Computational Intelligence paradigms for the energy management of polygeneration microgrids

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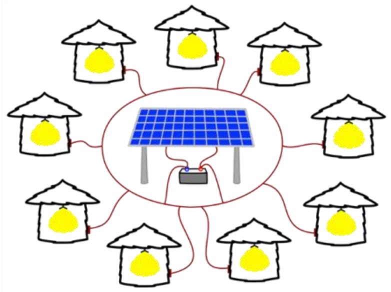
Background on rural electrification

- Access to Affordable and Clean Energy is one of the Sustainable Development Goals (SDG) of the United Nations (UN)
- The electrification rate in Sub-Saharan Africa is 35%, with 63% being the urban electrification rate and only 19% the rural electrification rate (Energy Outlook 2016)
- The main grid will not be able to provide access to all of the African population before 2030 (horizon for the SDGs)

Attributes	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Peak available capacity (W)	–	>1	>500	>200	>2,000	>2,000
Duration (hours)	–	≥4	≥4	≥8	≥16	≥22
Evening supply (hrs)	–	≥2	≥2	≥2	≥4	≥4
Affordability	–	–	√	√	√	√
Legality	–	–	–	√	√	√
Quality (voltage)	–	–	–	√	√	√

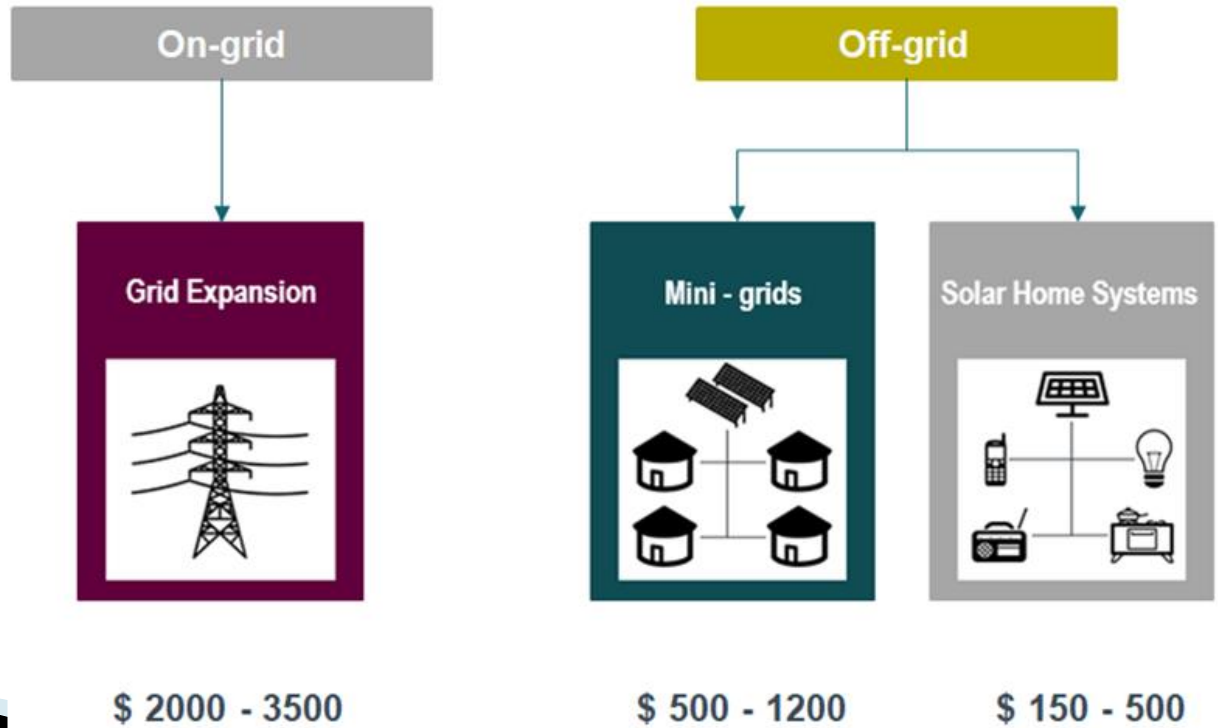


Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
–	Task lighting AND Phone charging (OR radio)	General Lighting AND Television AND Fan (if needed)	Tier 2 AND Any low-power appliances	Tier 3 AND Any medium-power appliances	Tier 4 AND any high-power appliances

013. Global tracking framework. Sustainable energy for all. Washington D.C. ; The World Bank. Angelou, Nicolina; Elizondo Azuela, Gabriela; Banerjee, Sudeshna Ghosh; Bhatia, Mikul; Bushueva, Irina; Inon, Javier Gustavo; Jaques Goldenberg, Ivan; Portale, Elisa; Sarkar, Ashok. 2

Economics of rural electrification in Africa

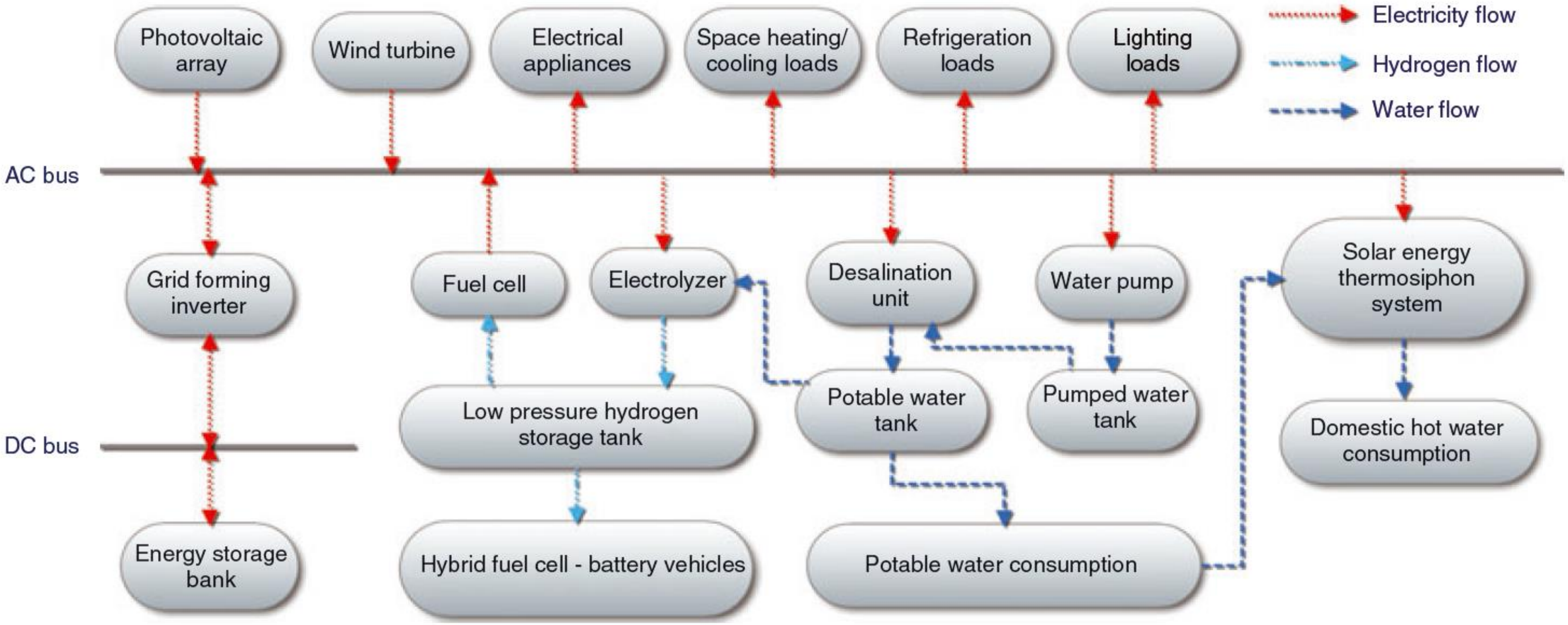
- Rural households spend on average ~10 USD per month on energy.
- Grid extension → access to higher power and energy | Can the new customers utilize this higher availability due to their economic situation?
- Autonomous microgrids can power effectively a vast array of appliances related to economic development.



Polygeneration

Polygeneration can be defined as the production of multiple products from a given system.

- Products can include electricity, heating, cooling, refrigeration, lighting, water pumping, water desalination, on site fuel production etc.



Computational Intelligence

- Computational Intelligence is a field of Artificial Intelligence that focuses on the understanding and reuse of living beings intelligence in a computer.
- Computational intelligence includes:
  - Fuzzy logic
  - Neural Networks
  - Evolutionary Computation (e.g. genetic algorithms, particle swarm optimization etc.)
  - Machine Learning (e.g. Backpropagation)
  - Probabilistic methods (e.g. Bayesian network

Computational Intelligence vs. Microgrids

- Supervise the energy producers | activation and deactivation as well as part load operation.

  Manage energy storage subsystems | short-term (e.g. batteries), medium-term (e.g. hydrogen), long-term (e.g. desalinated water

  Energy Management System → Fuzzy Cognitive Maps – Petri Nets

- Predict power production from renewables and loads

  Predictor → Grey Systems Theory

- Employ demand side management | smart activation and deactivation of loads, scheduling etc.

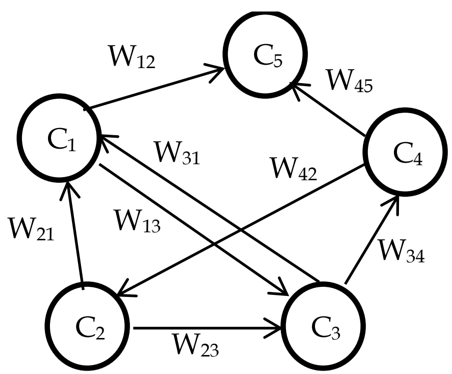
  Demand Side Management System → Multi-agent System

- Size the various components

  Sizing → Particle Swarm Optimization

Fuzzy Cognitive Maps (FCM)

- FCMs are graphs which represent cause and effect relationships and are used for computational inference processing.
- Concepts (C_n) are used to present different aspects of he modeled system such as inputs, outputs, rules or intermediate states.
- These node-concepts are interconnected with arcs which have different weights (w_{ij}) in order to express their relations.



- The FCM reaches a converged state after a number of iterations.
- Function f is the activation function.

$$A_i(k+1)=f\left(A_i(k)+\sum_{\substack{j=1\\ j\neq i}}^{n} W_{ji}A_j(k)\right)$$

$$f(x) = \frac{1}{1+e^{-cx}}$$ (Sigmoid function)

Petri Nets (PN)

A Petri Net (PN) is a weighted bipartite graph which is defined by four parameters P, T, A^P and w

P: This is the finite set of places and is depicted as one type of node in the graph

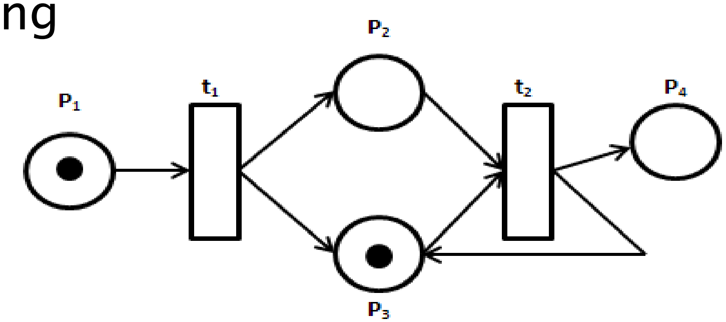
T: This is the finite set of transitions and is depicted as a second type of node in the graph

A^P: is the set called flow relation which includes the arcs from transitions to places and from places to transitions in the graph

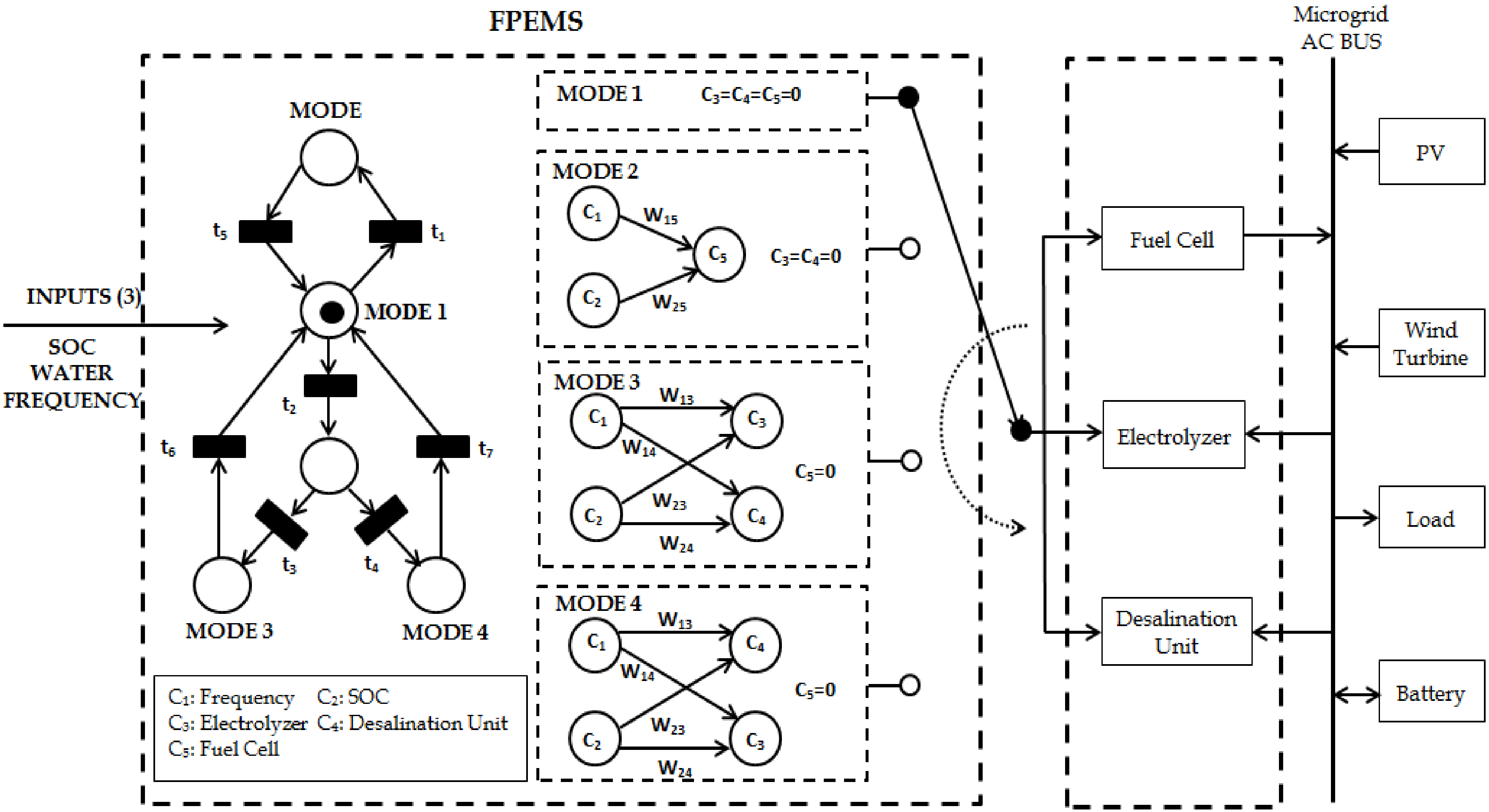
w: is the weight function of the arcs

The mechanism used to indicate in a PN if a condition is met or not is the assignment of tokens to places – if a condition is satisfied, then a token is placed.

The movement of tokens through the PN presents the state transition function of the PN – this is called firing



PN – FCM Energy Management System



Grey Systems Theory

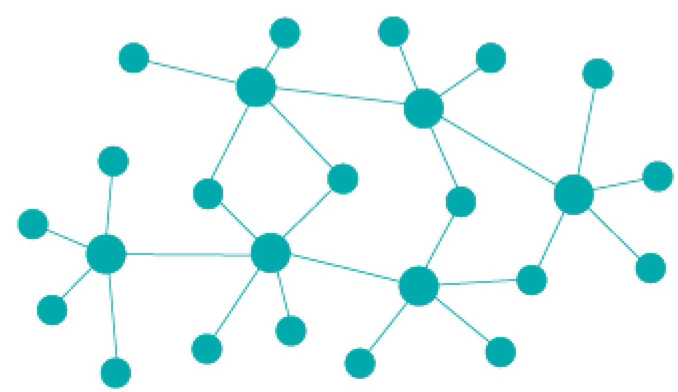
- Grey Systems Theory (GST) is concerned with the study of uncertain systems with partially known information.
- The information samples can be small and poor in quality with high noise.
- GST aims to extract useful information from the available limited information.
- The Grey Model of First Order and One Variable – GM(1,1) is used.
- Values from 3 previous time steps and the current time step are utilized to predict the value of the variable in the next time step.
- It is used to predict solar irradiation (PV output), wind speed (Wind turbine output) and power consumption.

Centralized Energy Management in microgrids

- Centralized supervisory management and control systems are hierarchical systems, where the central controller resides on the highest level of the hierarchy pyramid and acts as an overall system manager.
- The control of large scale power systems is, usually, performed through a centralized supervisory control and data acquisition system (SCADA).
- The existing lower level controllers gather operational data, send it to the main controller, which in turn after processing the data, sends out operation commands to the lower level controllers and takes the final decisions.

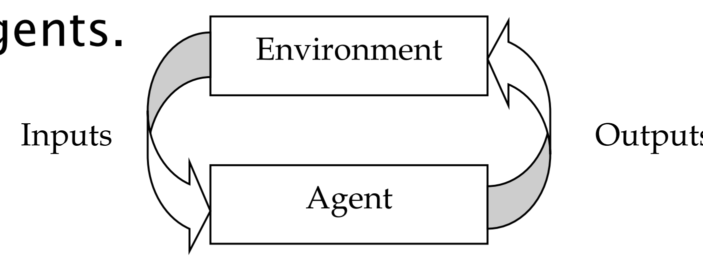
Decentralized Energy Management in microgrids

- A decentralized management and control system, is based on a network of autonomous local controllers, each responsible for a component of the system, without the existence of a single main controller
- Each component of the system must be equipped with a control unit in a decentralized architecture.
- The controllers can communicate and negotiate directly between each other in order to achieve their goals without a central influence.
- One of the main advantages of a decentralized approach is the high reliability of the system. In the case of a controller failure, the rest of the system can still operate in part and not affect the whole system's performance.

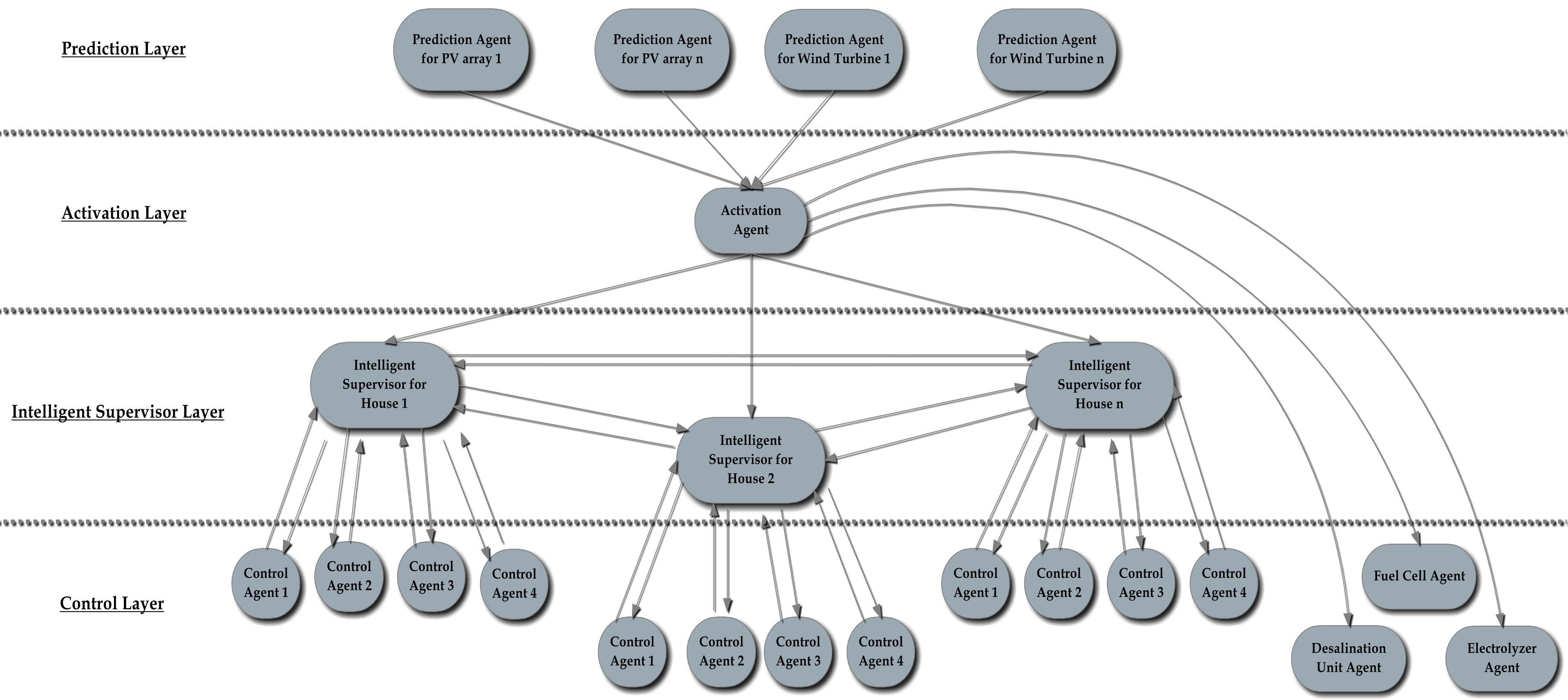


Multi Agent Systems

- *An agent is a computer system situated in some environment and that is capable of autonomous action in this environment in order to meet its design objectives*.
- Distributed Artificial Intelligence (DAI) can be described as "*the study, construction and application of multiagent systems, that is, systems in which several interacting intelligent agents pursue some set of goals or perform some set tasks*"
- An agent needs to be reactive, proactive and social in order to be considered as intelligent.
  - Reactivity means that the agent must be aware of its environment and to respond to the inputs from the environment according to its design and programming.
  - Proactivity of an intelligent agent can be described as the ability to take initiative in acting in a way to fulfill its design objectives.
  - Social ability finally can be described as the ability to cooperate with other intelligent agents or even humans in order to fulfill its design objectives.
- A Multi-Agent System (MAS) can be defined as a system that comprises of a number of intelligent agents.



Intelligent Demand Side Management System structure



Particle Swarm Optimization (PSO)

- PSO is a stochastic optimization technique modeled after the social behavior of members of bird flocking or fish schools and swarming in general.
- PSO algorithms use a set of potential solutions for the optimization procedure.
- Each such solution is called particle and the set in a given iteration step is called a population.
- PSO is
  - an efficient global optimizer for continuous and discrete variable problems,
  - easily implemented, with very little parameters to fine-tune,
  - insensitive to scaling of design variables,
  - derivative free,
  - very efficient global search algorithm
  - Accommodating to constraints by using a penalty method.

Sizing through Optimization

- A common approach used is the direct comparison through an objective function of all possible parameter combinations.
- The objective function usually takes the form of a monetary cost function namely the net present cost for each system.
- The systems that fulfill all the technical constraints are compared and the one with the minimum cost is chosen.
- In polygeneration systems a big number of variables need to be optimized at the same time (e.g. pv power, wind turbine power, battery bank capacity, electrolyzer power, fuel cell power, hydrogen storage volume, etc.). The combinations of all possible values for all parameters to be can easily reach very high numbers. Eg. For 10 variables with 10 possible discrete values the combinations would be 10^{10}.
- Particle Swarm Optimization can solve such a problem.

Software

TRNSYS 17

GenOpt

Generic Optimization Program

TESS

Experts in Energy Modeling & Analysis

MATLAB

The MathWorks

NATIONAL INSTRUMENTS

LabVIEW

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Thank you for your attention!

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