Implementation of a Fully-automated Optimized Fog-computing Based IoT-controlled PV Network*

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- Ph.D. Stanford University, EE/CS, Jan. 1978
- IBM T.J. Watson Reseatrch Center, Yorktown Heights, NY, Dec. 1977 - Aug. 1979
- Yarmouk University, Jordan, Sept. 1979 – Aug. 1986 (Founder of 1st Computer C.)
- Jordan University of Science and Technology, Sept. 1986 – present (Chair, Dean, VP)
- UN scholarship, 2 x Fulbright, Alexander-von-Humboldt, YU award, Shuman prize, …
- Founder and Director, National Tempus/Erasmus+ Office, since 2003 (Coop w EU)
- Founder and Chairman, Specto Ltd., since 2005 (capacity building in IT Skills)
- Consultant UNESCO, World Bank, ITU, Islamic Development Bank, etc.

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IoT & Smart Grid

- What is IoT?
  - Augment the Internet with new connected things
  - Move local network of connected objects to cloud
  - Gain insights about objects, analyze, automate, and optimize
- How it relates to Smart Grid?
  - Can be used to get full visibility of grid
  - Solve problems:
    - Energy management
    - Control generation, distribution, RES integration
  - Make more efficient, reliable, and sustainable

Contributions

- A detailed implementation of IoT for a two PV systems:
  - Sensor Node
  - Gateway (Edge Node)
  - Fog Node
- Evaluate the setup with load swapping algorithm
- Make codes available at github for similar works

Related Work

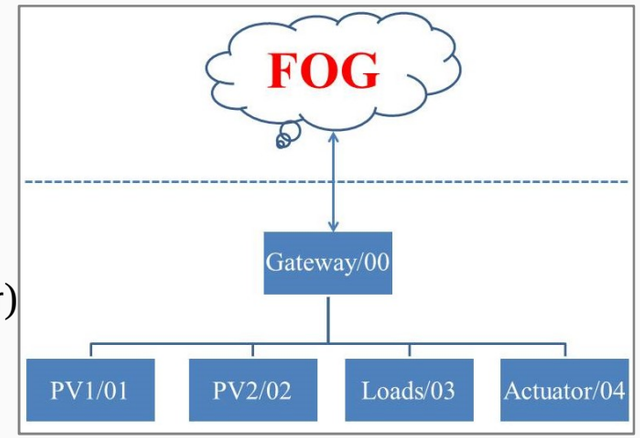
- In the IoT domain [1]:
  - Monitoring domestic conditions (i.e. temperature, light intensity)
  - ZigBee-based WSN
  - MySQL database, PHP and JavaScript.
- In the smart grid domain [2]:
  - Energy management algorithm
  - Match output power to load for PV and wind energy system

[1] S. D. T. Kelly, N. K. Suryadevara, and S. C. Mukhopadhyay, "Towards the implementation of IoT for environmental condition monitoring in homes," IEEE Sensors J., vol. 13, no. 10, p. 3846–3853, Oct. 2013

[2] M. Kumar, A. F. Minai, A. A. Khan, and S. Kumar, "IoT based energy management system for smart grid," in Int. Conf. Adv. Comput., Commun. Mater. (ICACCM), pp. 121–125, Aug. 2020.

Implementation Setup - Sensor Nodes

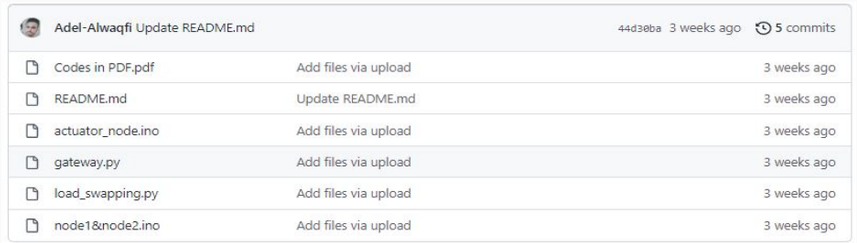
- PV1 and PV2:
  - UNO microcontroller unit (MCU)
  - LM7805 (linear voltage regulator)
  - three ACS712 (measure DC current)
  - DC voltage-divider sensor
  - ZMPT101 (measure AC voltage)
  - nRF24L01+ (wireless communication transceiver)
- Loads:
  - UNO MCU, four ACS712, nRF24L01+
- Actuator:
  - UNO MCU, eight SSR-40DA, nRF24L01+



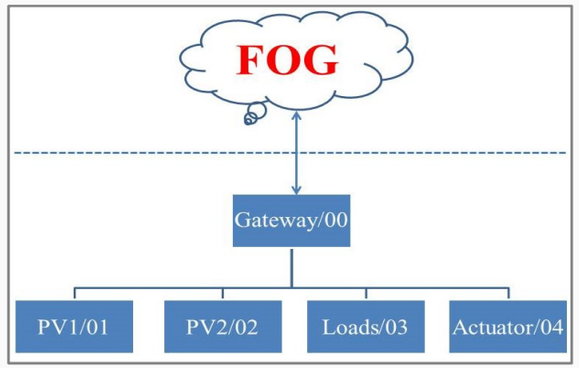
WSN Tree Topology

Implementation Setup - Gateway

- Gateway:
  - RPi 4
  - nRF24L01+
  - Our gateway code as a github repository [3]



Github Code Repository

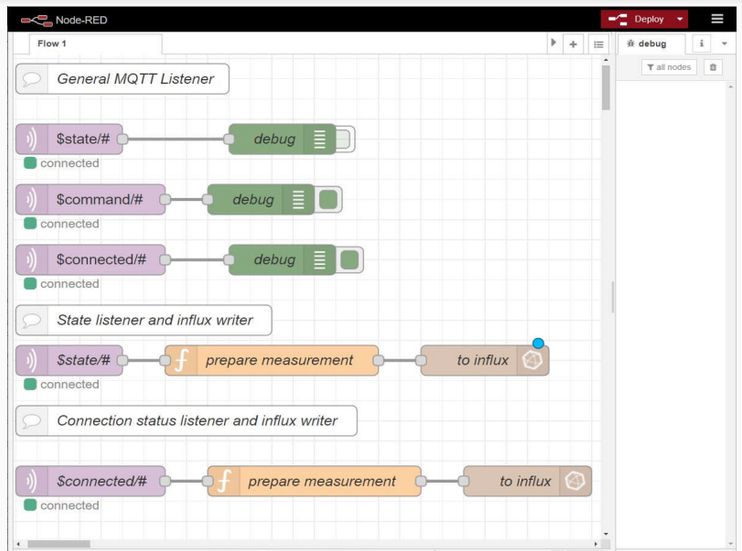


WSN Tree Topology

[3] A. M. AlWaqfi, Implementation Codes, https://github.com/Adel-Alwaqfi/Implementation-of-a-Fully-automated-Optimized-Fog-computing-based-IoT-controlled-PV-Network

Implementation Setup - Fog Node - NodeRED

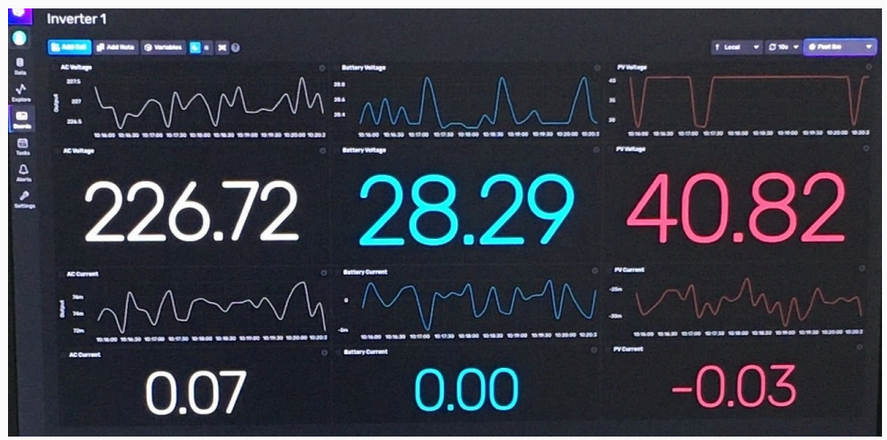
- NodeRED:
  - Middleware between backend and frontend
  - Event-driven
  - Needs almost zero code
  - User-friendly interface for deployment



NodeRED Interface

Implementation Setup - Fog Node - InfluxDB

- InfluxDB:
  - Schemaless database
  - Suitable for real-time IoT data
  - Lightweight scripting language, FLUX
  - Built-in interface for:
    - Explore data
    - Build dashboards
    - Schedule tasks on data
    - Rich mathematical tools for manipulation of raw data

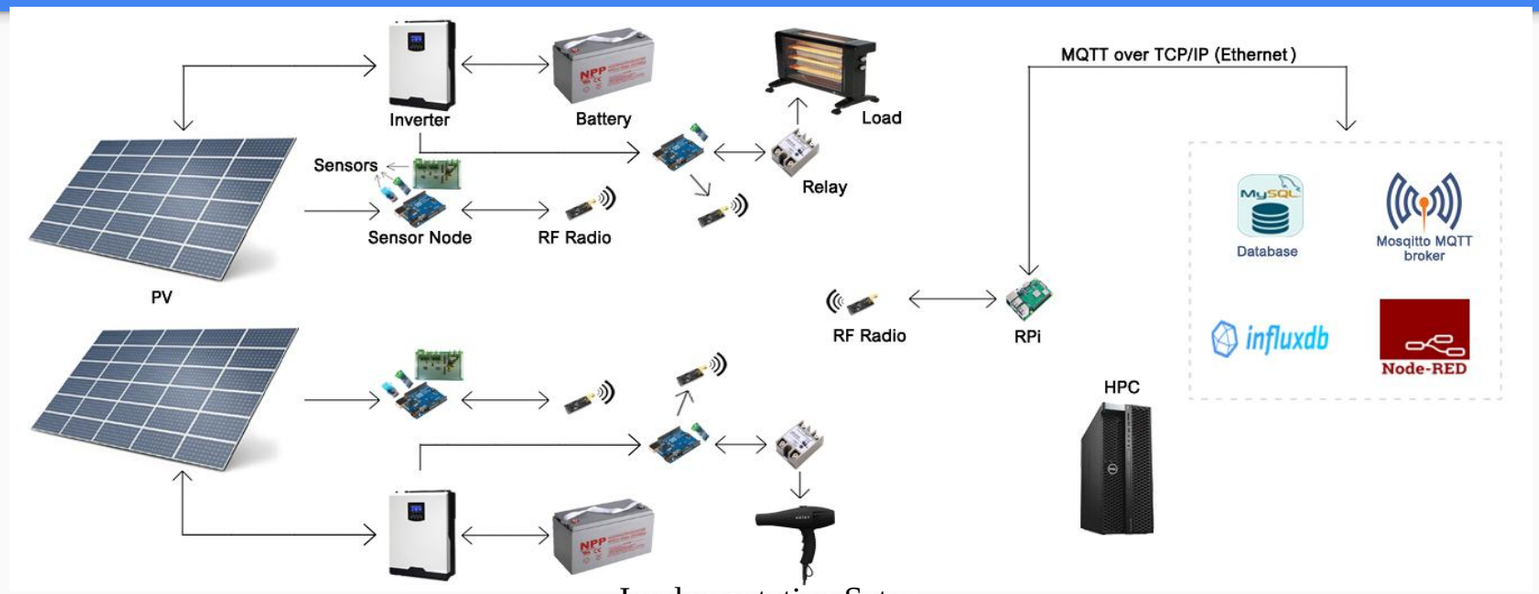


InfluxDB Example Dashboard

Setup properties

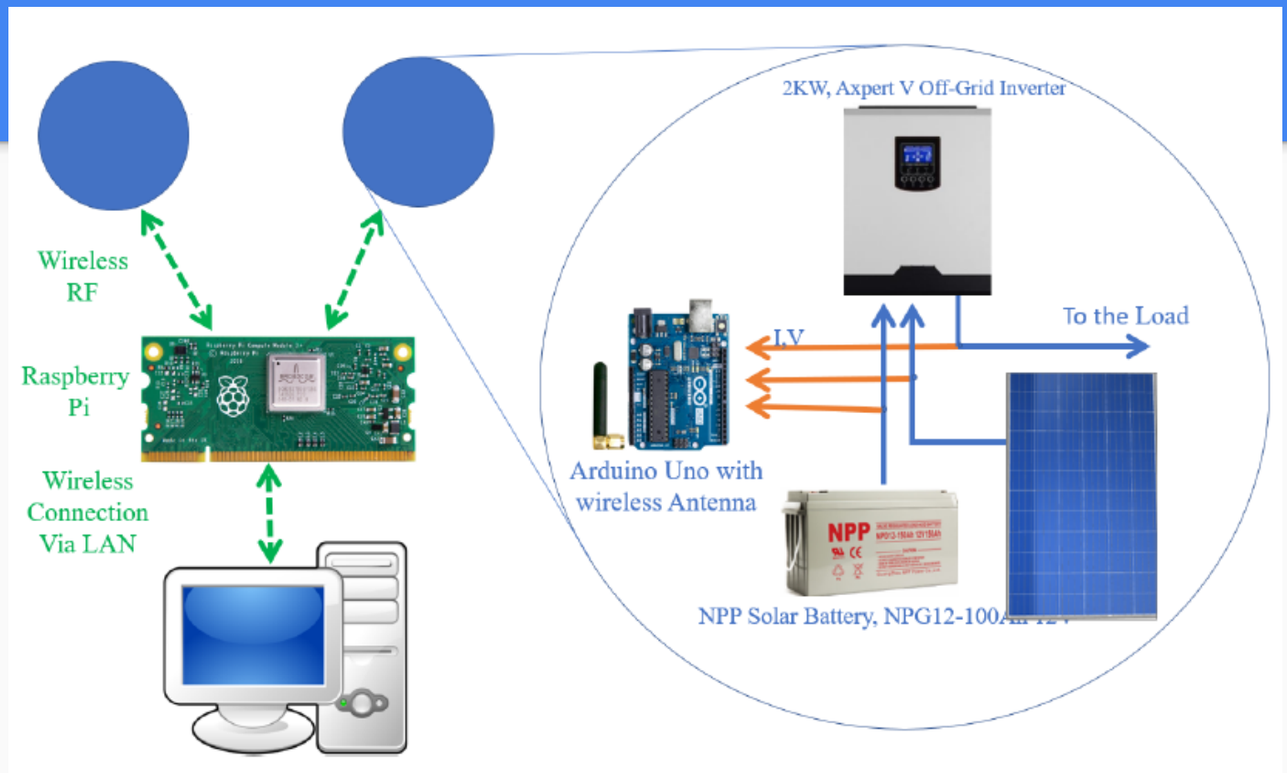
- Our setup:
  - Combines reliable and networked NRF24-based local WSN
  - Powerful edge with MQTT
  - Structured SQL with dynamic time-series influxDB
  - Illustrate whole IoT cycle of data:
    - Data generation (i.e., sensing)
    - Fog response and actuation
    - WSN provisioning
    - Channeling and storing data
    - Query data and algorithm deployment

Implementation Setup - Overview



Implementation Setup

Experimental Setup Schematic Diagram



Experimental Setup Front and Rear Views

(a) Front View

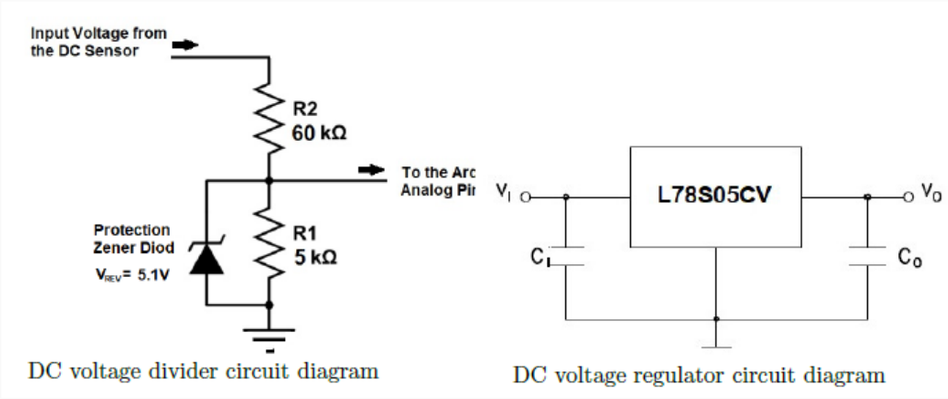
(b) Rear View

Inverter and Batteries Enclosure

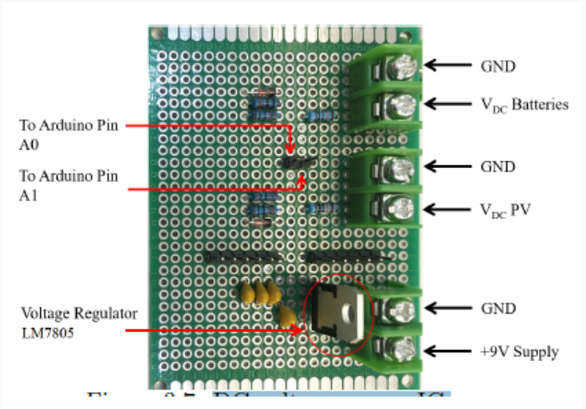
PV setup on the roof of HTU

RF Radio

DC voltage sensor, circuit diagrams and IC



The used DC voltage divider and regulator circuit diagrams



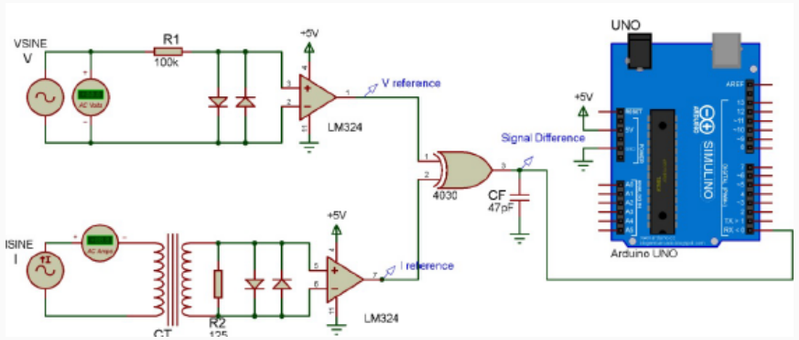
DC voltage sensor IC

Used voltage and current sensors

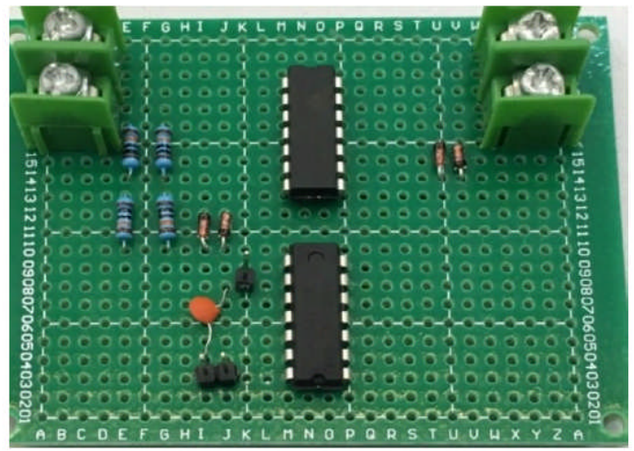
AC voltage sensor
ZMPT101B

Current sensor
ACS712

Power Factor schematic diagram and board

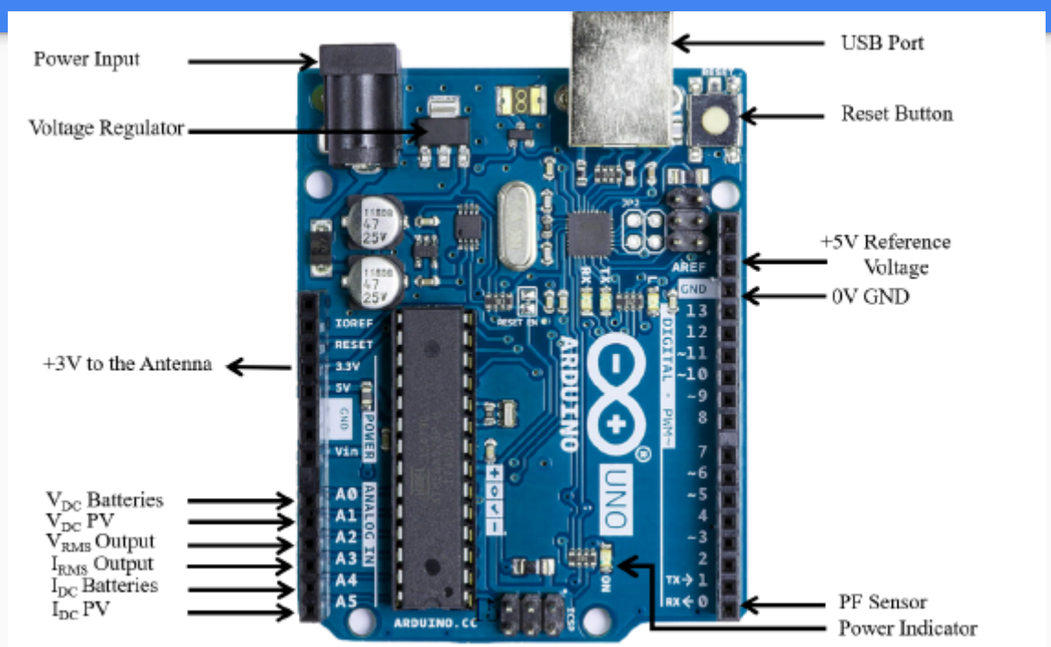


PF schematic circuit diagram

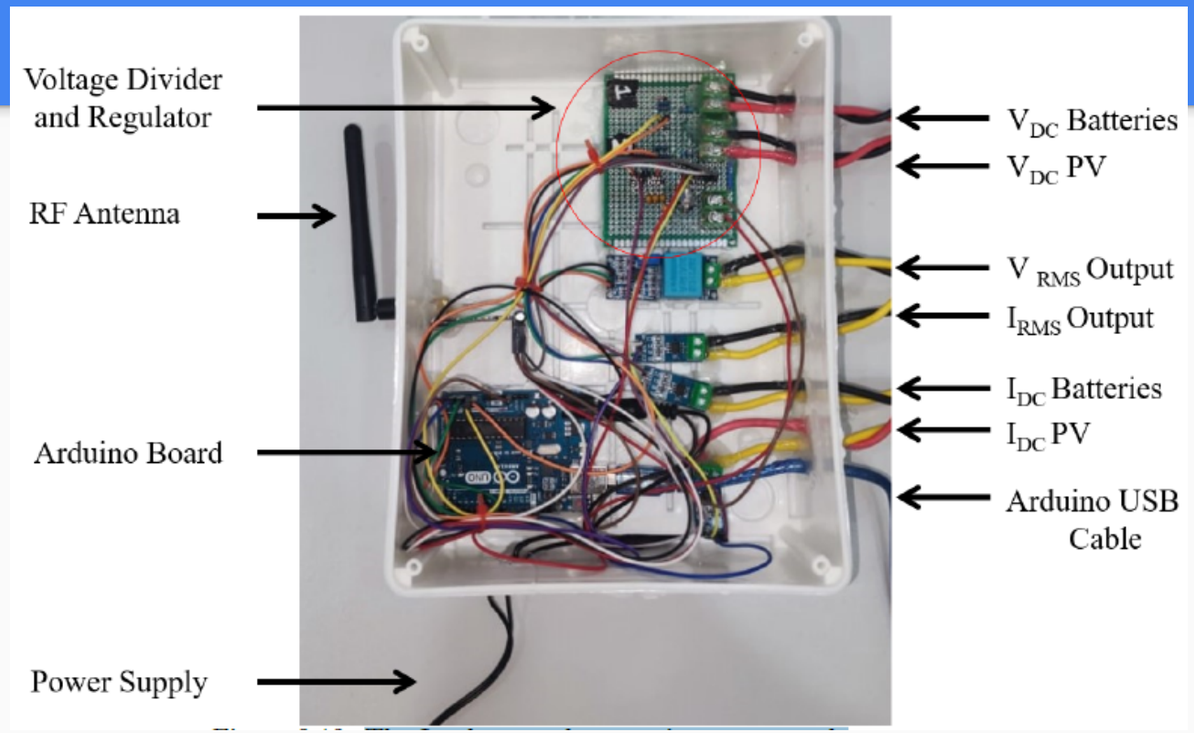


Power factor board

Arduino Uno board wiring



The implemented measuring sensor node

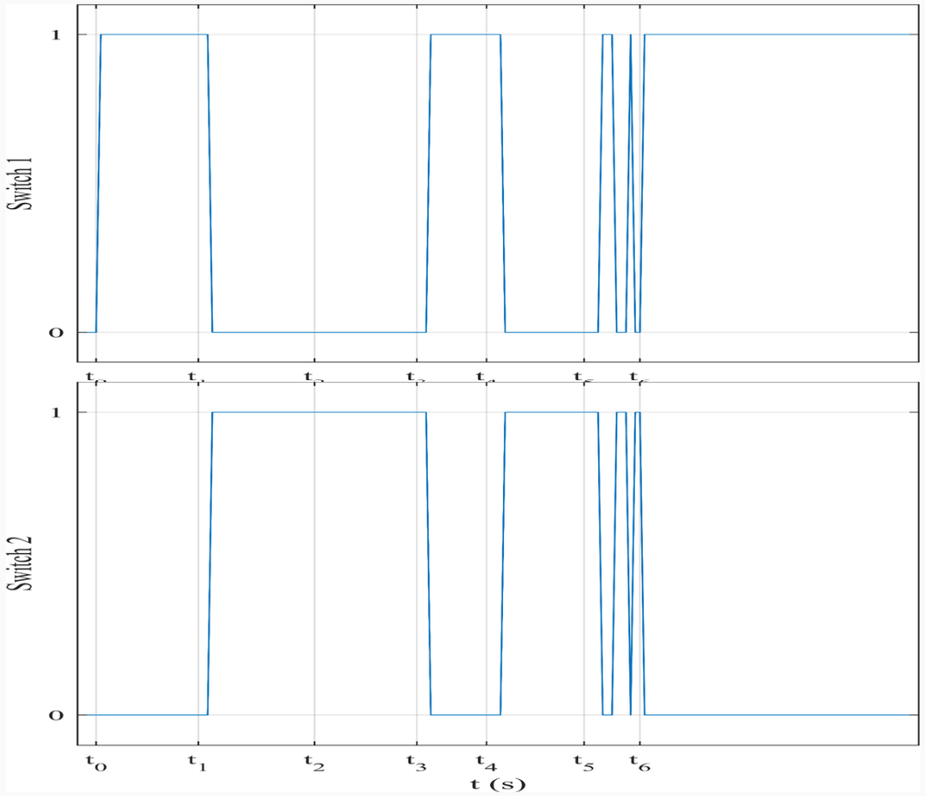


HPC (fog node) in WiNS Lab

Load Swapping Algorithm

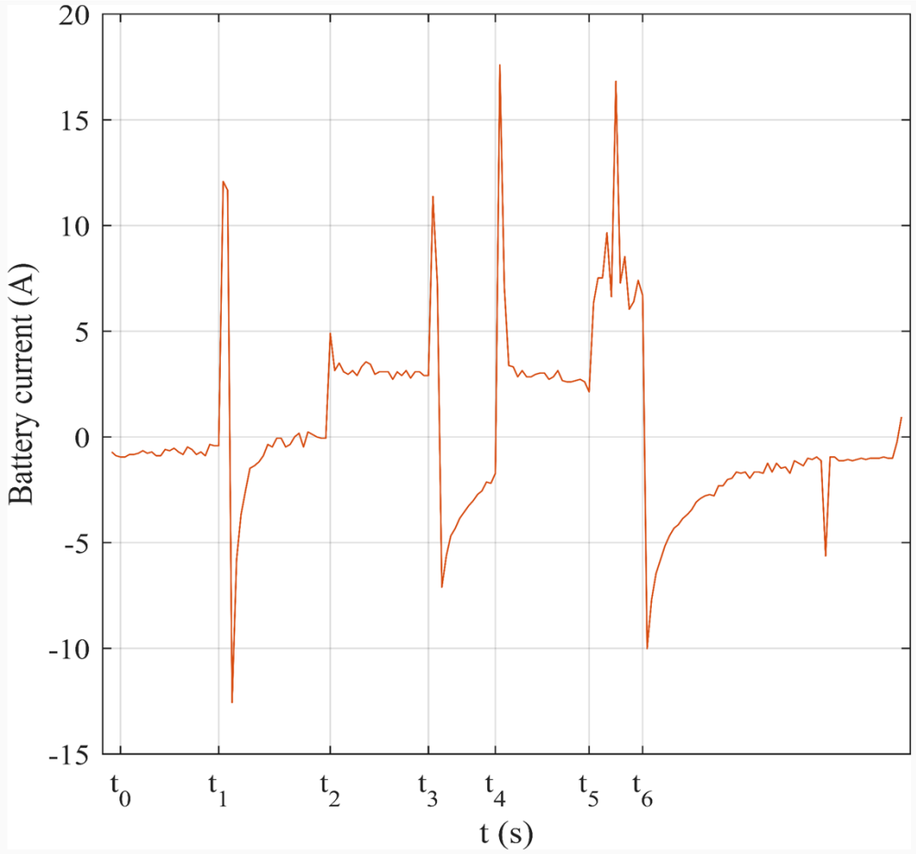
Input: I_b, I_o, $I_{\text{th},b}$, $I_{\text{th},o}$, τ_{delay}, and N.
Output: x_l, $\forall l \in \mathcal{L}$.
for $i = 1 : N$ **do**
    Set $x_0 = 1$ and unset $x_1 = 0$.
    Wait for τ_{delay}.
    Query latest I_b and I_o from database.
    while $I_b \leq I_{\text{th},b}$ **or** $I_o \leq I_{\text{th},o}$ **do**
        Wait for τ_{delay}.
        Query latest I_b and I_o from database.
    end while
    Unset $x_0 = 0$ and set $x_1 = 1$.
end for

Performance Evaluation



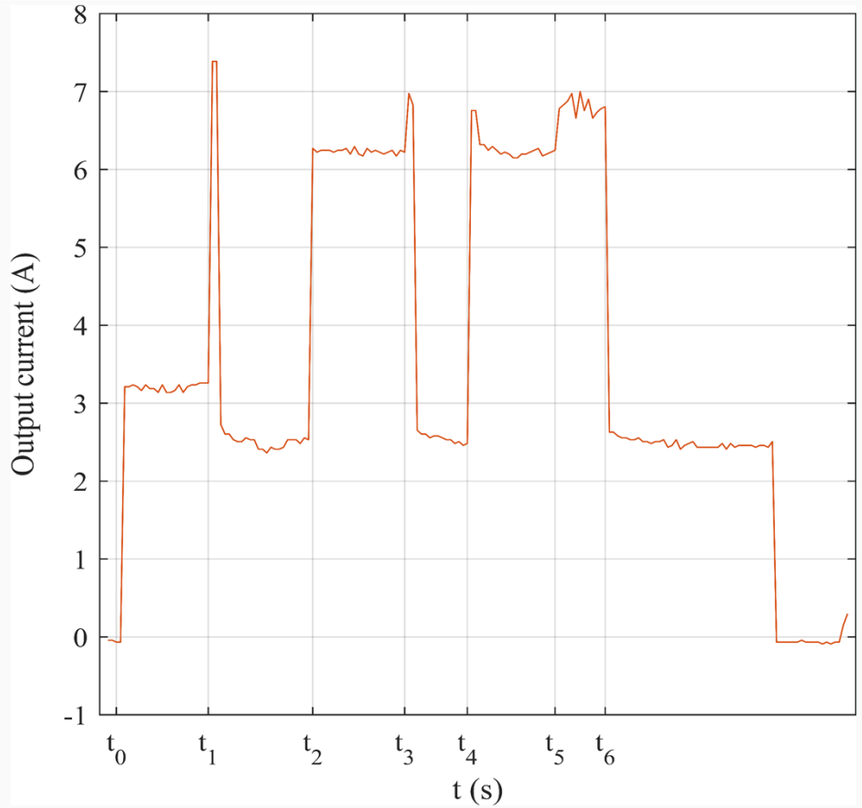
State of Switch 1 and Switch 2 during the testing period

Performance Evaluation



Battery current (Ampere DC) during the testing period

Performance Evaluation



Load current (Ampere, RMS) during the testing period

Conclusion and Future Work

- We showed the whole IoT stack integration
- Validated the work with the load swapping algorithm
- Our work can be used as a base to solve similar problems:
  - Load scheduling
  - Energy cost optimization
  - Energy routing

Thank You