Machine Learning in Smart Grid – Scenario Reduction and Coherent Generator Grouping

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Objective

By the end of this talk, you will be able to

- understand the concept, types & typical applications of machine learning
- understand two applications of machine learning in smart grid:
  - Scenario Reduction
  - Coherent Generator Grouping

Agenda

- Introduction
- Machine Learning - Introduction
- Scenario Reduction
- Coherent Generator Grouping
- Funding & Teaching
- Summary

Education, Employment & Training

- Sep. 2005 - Jun. 2014: Zhejiang University, Bachelor & Ph.D.
- Jan. 2012 - Aug. 2013: University of Liverpool, U.K., Visiting Research Assistant
- Sep. 2013 - Dec. 2013: South China University of Technology, China, Visiting Research Assistant

- Oct. 2014 - Dec. 2014: The Hong Kong Polytechnic University, Postdoctoral Fellow
- Mar. 2015 - Aug. 2018: University of Saskatchewan, Canada, Postdoctoral Fellow

- Aug. 2018 – present: Brookhaven National Laboratory, U.S.A., Research Associate Electrical Engineer

Research - Motivation

➢ **Blackout:**

- Jun. 2019, Argentina
- Jul. 2019, New York City
- Aug. 2019, London Power Cut
- Aug. 2003, Northeast Blackout

➢ **Severe Weather → blackout:**

- Hurricane Katrina (2005)
- Superstorm Sandy (2012)

➢ **Increased Interdependency:**

- Electricity, gas, water systems

➢ **Cyber-security:**

- Ukraine power grid in 2015 switched off 30 substations

➢ **Increasing Renewables:**

- UK: 50% by 2025
- NY: 70% by 2050

Research – My Experiences

Machine Learning & Analytics

- *Deep Learning*
- *Clustering & Classification*
- *Open-source Platforms*

Transmission System

- *Expansion Planning*
- *Generation Scheduling*
- *Python-Based PSS/E Tool*

Energy Storage

- *Compressed Air Energy Storage*
- *Sizing and Siting*

Microgrid / Distribution

- *Reconfiguration*
- *Expansion Planning*

Proposals

- *10 U.S. Depart. of Energy (DOE)*
- *Industry Research Chair ($3.5 M)*
- *NYS Energy R&D Authority*

Projects

- *4 U.S. DOE*
- *2 Canada NSERC*
- *U.K. & China*

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What is Machine Learning?

Machine Learning Concept: A computer program is said to learn from experience E, if its performance at task T, as measured by performance P, improves with experience E – *Tom Mitchell*

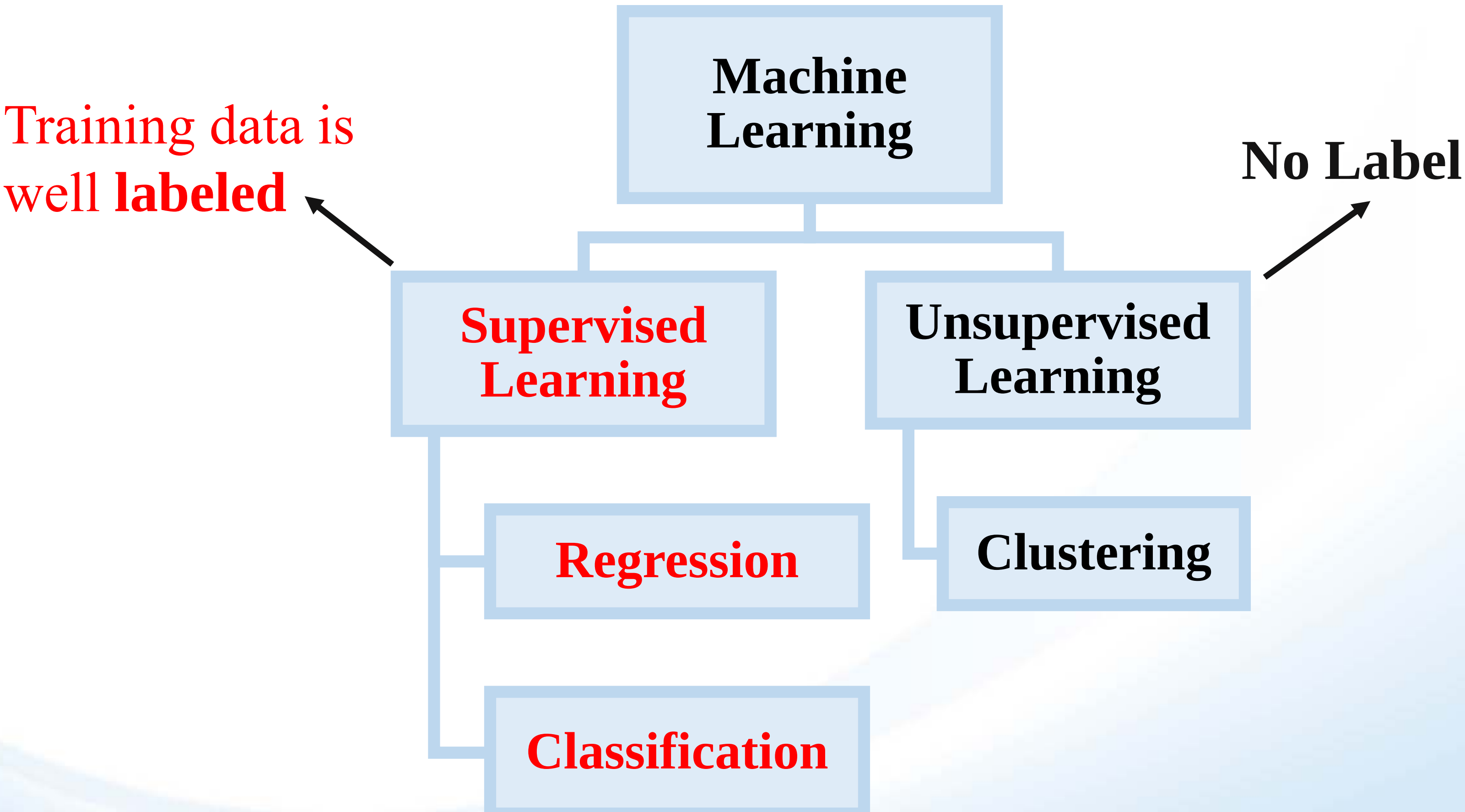
Computer program
Task T
Experience E
Performance P

Source: Boston Dynamics

Walk
Walk more
Walk better

Source: Deepmind.com

Machine Learning: Different Types



Clustering vs. Classification

Clustering (unsupervised):

- Divide the data into K clusters
- Given **unlabelled** data

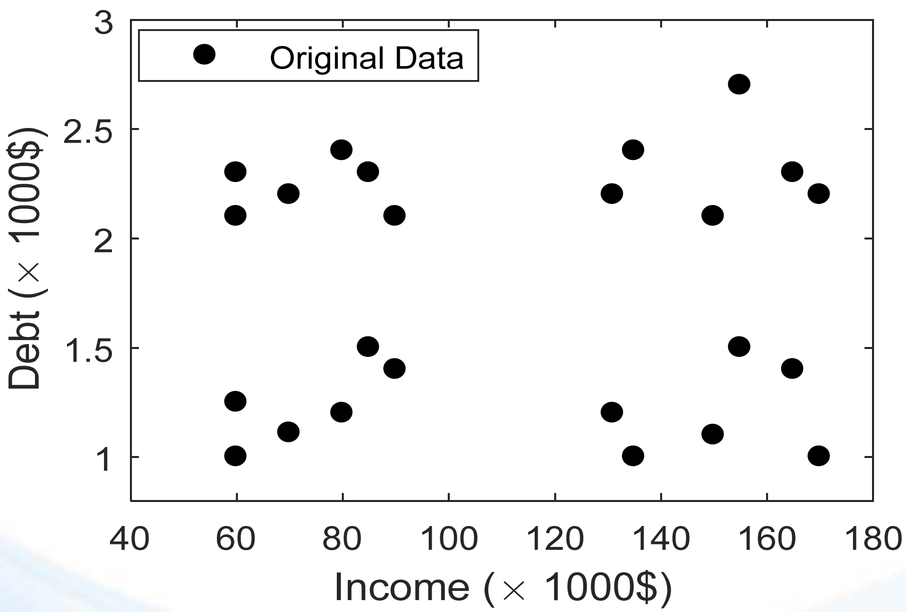


Fig. 1. Income & Debt of Households

Classification (supervised):

- Divide the data into K clusters
- Given **labelled** data (red or blue)

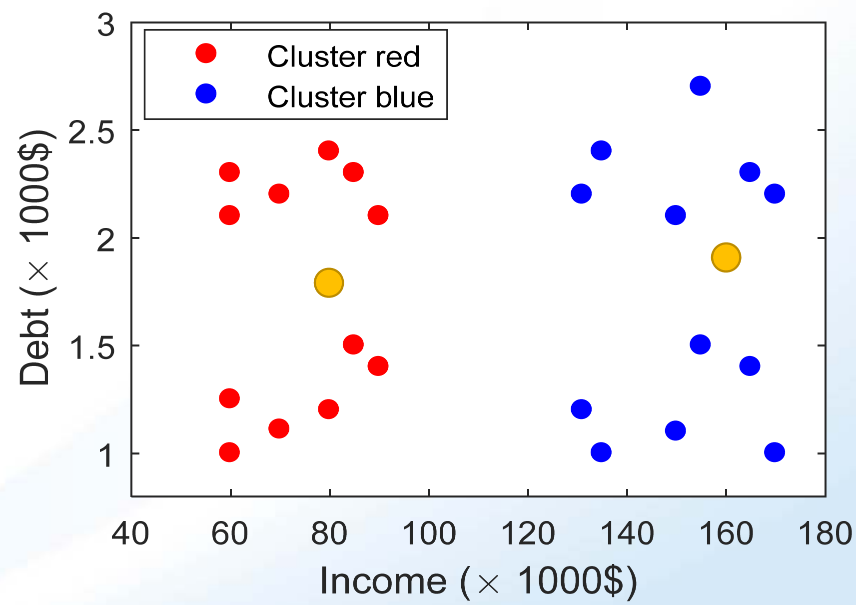


Fig. 2. Income & Debt of Households

https://github.com/zhanjunpeng/SmallProjects

Neural Network

- Neural network have multiple layers
- Input layer: input data
- A layer can have multiple neurons
- Neuron is a **function between x_i and y_j**:

$$y_j = f\left(\sum_{i=1}^{n} x_i w_i + b_j\right)$$

- f is an activation function, example:

$$f = \max(0, x)$$

- Deep learning:
  - Many-layer neural network
  - Many parameters

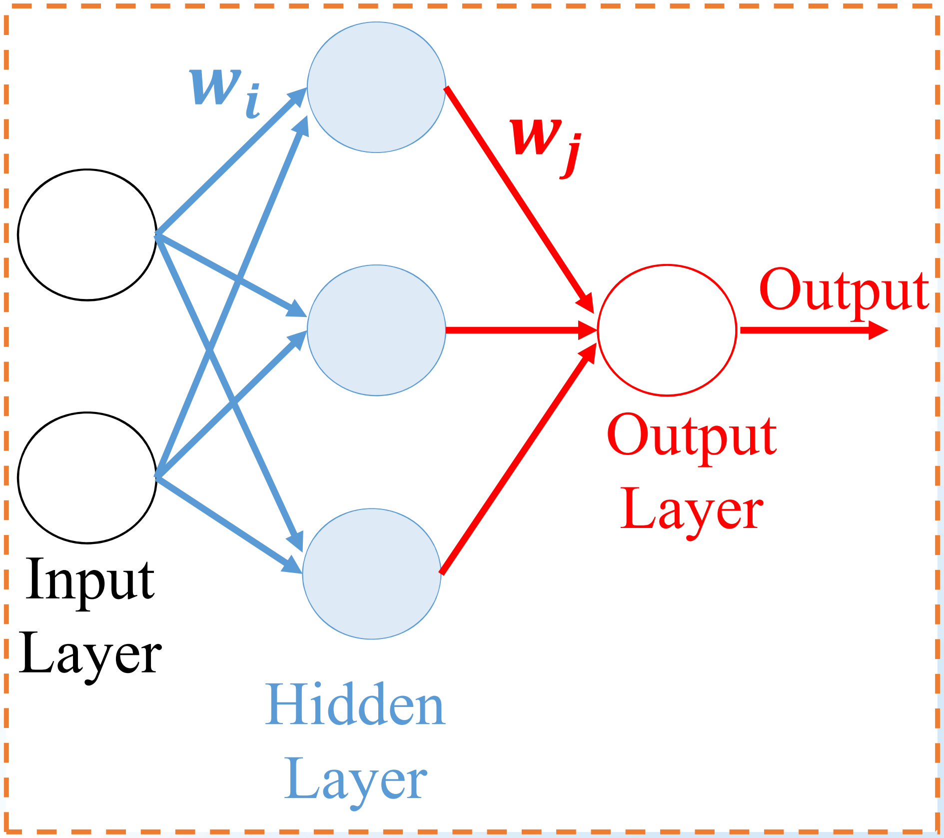


Fig. 1. Multi-layer Neural Network

Typical Applications of Machine Learning

- **Classification:**
  - Identify objects in images
  - Junk email
- **Clustering:**
  - Netflix recommendation systems
  - Scenario reduction
- **Regression:**
  - Predict stock price, weather, etc.

- Further reading, e.g., http://www.yaronhadad.com/deep-learning-most-amazing-applications/

Machine Learning in Smart Grid: Example

- **Load**
  - Predict responsive load
- **Generation**
  - Predict renewable power
  - Early fault diagnosis
- **Transmission**
  - Transmission line inspection
- **Distribution**
  - Topology identification
- **Anomaly Detection**
  - Cyber attack

Source: lancasteronline.com/

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Scenario Reduction for Stochastic Programming

- Scenario reduction
  - Scenarios accurate represent uncertainty
  - Using many scenarios in stochastic programming is intractable as it needs a very long time
  - Need to reduce to a small number
- K-means clustering algorithm
  - Fast but inaccurate
- Forward selection algorithm (FSA)
  - Widely used & Accurate
  - **Very time consuming** to reduce a large number of scenarios
- Proposed an improved FSA (IFSA)

Table: Probability of Wind Power Output

Probability	Wind Power
0.2	100 MW
0.8	50 MW

0.2*100+0.8*50=60 MW

Scenario Reduction: Improved Forward Selection Algorithm

- **Forward selection algorithm (FSA)**
  - Goal: obtain a reduced set of the original set
  - Minimize the distance between the two sets
  - In each iteration: traverse the whole original set → determine the best element to be added to the reduced set
- **Improvement 1:**
  - Firstly, obtain cluster centers
  - Then, traverse cluster centers → find the best center
  - Then, traverse the single cluster associated with the best center
- **Improvement 2:**
  - Utilize the information used in previous iterations → avoid repeated calculation

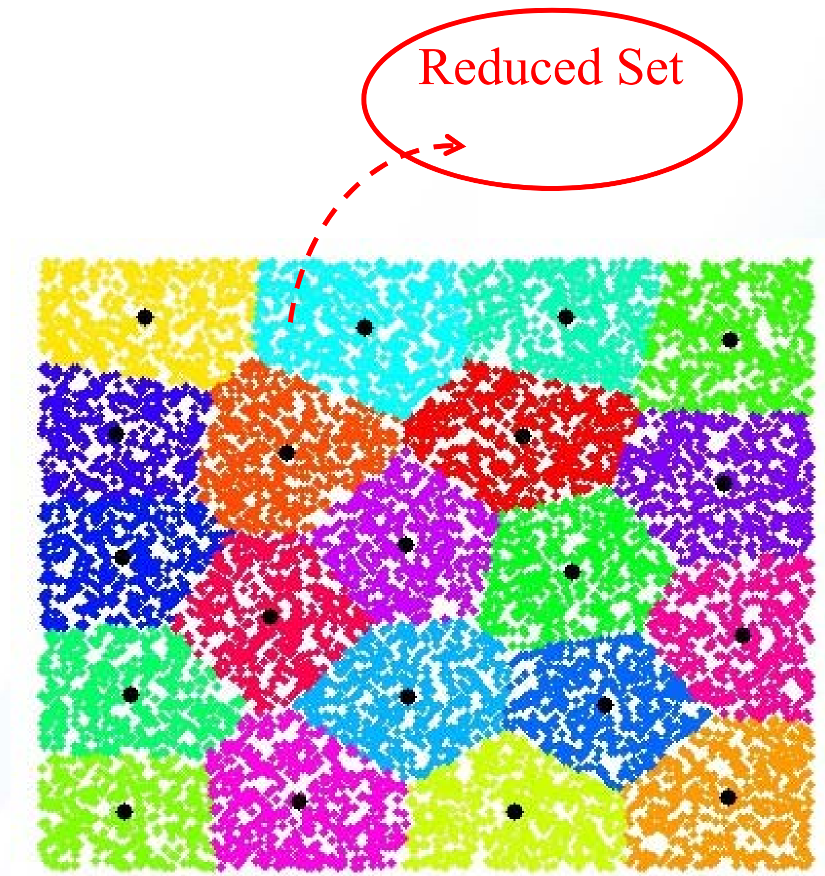

Fig. 1: Original Set (each dot is an element)

Scenario Reduction: Improved Forward Selection Algorithm - Result

- FSA is time consuming
  - Fail to reduce a large number of scenarios
- IFSA is significantly faster than FSA [J12]
  - Can reduce a large number of scenarios in a short time

Table: Time Consumption for Reducing Scenarios to 500

Method	**No. of Original Scenarios**	
	40,000	131,040
FSA	24,493 s	---
IFSA	99.3 s	571.5 s

- Applications: Transactive energy control [J17]; Stochastic Distribution System Reconfiguration [J20, github.com/zhanjunpeng/SOE]

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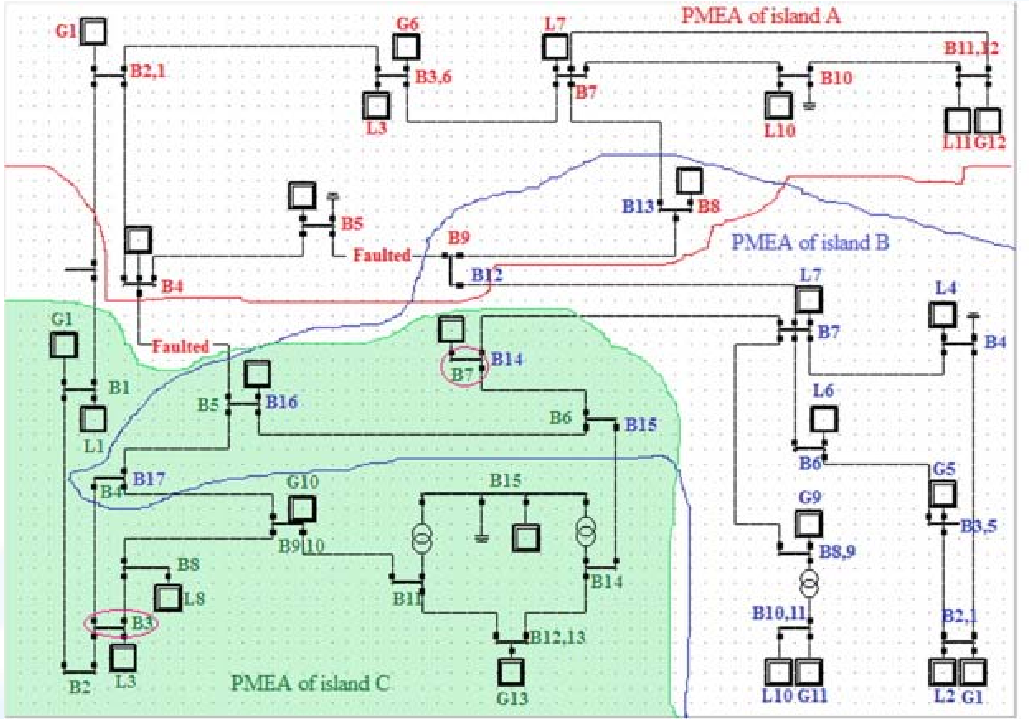
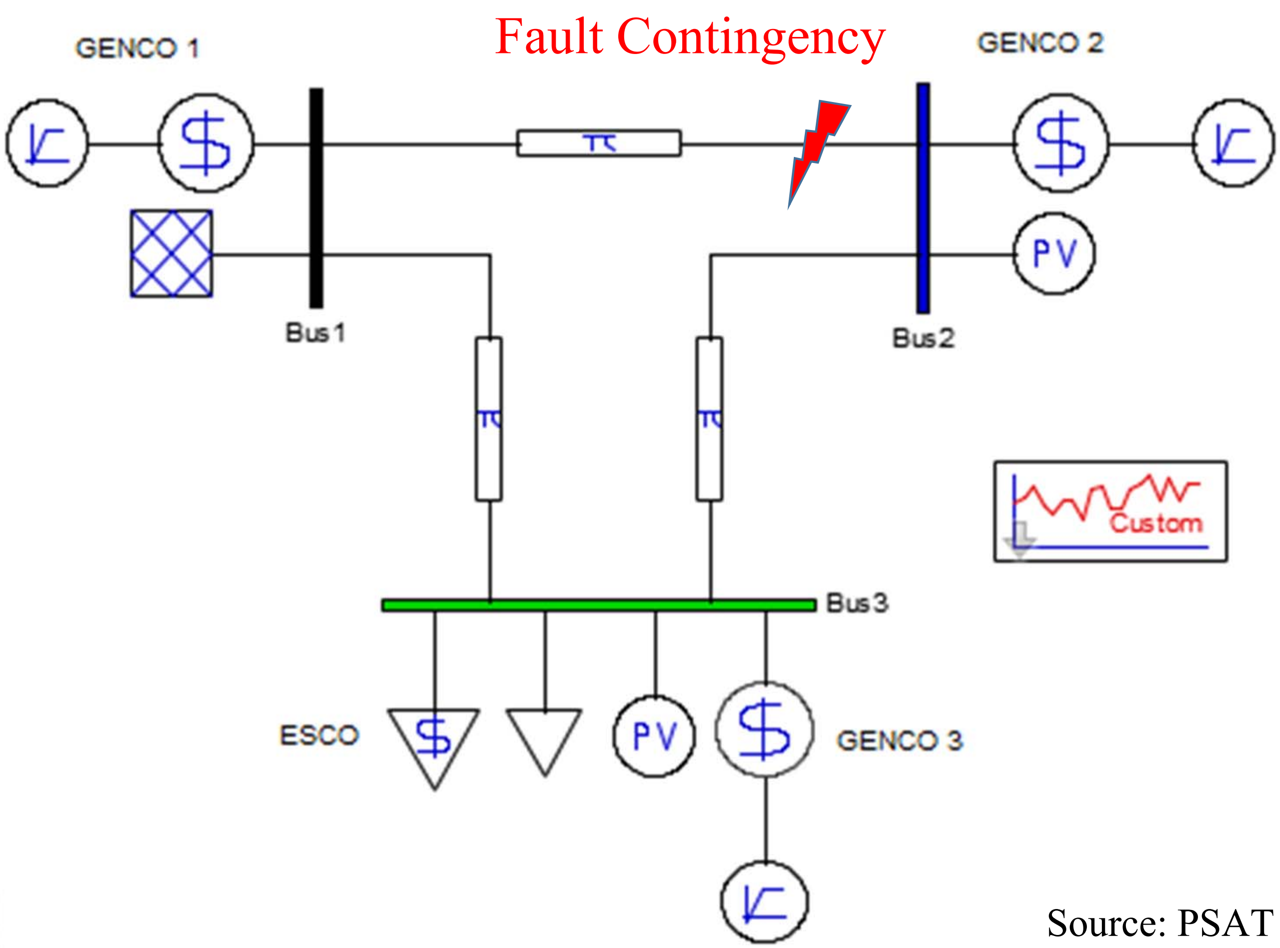
Deep Learning for Coherent Generator Grouping

- ➢Interconnected system: all generators are synchronized
- ➢After severe disturbances, generators may lose synchronism
- ➢Controlled islanding or separation → avoid a widespread blackout
- ➢Coherent generator grouping (CGG): determine where to separate
- ➢CGG can be casted as a classification problem
- ➢Deep learning techniques are very promising
  - Convolutional Neural Network, Long Short-Term Memory



Source: Jabari, IJEPES, vol. 67, 2015. pp. 368-380

Power System Simulation



Source: PSAT

Deep Learning for Coherent Generator Grouping: Procedure

- Generate training/testing data:
  - Power system simulation for 1080 contingencies
  - Input data: 10-second generator rotor speed
  - Output data (label): 70 types of clustering

123456789

123456789

- Classification:
  - 2-second input data & output data
  - Train neural networks

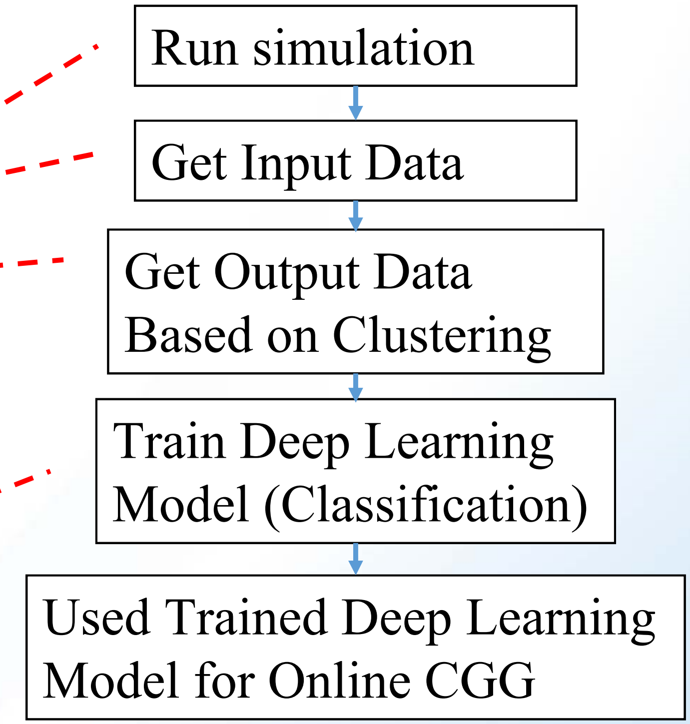


Fig. 1. Flowchart of Deep Learning for CGG

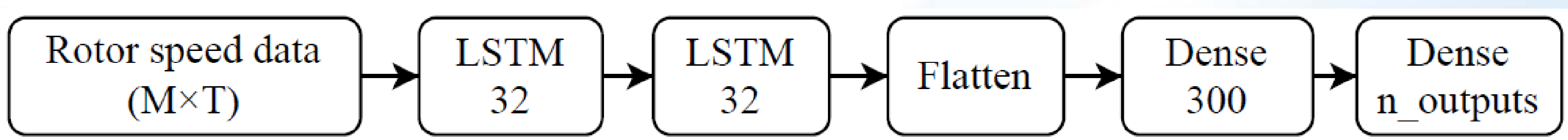


Fig. 2. Structure of the LSTM-based Deep Learning

Deep Learning for Coherent Generator Grouping: Result

- ➢ Accuracy is 90.28% for LSTM [C1]
- ➢ Online application of the obtained neural networks:
  - Use new input data measured → determine cluster type

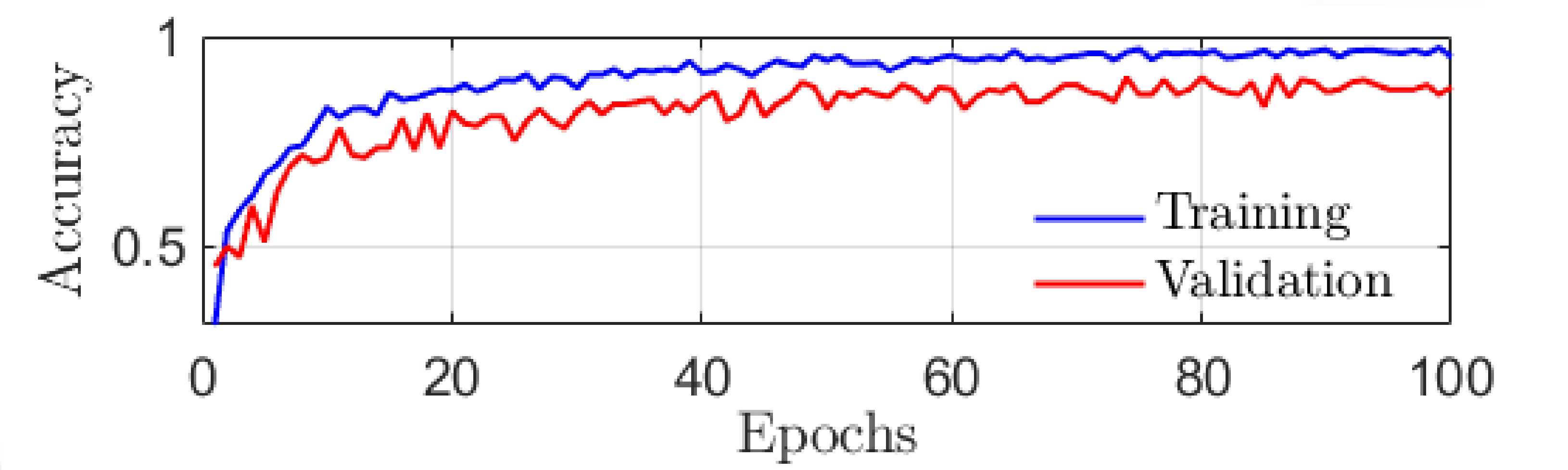


Fig. 1. Training and Validation Accuracy

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Funding & Proposals

- Funding: NSF, DOE, DHS, NYSERDA, NYPA & other utilities, Siemens, GE, ABB, etc.
- Proposals:
  - Power system resiliency (planning, restoration)
  - Machine Learning based power grid emergency control (conference paper, platform, on-going AGM project,)
  - Cyber-physical security of power systems (Anomaly detection)

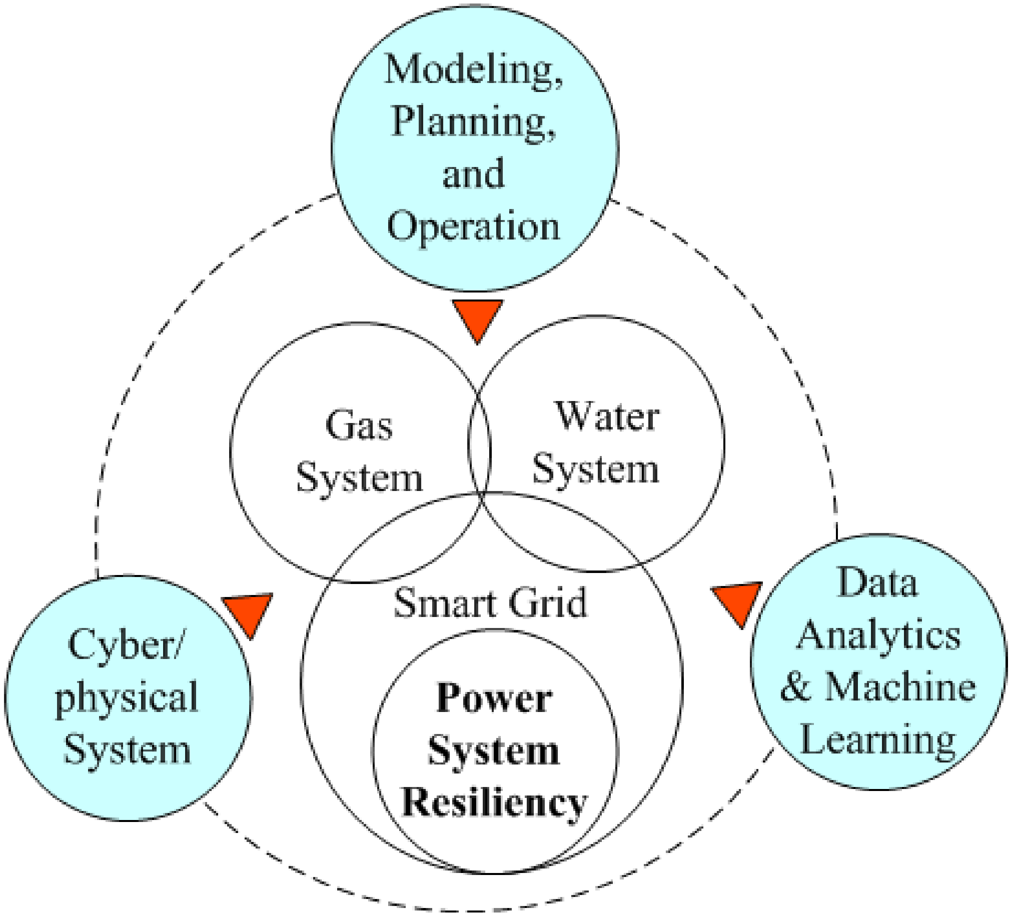
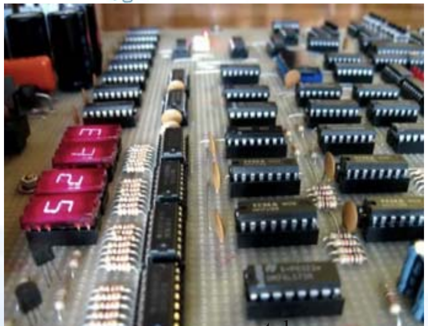


Fig. 1. My Future Research Direction

Teaching

https://www.1001freedownloads.com/

techiexpert.com



youtube.com

- Power System Generation, Control & Operation
- Data Analytics & Machine Learning
- Renewable Generation
- Power System Analysis
- Electric Circuits
- Engineering Mathematics
- Digital Systems & Microprocessors

Publication List

[J20] **J. P. Zhan**, et. al., “Switch Opening and Exchange Method for Stochastic Distribution Network Reconfiguration”, ***IEEE Trans. Smart Grid***, accepted 2020.
[J19] W. J. Liu, **J. P. Zhan**, C. Y. Chung and L. Sun. Availability Assessment Based Case-Sensitive Power System Restoration Strategy, ***IEEE Transactions on Power Systems***, accepted in September 2019
[J18] **J. P. Zhan**, O. A. Ansari, W. J. Liu, and C. Y. Chung. An Accurate Bilinear Cavern Model for Compressed Air Energy Storage. ***Applied Energy***, 2019.
[J17] W. J. Liu, **J. P. Zhan**, and C. Y. Chung. A Novel Transactive Energy Control Mechanism for Collaborative Networked Microgrids. ***IEEE Transactions on Power Systems***, accepted in November 2018.
[J16] W. J. Liu, **J. P. Zhan**, and C. Y. Chung. Day-Ahead Optimal Operation for Multi-Energy Residential Systems with Renewables. ***IEEE Transactions on Sustainable Energy***, accepted in Oct. 2018.
[J15] **J. P. Zhan**, W. J. Liu, and C. Y. Chung. Stochastic Transmission Expansion Planning Considering Uncertain Dynamic Thermal Rating of Overhead Lines. ***IEEE Transactions on Power Systems***, vol. 34, no. 1, pp. 432-443, 2019.
[J14] Y. F. Wen, **J. P. Zhan**, C. Y. Chung, W. Y. Li. Frequency Stability Enhancement of Integrated AC/VSC-MTDC Systems with Massive Infeed of Offshore Wind Generation. ***IEEE Transactions on Power Systems***, vol. 33, no. 5, pp. 5135-5146, 2019.
[J13] A. Zare, C. Y. Chung, and **J. P. Zhan**. A Distributionally Robust Chance-Constrained MILP Model for Multistage Distribution System Planning with Uncertain Renewables and Loads, ***IEEE Transactions on Power Systems***, vol. 33, no. 5, pp. 5248-5262, 2018
[J12] **J. P. Zhan**, et. al., A Fast Solution Method for Stochastic Transmission Expansion Planning. ***IEEE Transactions on Power Systems,*** 2017.
[J11] **J. P. Zhan**, et. al. Time Series Modeling for Dynamic Thermal Rating of Overhead Lines. ***IEEE Transactions on Power Systems,*** 2017.
[J10] **J. P. Zhan**, Q. H. Wu, C. X. Guo, and X. X. Zhou. Economic Dispatch With Non-convex Objectives–Part II: Dimensional Steepest Decline Method. ***IEEE Transactions on Power Systems***, vol. 30, no. 2, pp. 722-733, 2015.
[J9] **J. P. Zhan**, et. al., Economic Dispatch With Non-convex Objectives–Part I: Local Minimum Analysis. ***IEEE Transactions on Power Systems***, 2015.
[J8] **J. P. Zhan**, Q. H. Wu, C. X. Guo, and X. X. Zhou. Fast λ-iteration Method for Economic Dispatch With Prohibited Operating Zones. ***IEEE Transactions on Power Systems*** *(Power Engineering Letters)*, vol. 29, no. 2, pp. 990-991, 2014.
[J7] **J. P. Zhan**, C. X. Guo, Q. H. Wu, and L. L. Zhang. Generation Maintenance Scheduling Based on Multiple Objectives and Their Relationship Analysis. ***Journal of Zhejiang University Science C (Computers & Electronics)***, vol. 15, no. 11, pp. 1035-1047, 2014.
[J01] **J. P. Zhan**, M. Yue, and P. Luh, “Stochastic Siting and Sizing of Battery Energy Storage Systems Considering Frequency Dynamics”, plan to submit to *IEEE Trans. Smart Grid.*
[C1] S. Q. Zhang, A. Yogarathinam, **J. P. Zhan**, M. Yue, and G. Lin “A Step Towards Machine Learning-based Coherent Generator Grouping for Emergency Control Applications in Modern Power Grid”, IEEE PES GM 2020 (accepted).

Summary

- What have you learned?
- Motivations: blackout, extreme weather, interdependent infrastructure, cyber attack, renewables
- Machine Learning: concepts, types & applications
- Scenario Reduction: Improved Forward Selection Algorithm
- Coherent Generator Grouping Based on Deep Learning
- Funding & Teaching

Acknowledgement

U.S. DEPARTMENT OF ENERGY

NSERC CRSNG

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Questions?

Source: www.gvaschools.org

Example of Transient Behavior

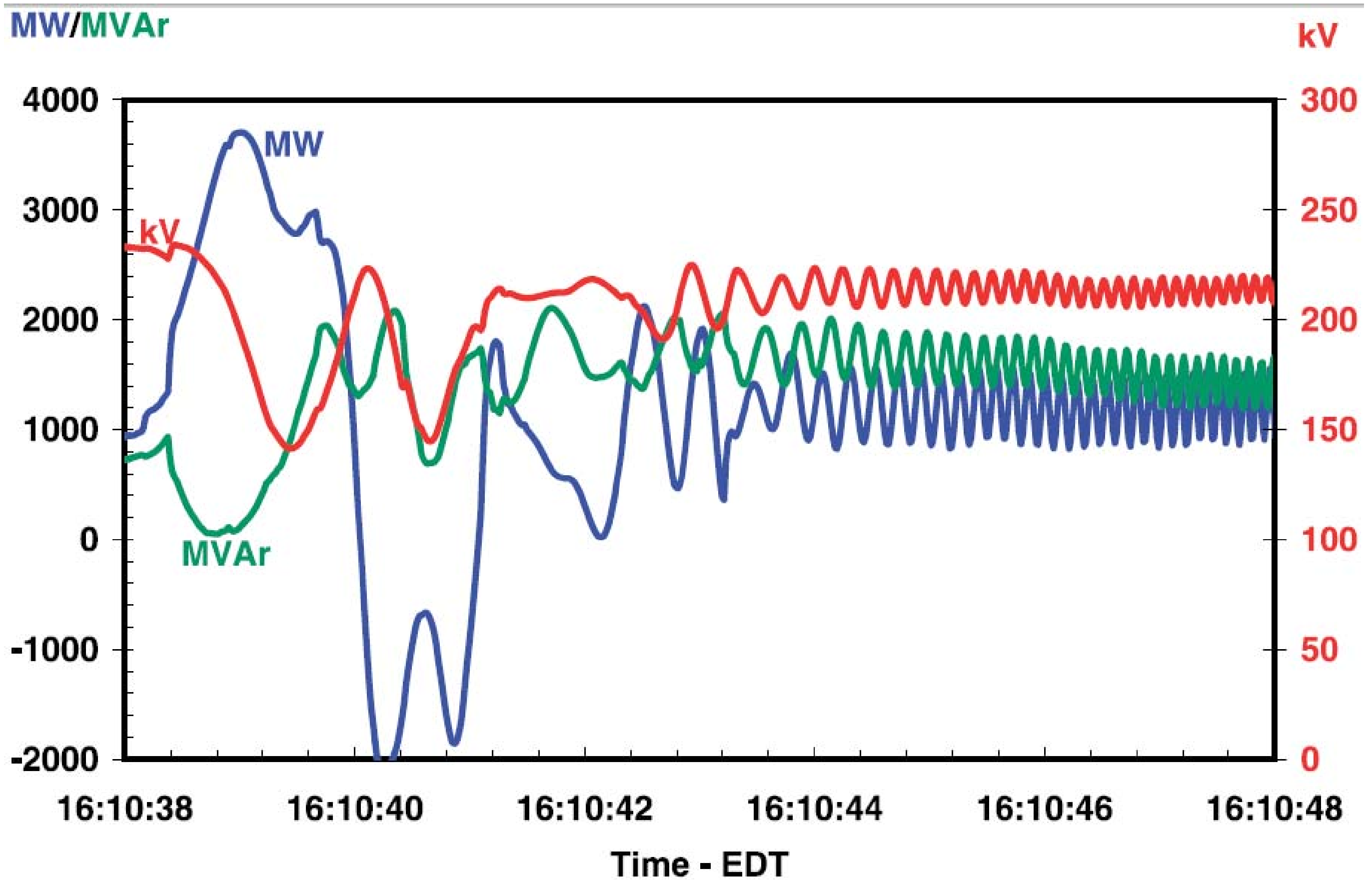

Figure 6.17. Measured Power Flows and Frequency Across Regional Interfaces, 16:10:30 to 16:11:00 EDT, with Key Events in the Cascade 30

Source: August 14th 2003 Blackout Final Report