. 401-406.Lausanne, 2007.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0 Mvar
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39
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36
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•Application to a Test System

RBTS System

- Results: “look-up table” for the decision maker

Solution MOGA:

- **Max Cost 19x10^6$**
- **Time dependent load**
- **Average load**

Sol.N o	**Connections: from-to**	**DG location (Bus No.)**	**Cost (10^{6}x $)**	**Rel. ENS (MWh)**
1	11-17	15	**17.97**	**28.43**
2	11-17;23-29	14;25	**18.03**	**19.83**
3	11-17;23-29	11;25	**18.16**	**19.67**
4	1-7;11-17;23-29	2;11;25	**18.32**	**18.37**
5	1-7;11-17;23-29;8-14	2;11;25	**18.52**	**18.20**

Sol. No	**Connections: from-to**	**DG location (Bus No.)**	**Cost (10^{6}x $)**	**Rel. ENS (MWh)**
1	11-17	14	**17.97**	**31.4**
2	1-7;11-17	4;21	**18.10**	**22.10**
3	1-7;11-17;23-29	5;20;25	**18.10**	**21.82**
4	1-7;11-17	3;13	**18.1**	**21.75**
5	1-7;11-17;19-25	4;11;23	**18.60**	**21.50**

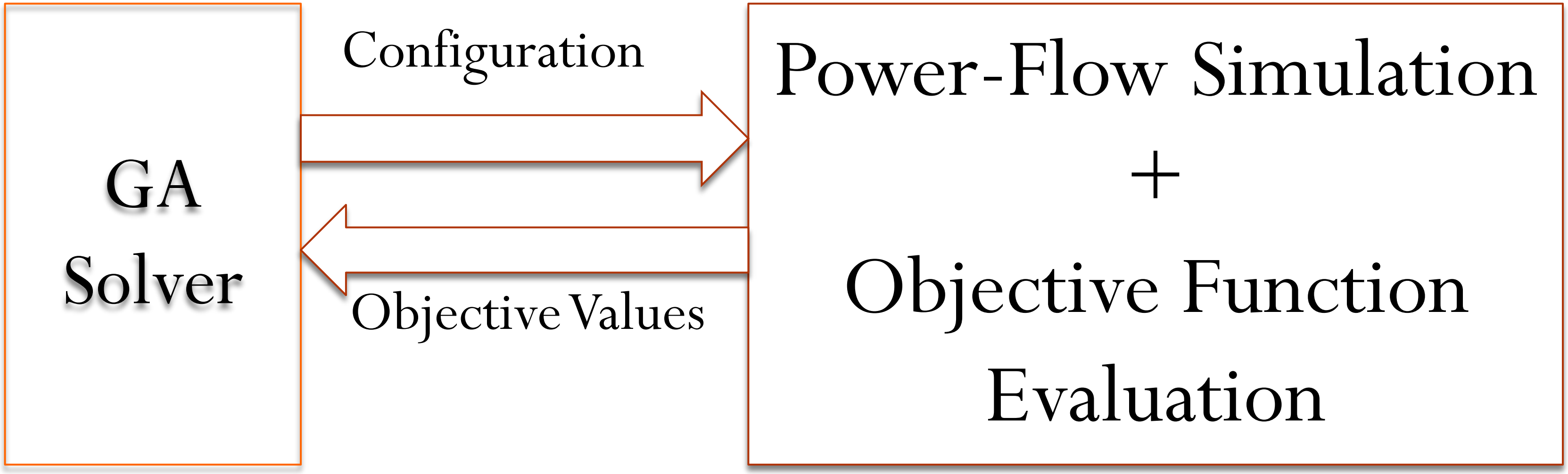
Complimentary work on computational complexity

- Classify complexity of feeder problem (Is it NP-hard?).
  - MS thesis student identified and funded under JISEA grant at CSU
  - Initial investigations on knapsack problem on going at CSU
  - Collaboration with Prof. S. Rajopadhye
  - Preliminary stages now; future meetings/presentations will have more information

“Blockading” using Machine Learning

Bottlenecks

- No known "easy" solution to optimization problem.
- Primitive for GA-based optimization:



GA Solver

Configuration

Objective Values

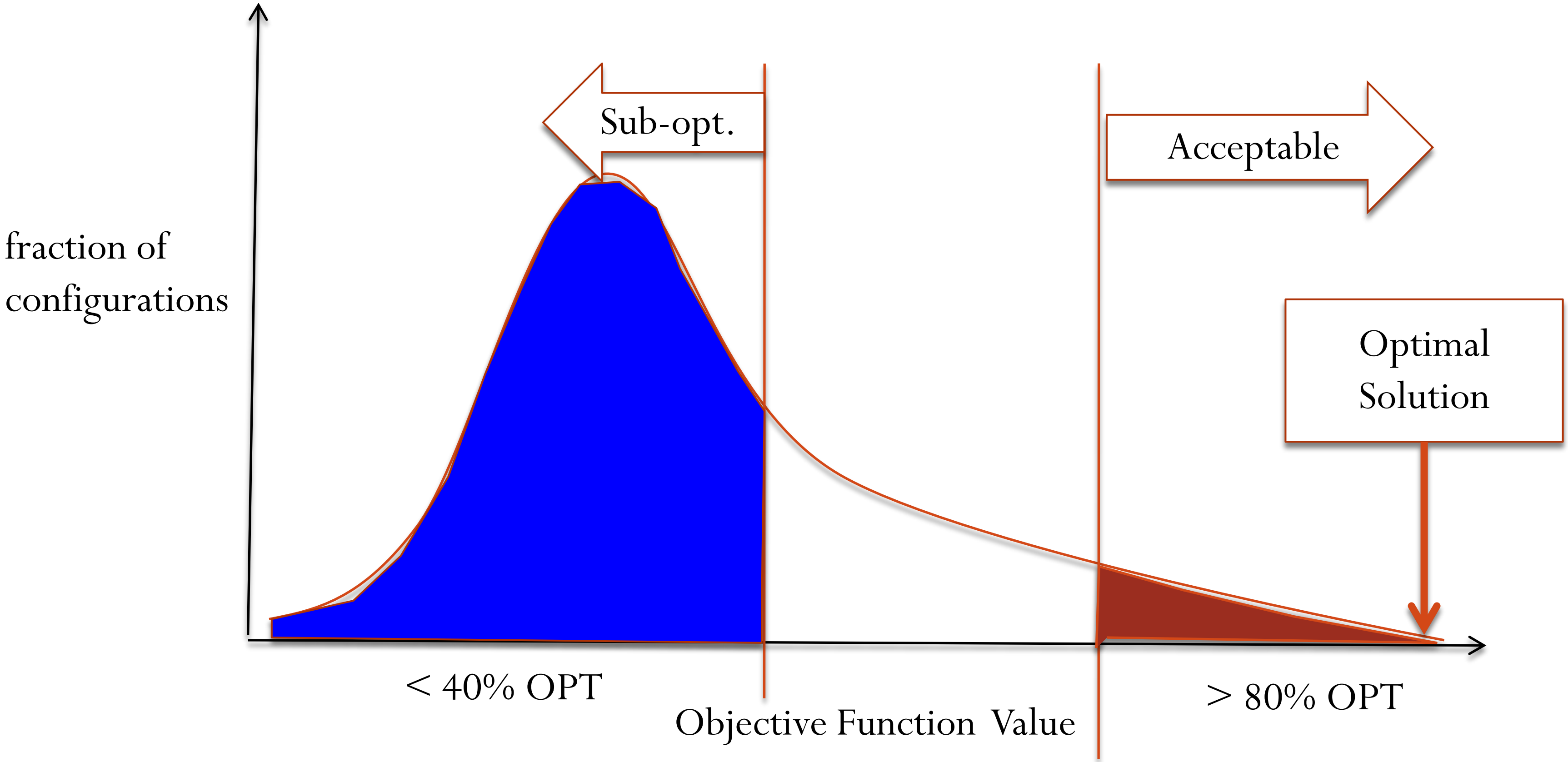
Power-Flow Simulation

+

Objective Function Evaluation

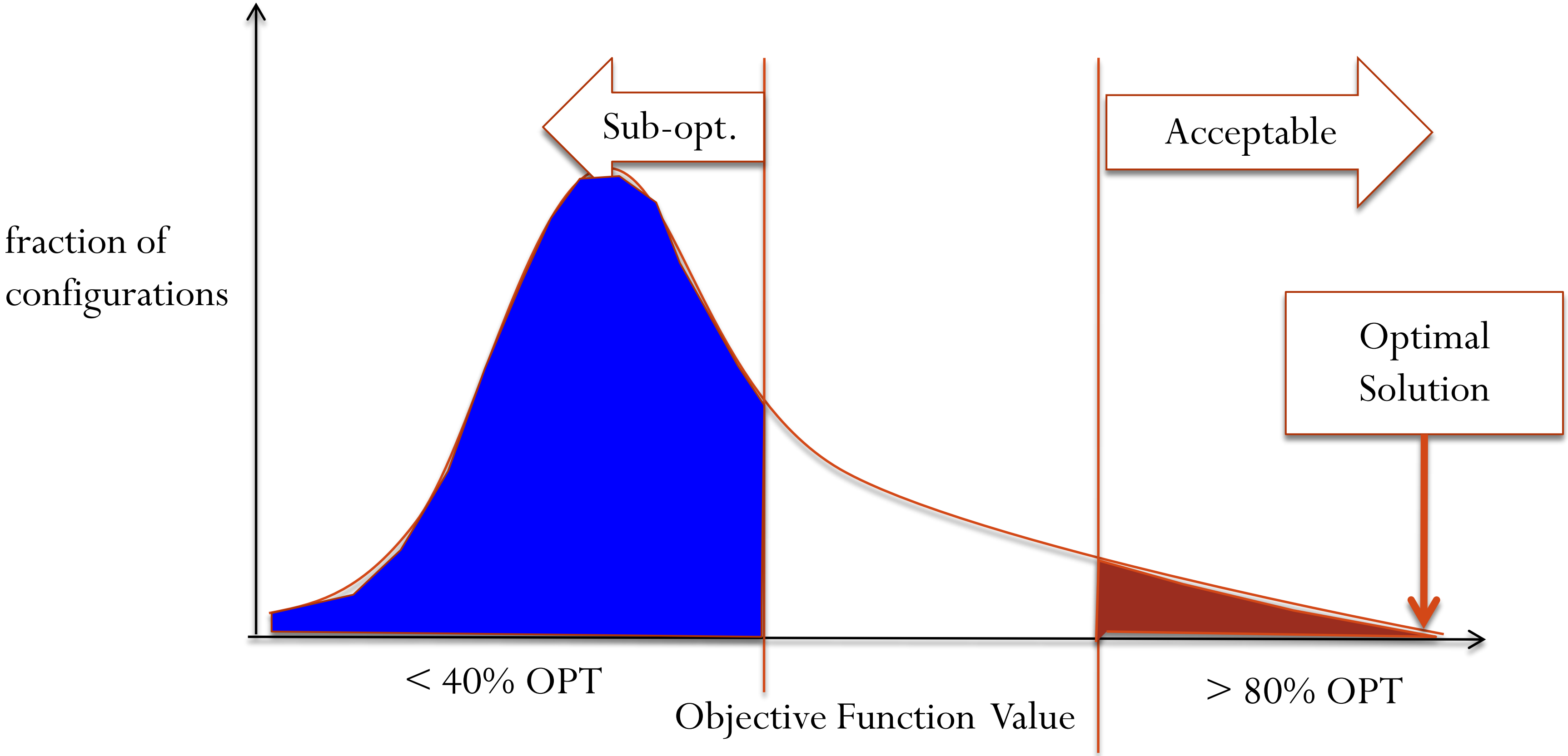
Solution Profile

- Profile of feasible region for “hard” optimization problems.

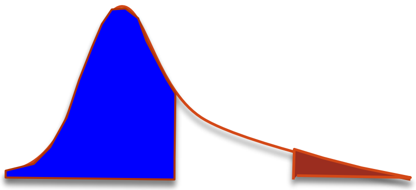


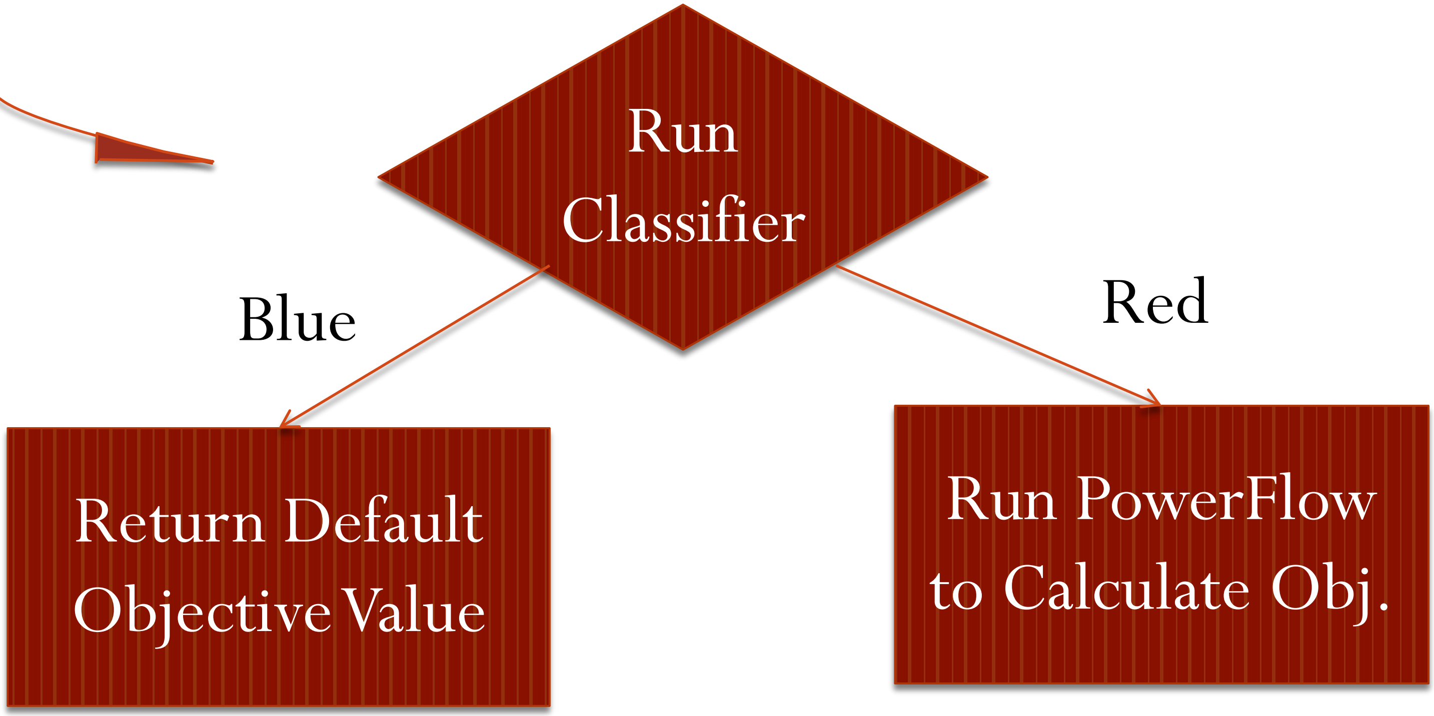
Blockade

- Learn a “classifier” to differentiate “blue” and “red” set.



Blockading during Simulation





Run Classifier

Blue

Red

Return Default Objective Value

Run PowerFlow to Calculate Obj.

Learning Classifiers

- Given two sets S1, S2.
  - Learn a function f, such that f(x) = 1 iff x in S1 and f(x) = 0 otherwise.
- Statistical Machine Learning:
  - Fit a function f from given examples of elements in S1, S2.
- Examples of techniques:
  - Decision Tree Learning
  - Logistic Regression
  - Support-Vector Machines
  - Neural Networks

Logistic Regression

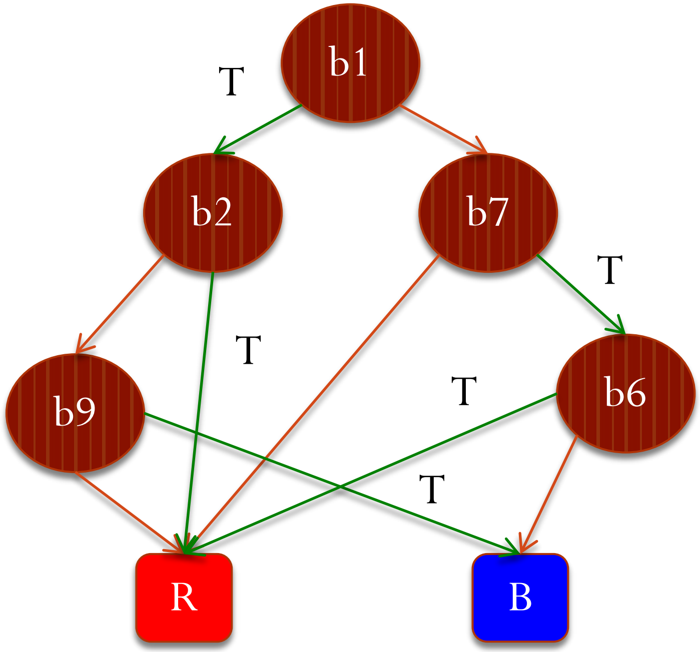
- Ideal for learning functions from [0,1] inputs and [0,1] output.
- Logistic model:

$$f(x_1, \ldots, x_n) = \frac{1}{1 + e^{-\beta_0 - \beta_1 x_1 - \cdots - \beta_n x_n}}$$

- Fitting to data using least-squares regression (gradient descent).
  - Module for logistic regression in statistical package R.

Decision Tree Learning

- Suitable when output is a Boolean function of input.
- Classifier learning algorithm: C4.5 [Quinlan et al., 1993].



Current Status

- Data collection ongoing for answering the following three questions:
  1. Can Machine Learning techniques be used to learn classifiers that avoid a significant fraction of objective function evaluations?
  2. If so, which classifier works best?
  3. Can the outcome of the GA solver remain unaltered if the "blockade" is implemented?

•Future Work

- Stochastic programming into planning electric distribution systems?
- Study of the contribution of PHEVs to distribution systems
  - Generate and store
  - Can be located at any bus at different times
- Study of the impact of PHEVs to distribution systems
  - Effect of different charging patterns
  - Optimizing a charging pattern in order to reduce losses, maintain voltage stability, increase reliability

Contact information

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