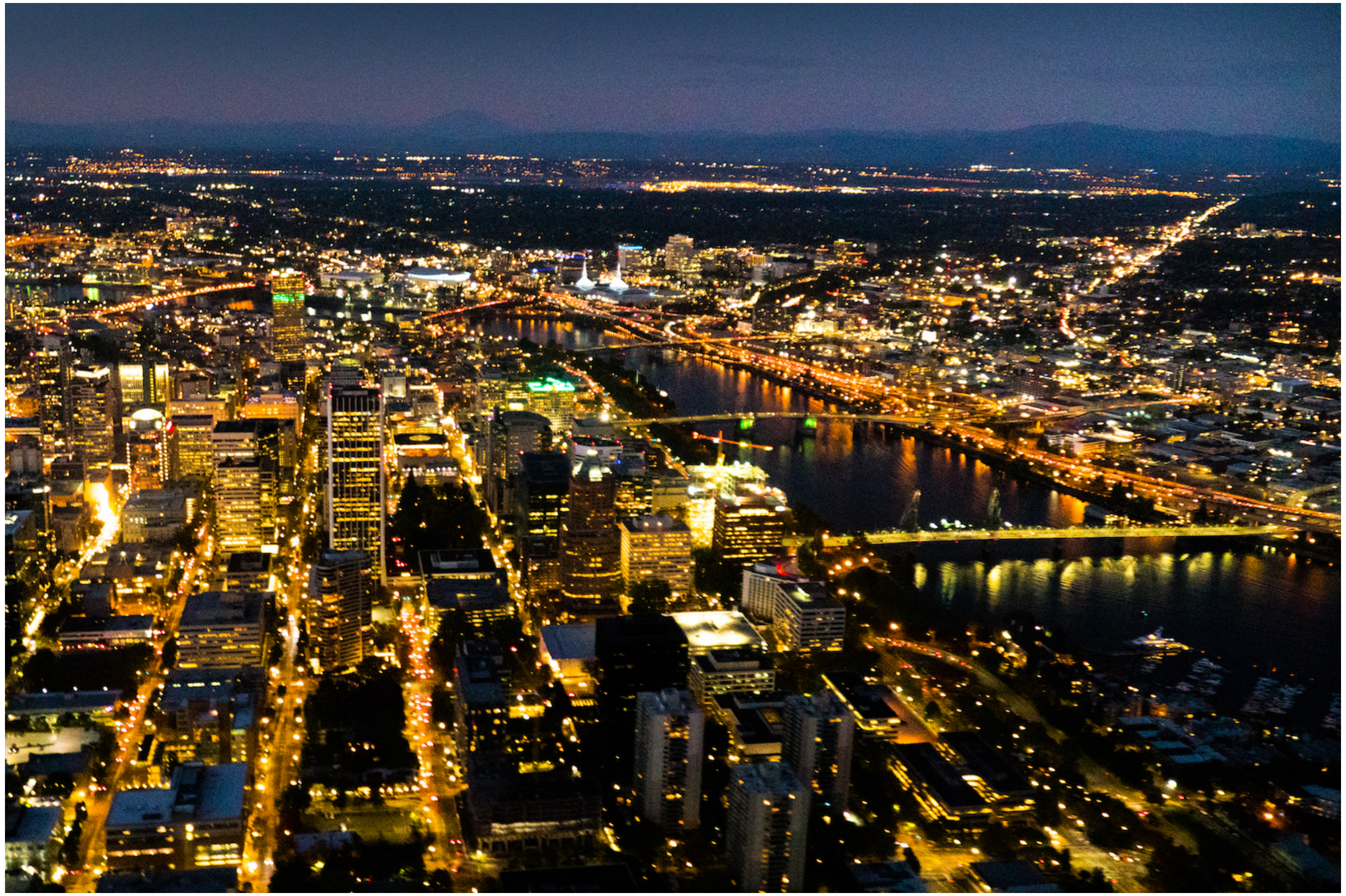
# Stepping into Helping the Power Grid

Directions, Concentrations and Challenges

# Power Systems



Expectations:

- Safe
- Reliable – Adequacy and Security
    - Minimal to no outages
    - High power quality

- Affordable

# Clean Reliable Power Systems vs our Reality


# Challenges

- Aging of infrastructure and load increase
    - the tension between reliability and cost
    - Site permits and environmental challenges
- Retiring Mass Generations due to aging or environmental policies
- Introduced Renewable Energy Sources to decrease $CO_2$ footprint

- Growth in system reliability concerns
    - Uncertainty
    - Inadequacy
- Growth in system complexity

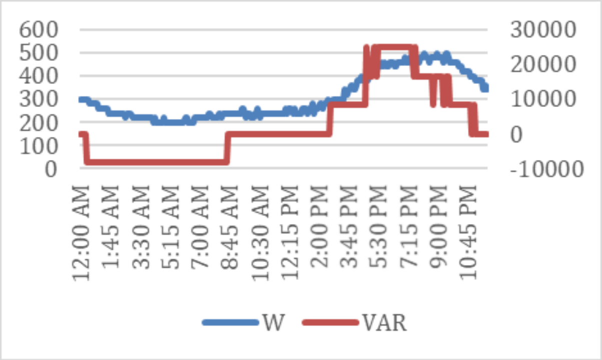
# Distribution Grid Challenges

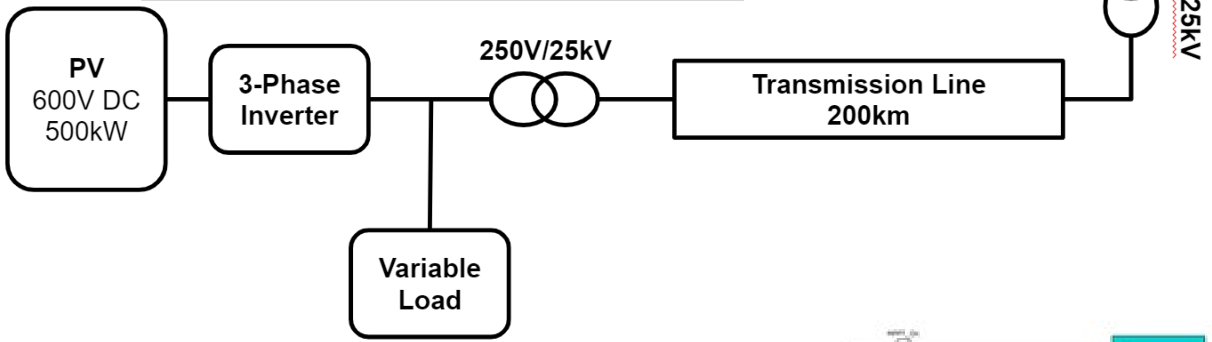
- RES over generation will cause really high voltages along the feeder
- Bidirectional power flow and protection equipment mal-function
- Voltage regulators and shunt capacitors may experience too many operations
- Voltage regulators functionalities are designed based on uni-directional power flow and they may present mal-function when dealing with bi-directional power flow.

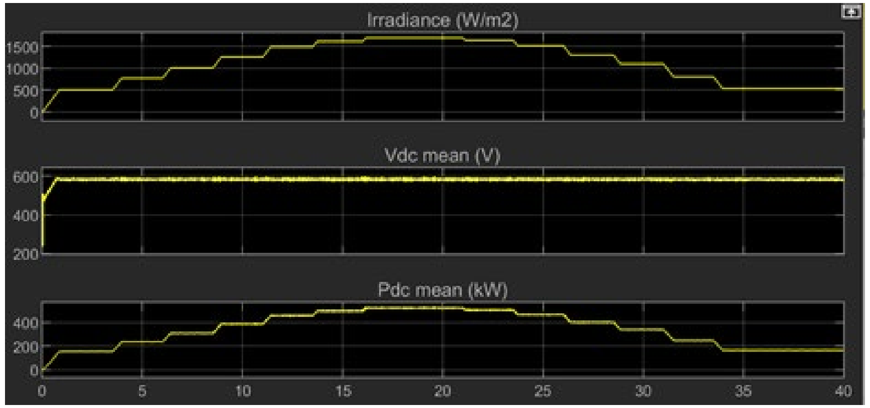
# Senior Design Projects

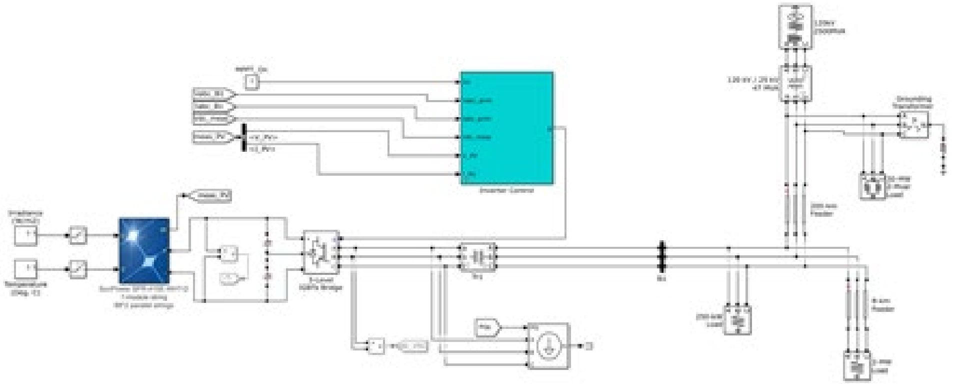
- Smart Inverters and Volt Var Optimization
- Scalable High Density Piezoelectric Energy Harvesting System from Roadway Traffic
- Optimized and Coordinated Charging Methods for Electric Vehicles Cost
- Distribution Systems Dynamic Service Restoration Utilizing Load Curves
- Frequency dependent line modeling and equipment sizing
- Flywheel Energy Storage
- Power system stability evaluation with mass free productions
- Fire in California the cause and solution
- …..

# Smart Inverters and Volt Var Optimization



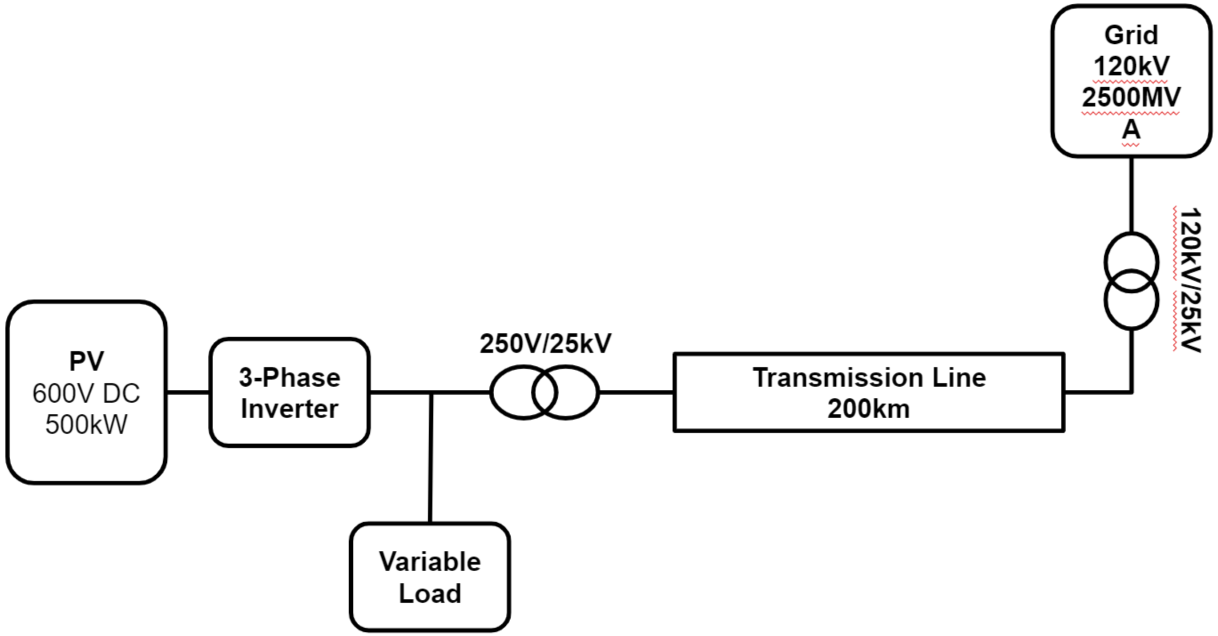



Rule 21

IEEE 1457

# Smart Inverters and Volt Var Optimization




$$Q = \frac{3}{2} \times \left(V_q \cdot I_d - V_d \cdot I_q\right)$$

The targeted VAR is noted as:

$$Q^* = Q_{meas} + \Delta Q$$

$$\frac{3}{2} \times \left(V_q \cdot I_d - V_d^* \cdot I_q\right) = \frac{3}{2} \times \left(V_q \cdot I_d - V_d \cdot I_q\right) + \Delta Q$$

$$\Delta Q = \frac{3}{2} \times I_q\left(V_q - V_d^*\right)$$

Iq_ref is found with the following:

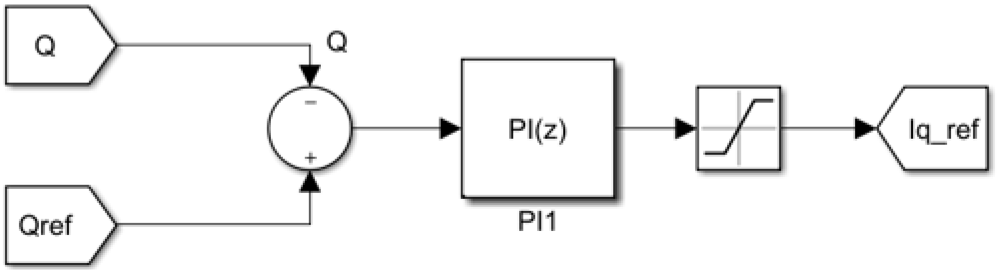



*Figure 9 - Iq_ref Model*

# Scalable High Density Piezoelectric Energy Harvesting System from Roadway Traffic

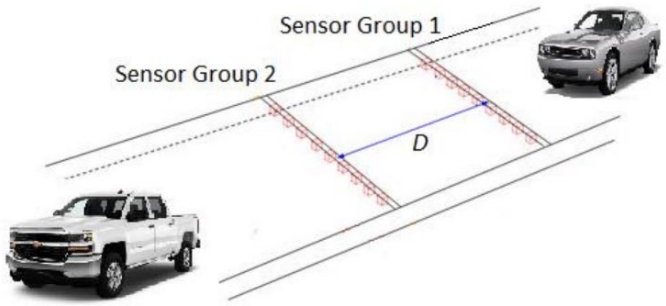



*Figure 1– Road with PZT Sensors*

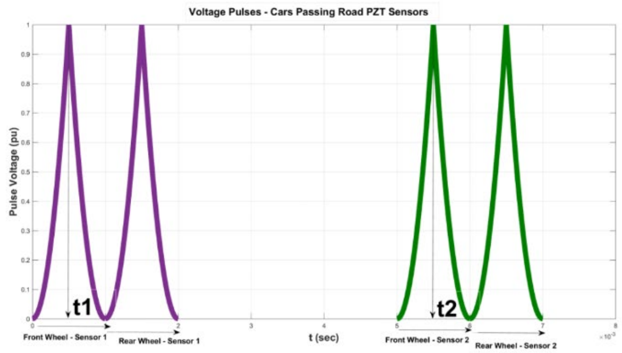
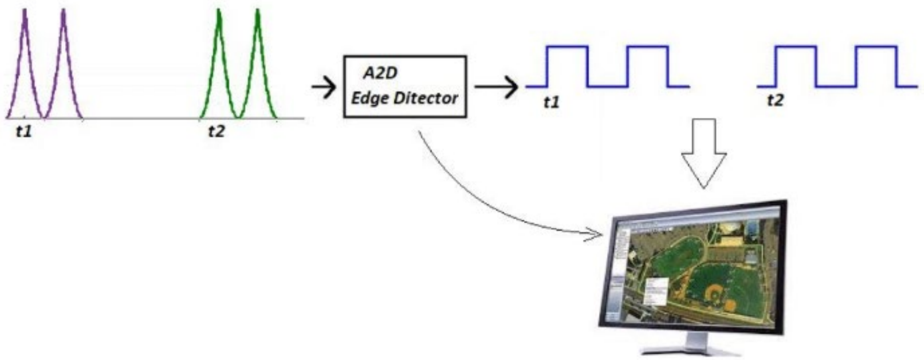
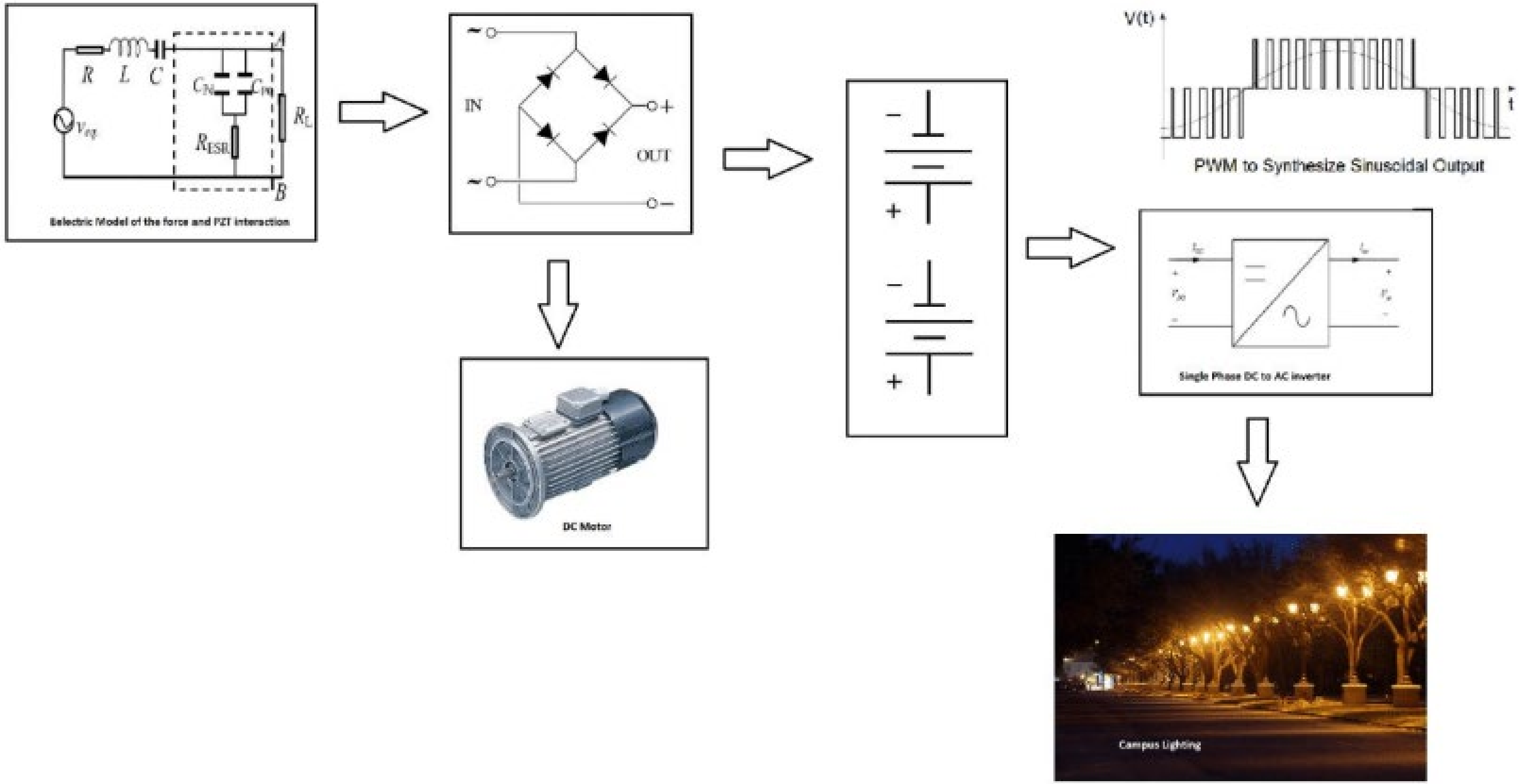


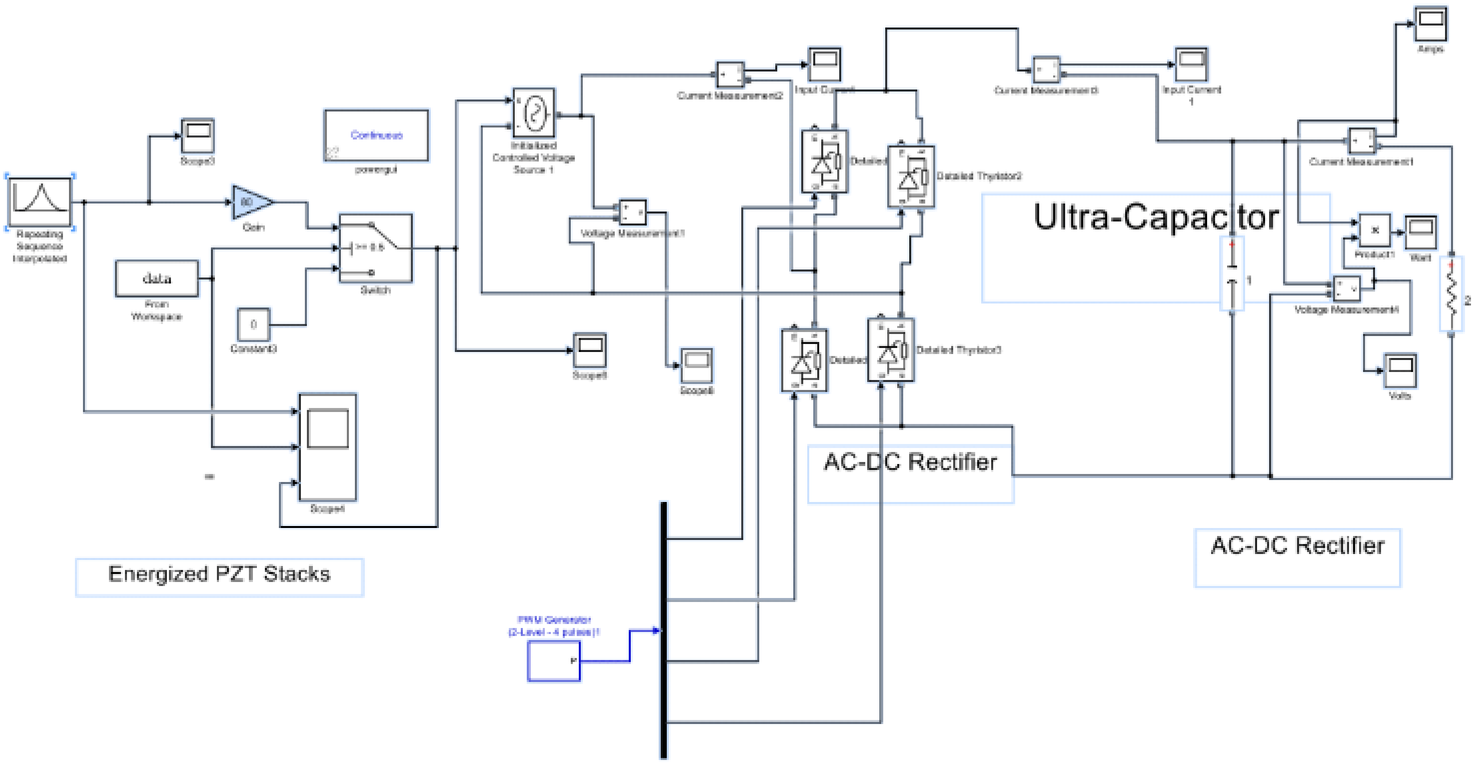

Figure 2– Voltage Pulse in pu




# Scalable High Density Piezoelectric Energy Harvesting System from Roadway Traffic



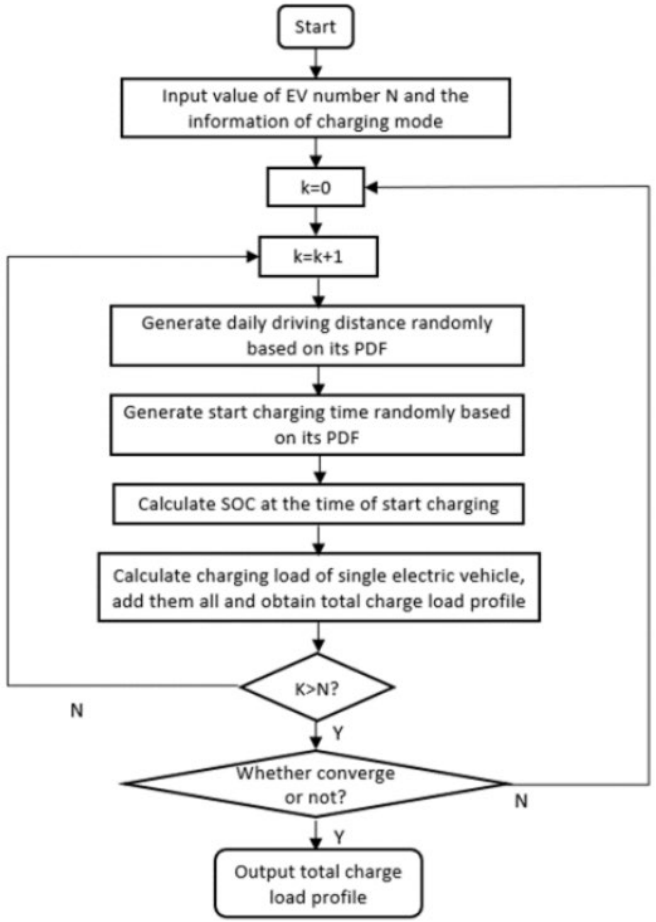
# Scalable High Density Piezoelectric Energy Harvesting System from Roadway Traffic



# Optimized and Coordinated Charging Methods for Electric Vehicles Cost

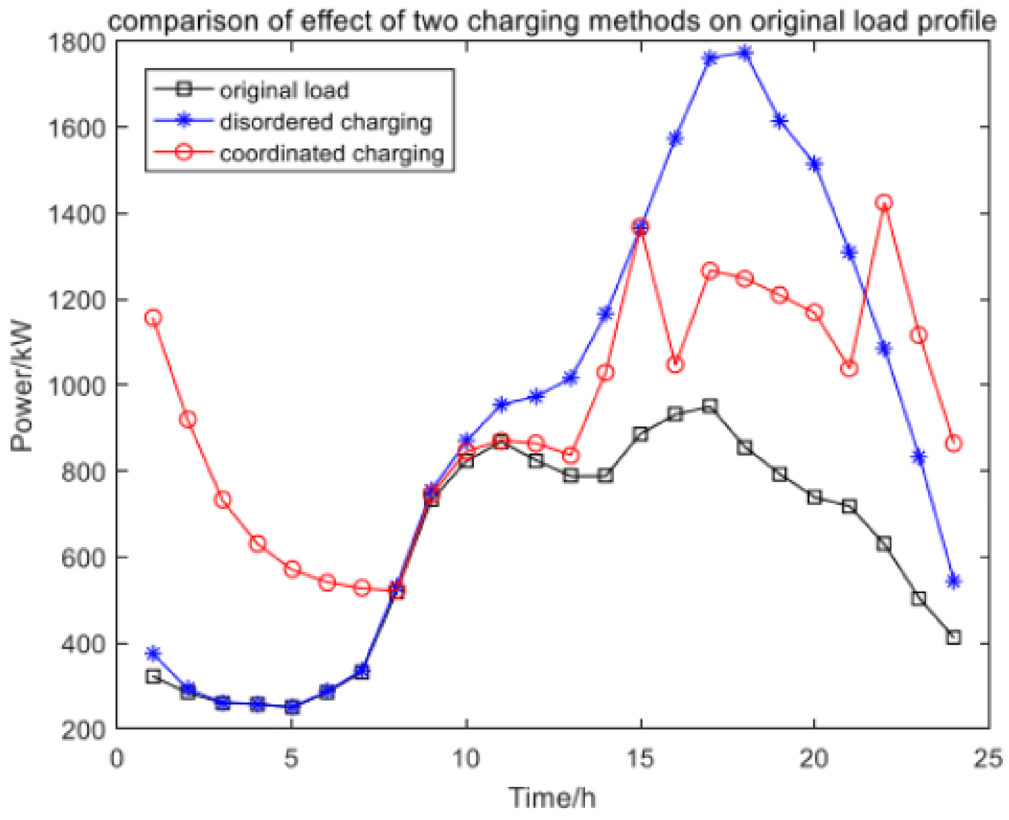
- Start time distribution function

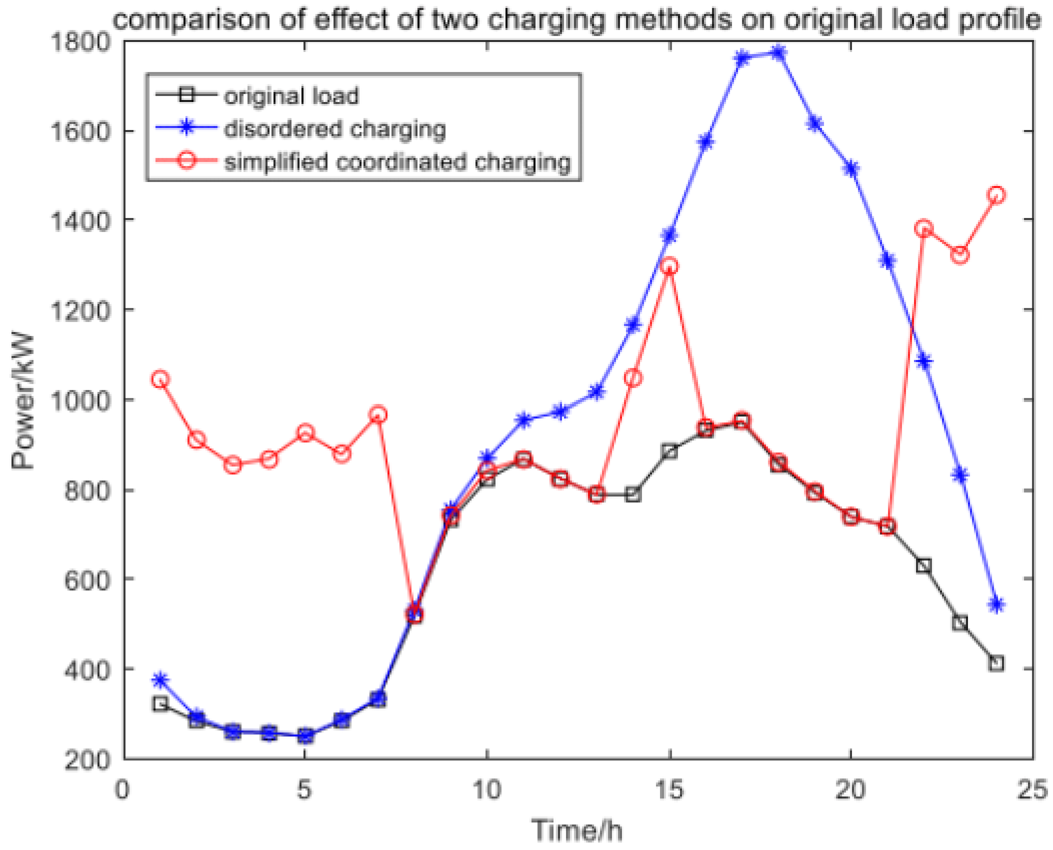
$$f_s(x) = \begin{cases} \frac{1}{\sigma_S\sqrt{2\pi}} \exp\left(-\frac{(x-\mu_S)^2}{2\sigma_S^2}\right), \mu_s - 12 \le x \le 24 \\ \frac{1}{\sigma_S\sqrt{2\pi}} \exp\left(-\frac{(x+24-\mu_S)^2}{2\sigma_S^2}\right), 0 \le x \le \mu_s - 12 \end{cases}$$




SOC
Type of Car
Type of Charge
Mileage of drive
Life style

# Optimized and Coordinated Charging Methods for Electric Vehicles Cost



# Distribution Systems Dynamic Service Restoration Utilizing Load Curves

- Optimization Process to find candidate networks for reducing frequency and duration of customer interruptions.
- Minimizing total loss of load
- Minimizing total number of switchings

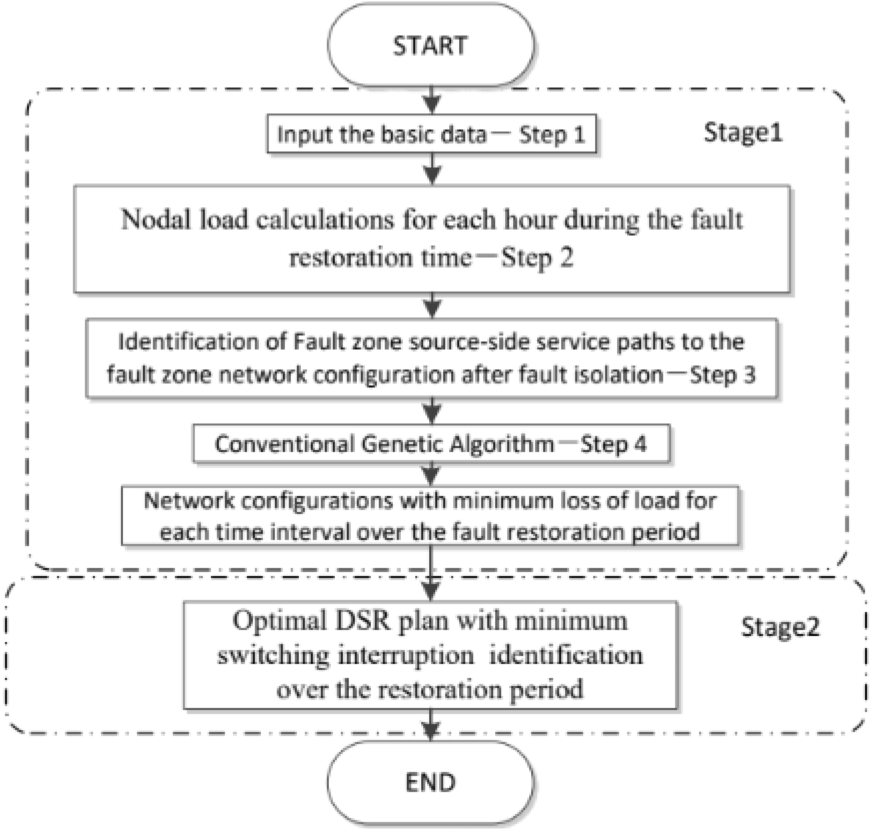



Figure 1. Flowchart of DSR method

# Distribution Systems Dynamic Service Restoration Utilizing Load Curves

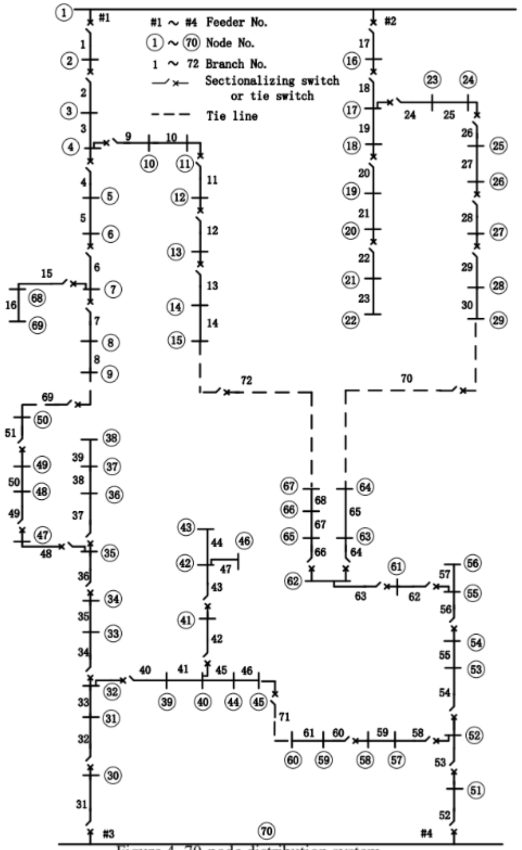


Figure 4. 70-node distribution system

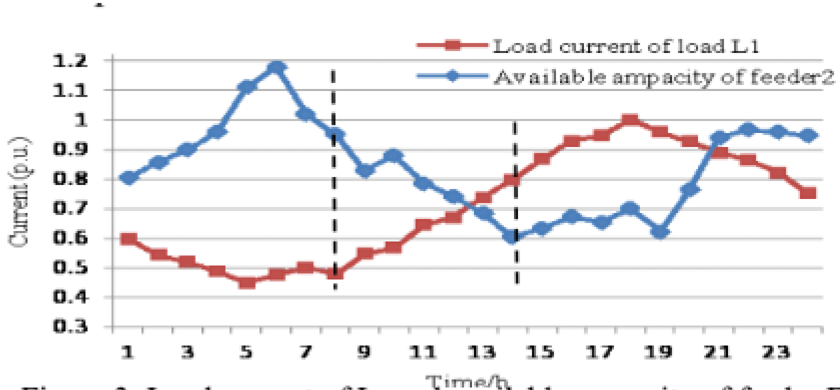


Figure 3. Load current of $L_1$ and available ampacity of feeder $F_2$ in each time interval

# Frequency dependent line modeling and equipment sizing

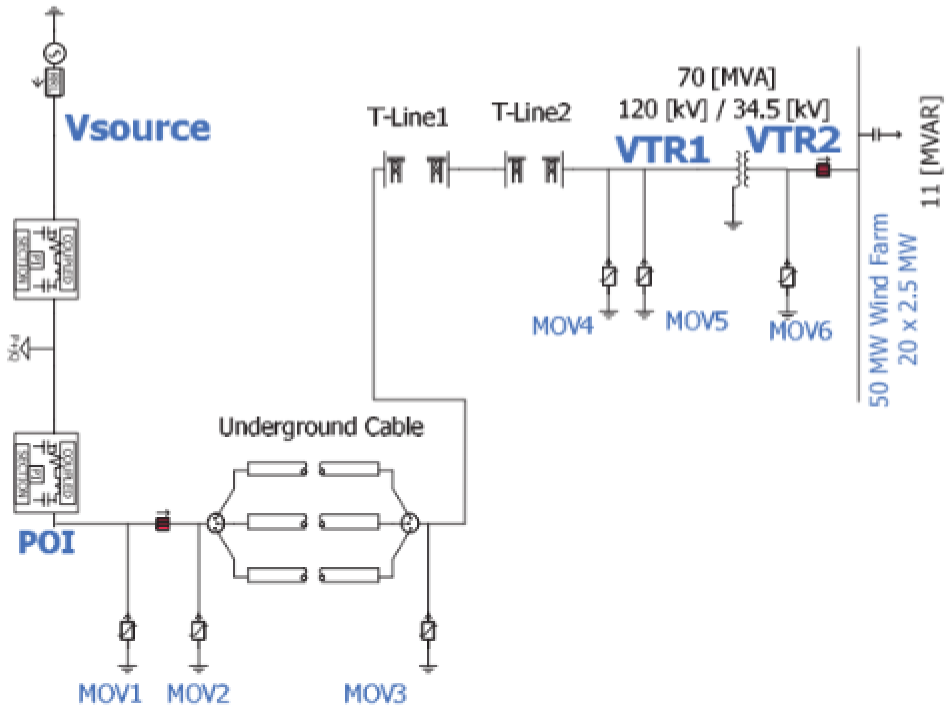
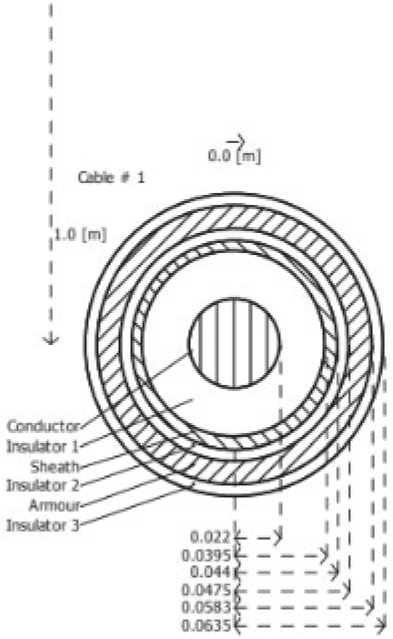
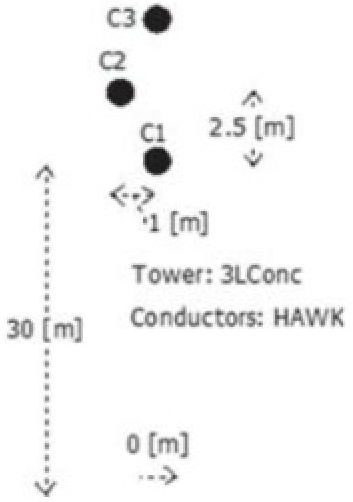



Figure 1- modeled wind farm interconnection to transmission system

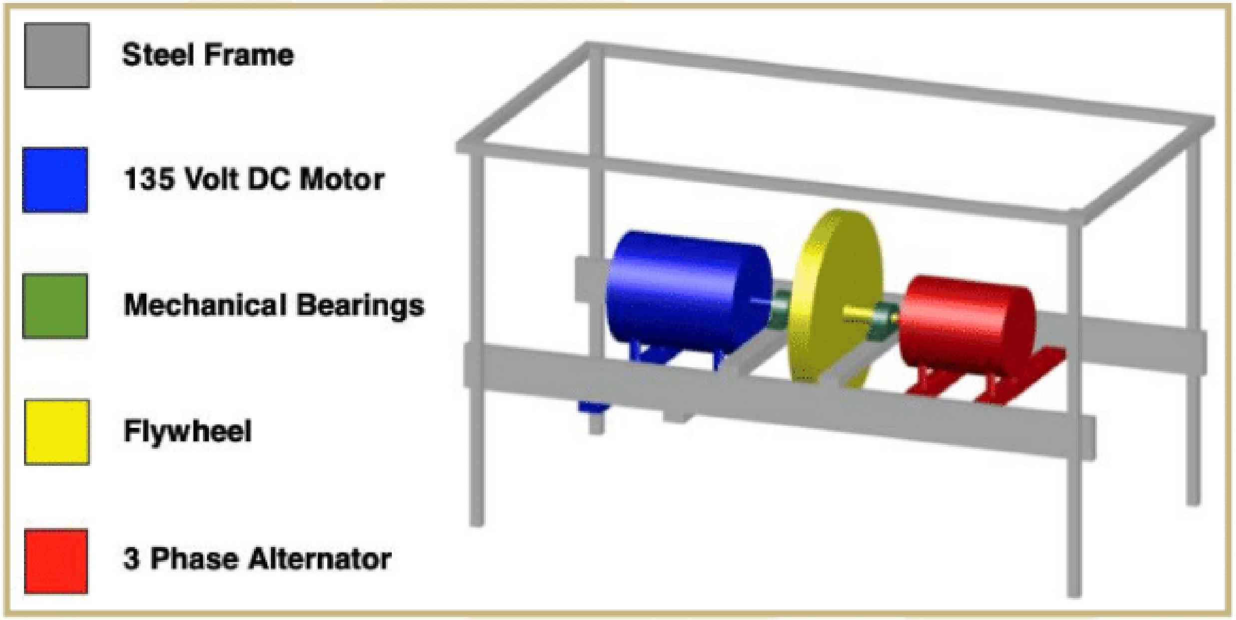


# Frequency dependent line modeling and equipment sizing

| | Impulse applied to Phase A of T-Line 1 | | Impulse applied to Phase A, Primary side of the transformer |
|---|---|---|---|
| **Measurement Point** | **Maximum TOV with 4 MOVs (kV)** | **Maximum TOV with 6 MOVs (kV)** | **Maximum TOV with 6 MOVs (kV)** |
| **Vsource** | 160 | 155 | 141 |
| **POI** | 310 | 160 | 142 |
| **VTR1** | 340 | 220 | 205 |
| **VTR2** | 140 | 140 | 170 |

# Our Flywheel Energy Storage Design




Our group decided to design and build a small scale flywheel energy storage system. The above diagram represents the general design of our project. The DC Motor will be used to spin the Flywheel up to a speed of around 3600 RPM. We will then control the excitation voltage across the armature of the 3 Phase Alternator in order to generate a steady voltage across the alternator field windings. Whatever load is placed across the field windings will extract energy from the Flywheel therefore decreasing its RPM. The system will be used to power a replica house which will consist of general household appliances such as fans, lights, water pumps, etc. Our design will include implementations of concepts learned while completing our degree, such as voltage and current metering, power and efficiency calculations, as well as circuits learned in power electronics.

## Theoretical Calculations and Useful Equations

| RPM | Energy (Watts) | Energy (Watt-Hour) |
|---|---|---|
| 0 | - | - |
| 1 | 0.01 | 0.00 |
| 225 | 487.15 | 0.14 |
| 450 | 1,948.61 | 0.54 |
| 900 | 7,794.43 | 2.17 |
| 1800 | 31,177.74 | 8.66 |
| 3600 | 124,710.96 | 34.64 |

Volume = π•radius²•height ---------------------------------- 0.00834 [m³]

Mass = Density•Volume ---------------------------------------- 67.1659 [kg]

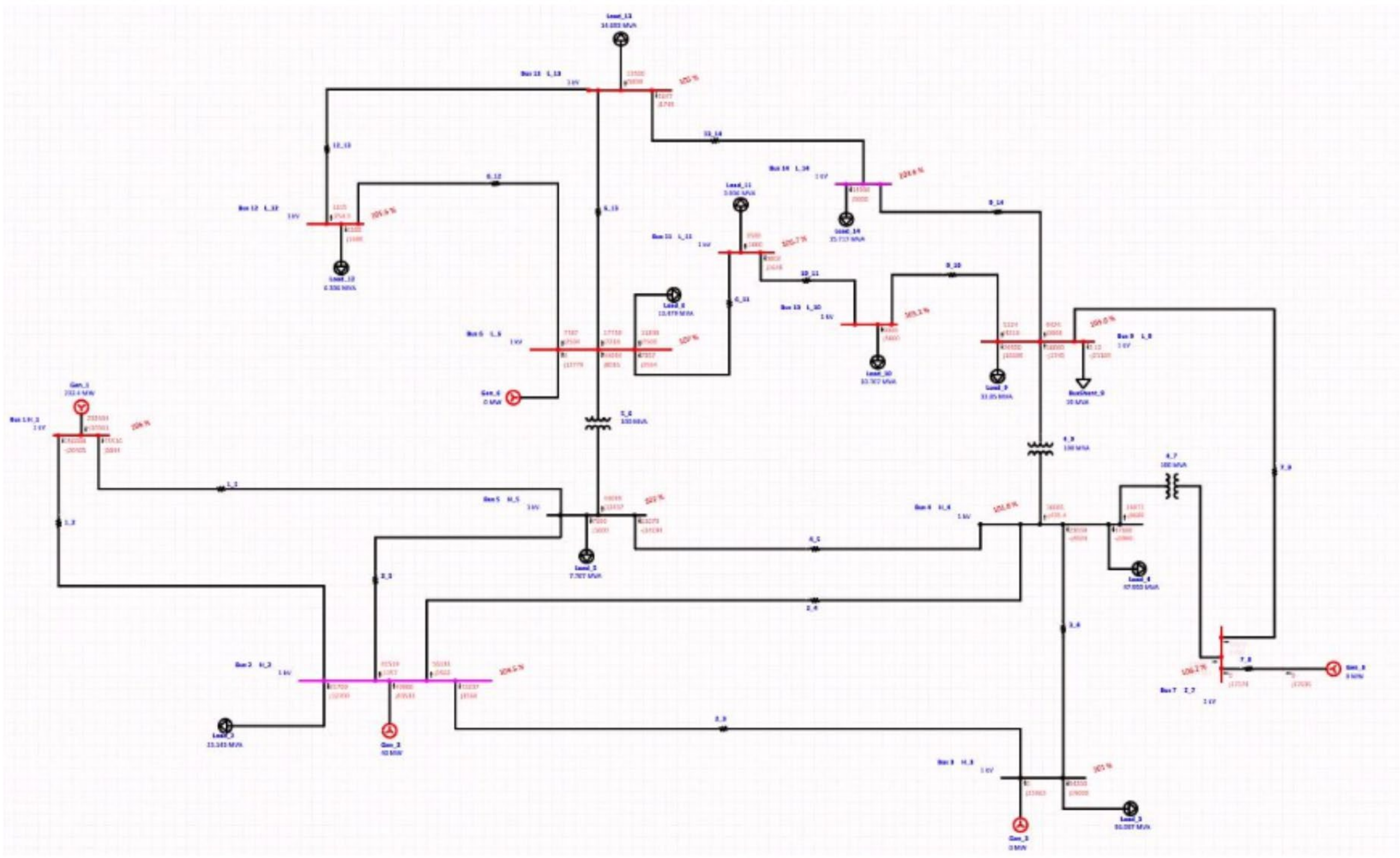
Moment of Inertia = K•mass•radius² ------------------------ 1.755 [kg·m²]

K = 0.5 for a solid cylinder

Rotational Kinetic Energy = 0.5•Moment of Inertia•Angular Velocity² [Joules]

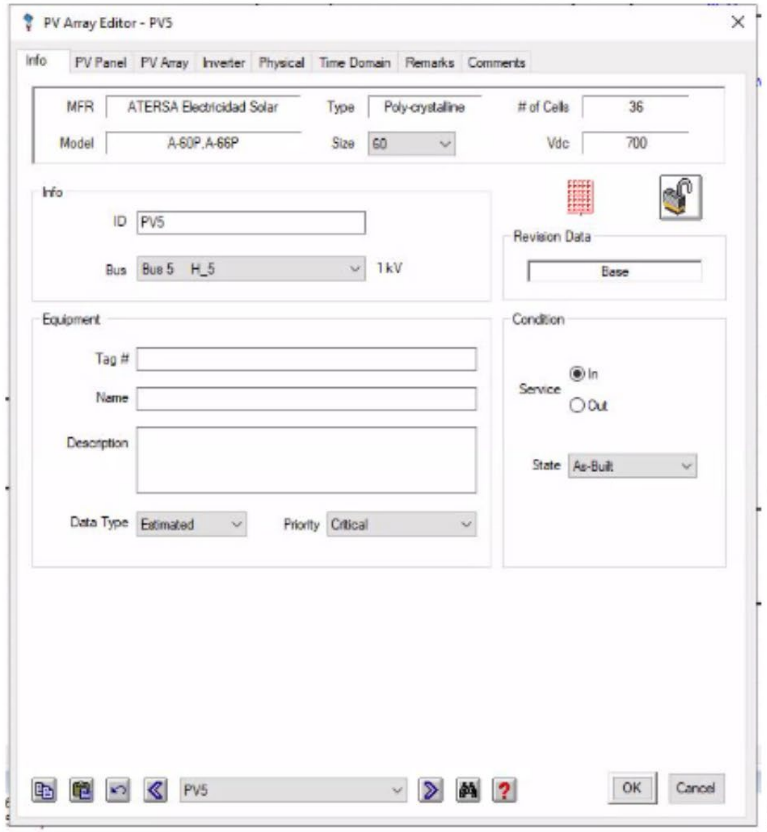
Power of Solar Array = Daily Watts/(Peak Sun Hours*Efficiency of System)

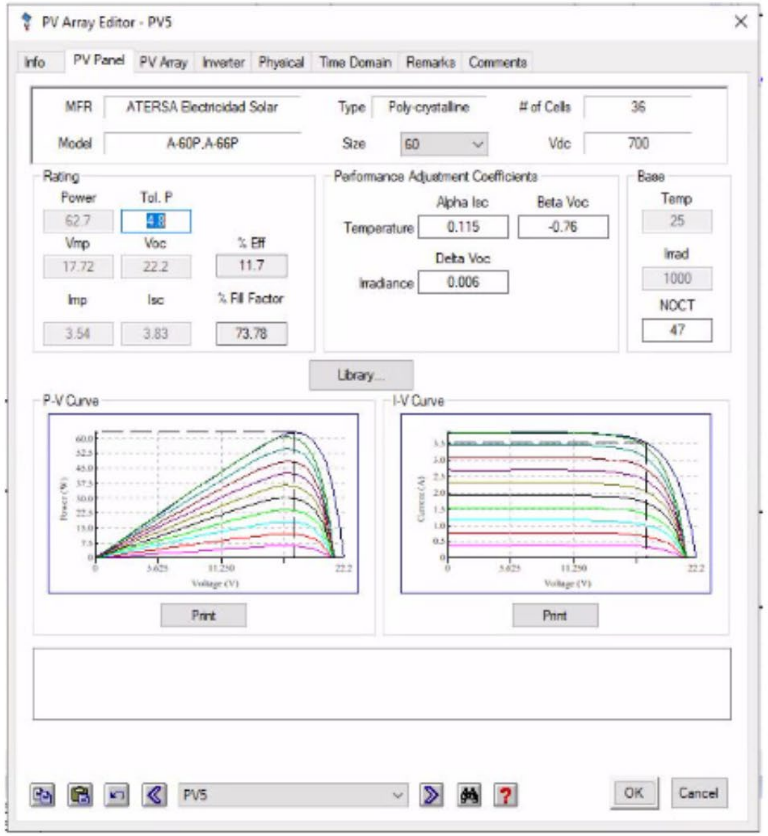
# Power system stability evaluation with mass free productions – IEEE 14 bus test system



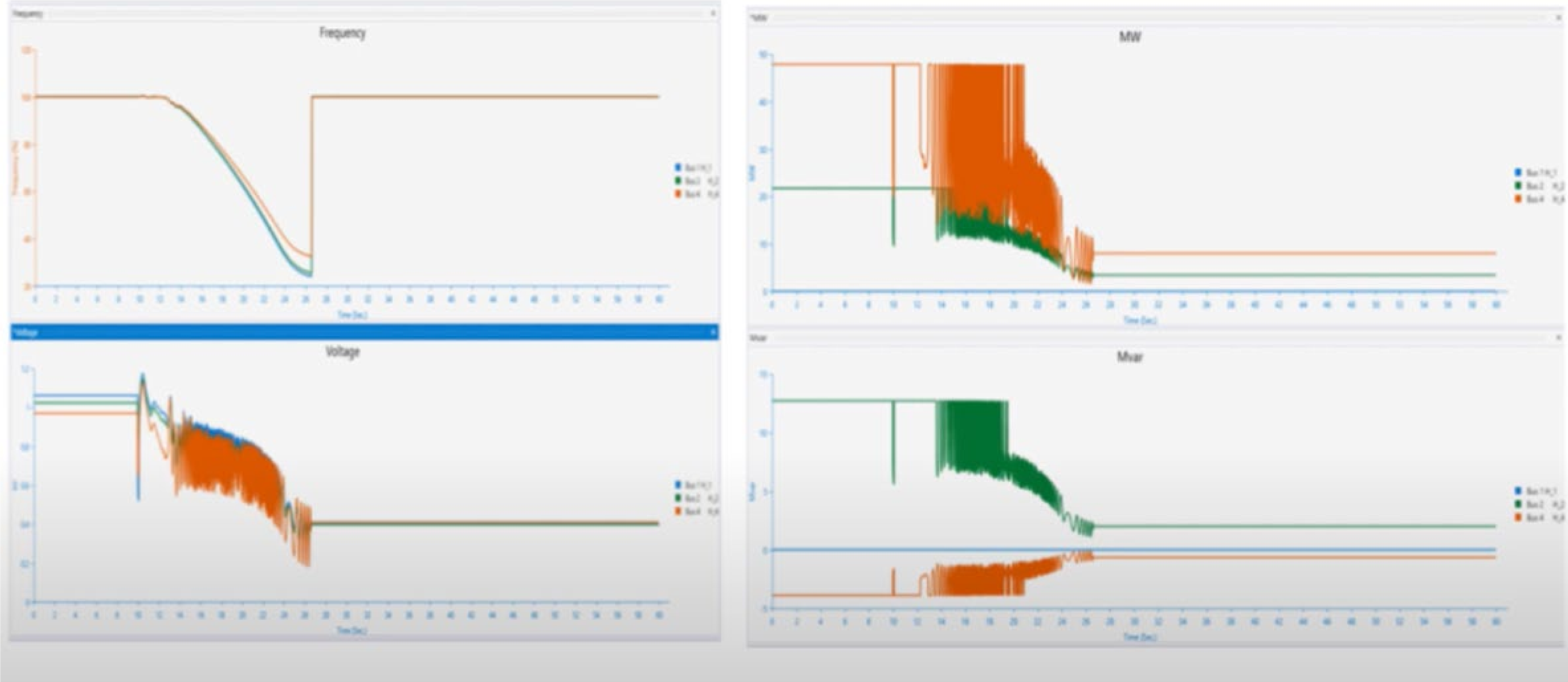
# Power system stability evaluation with mass free productions

IBR Settings:



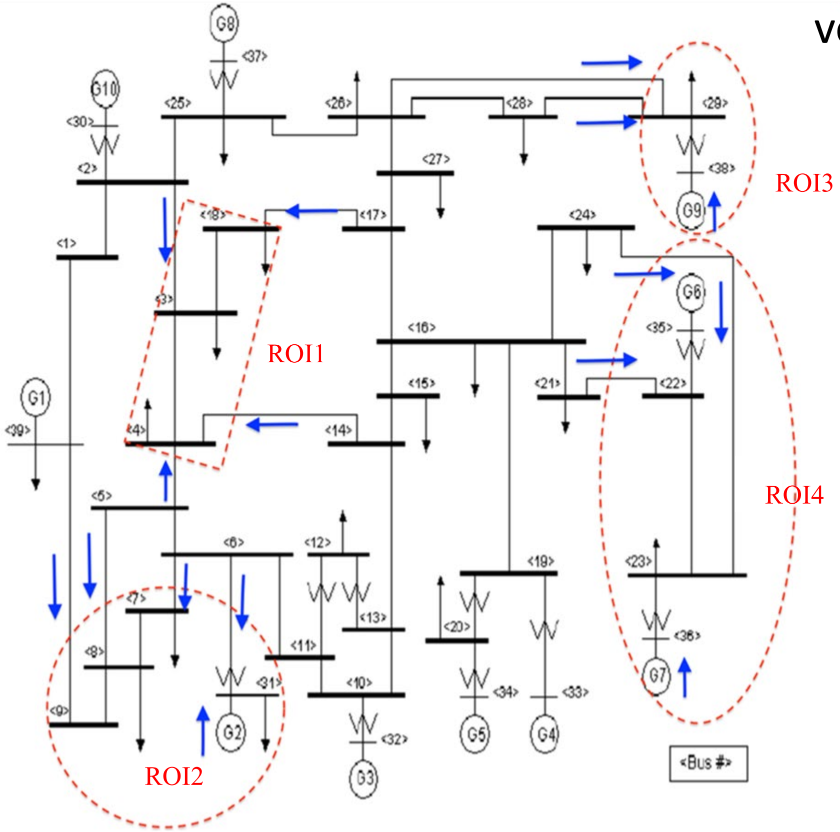



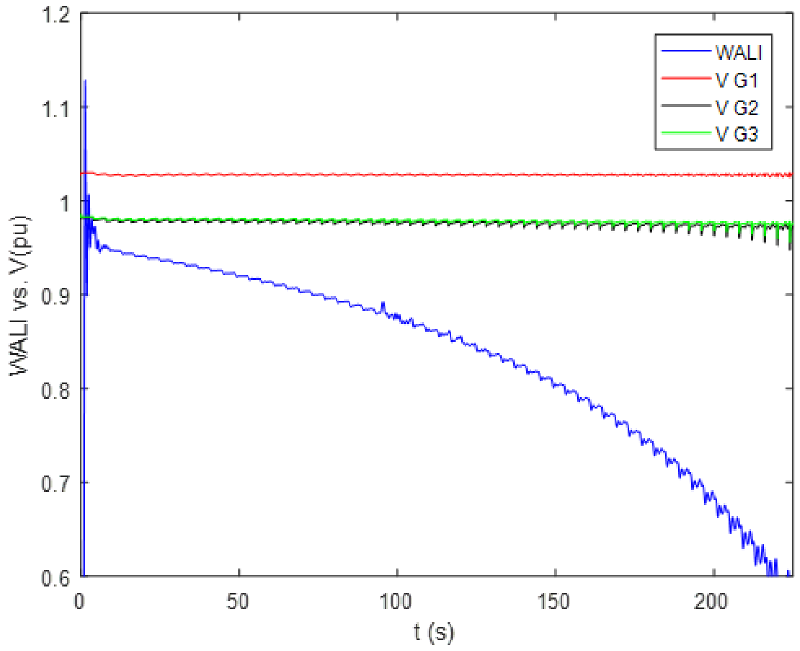
# Power system stability evaluation with mass free productions



# Voltage Stability Indicator

WALI index can predict the system's move towards instability well ahead of time. When WALI becomes smaller than 0.9, voltage profiles are still above 0.95.



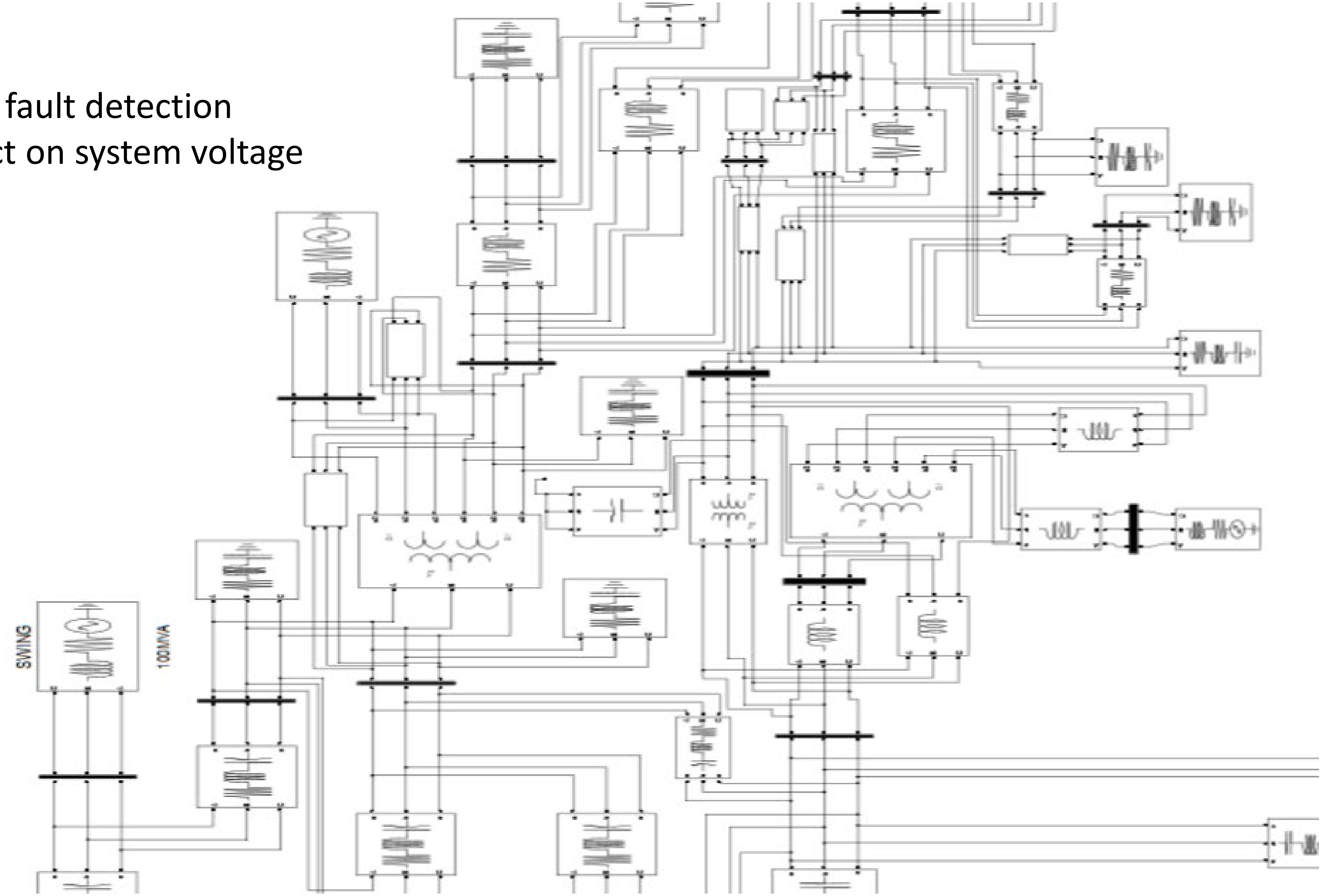
# Fire in California the cause and solution

- Approximate Entropy Method in MATLAB – To quantify the behavior associated with data
- High Impedance Fault in Power Systems – Voltage Data from Grid

Prove ApEn theory - small ApEn values means data is regular or predictable, whereas higher ApEn values mean the data is irregular or unpredictable

# Fire in California the cause and solution

High impedance fault detection
No obvious effect on system voltage



# Fire in California the cause and solution

High impedance fault detection
No obvious effect on system voltage

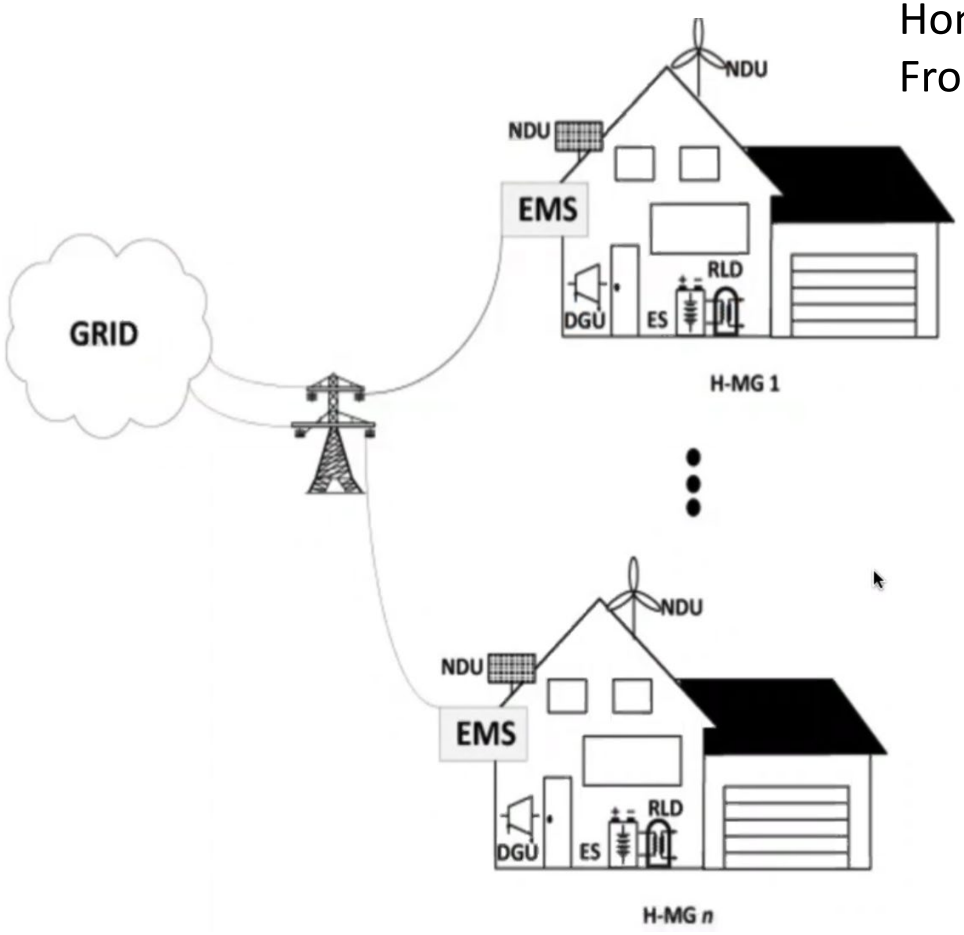
ApEn Values

| | Dimension = 1, r = 0.1*var(data) | | | Dimension = 2, r = 0.1*var(data) | | | Dimension = 1, r = 0.25*var(data) | | | Dimension = 2, r = 0.25*var(data) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus Location | ApEn (Unfaulted) | ApEn (Faulted @ Fault 1) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 1) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 1) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 1 | % Difference |
| 1 | 0.1397 | 0.1782 | 27.6% | 0.1692 | 0.1753 | 3.61% | 0.0538 | 0.0653 | 21.4% | 0.0575 | 0.0581 | 1.04% |
| 6 | 0.1450 | 0.2887 | 99.1% | 0.1771 | 0.2135 | 20.6% | 0.0562 | 0.0942 | 67.6% | 0.0603 | 0.0629 | 4.31% |
| 9 | 0.1452 | 0.1955 | 34.6% | 0.1775 | 0.1860 | 4.79% | 0.0552 | 0.0698 | 26.4% | 0.0591 | 0.0599 | 1.35% |
| 14 | 0.1453 | 0.1872 | 28.8% | 0.1779 | 0.1847 | 3.82% | 0.0552 | 0.0674 | 22.1% | 0.0591 | 0.0596 | 0.85% |
| 16 | 0.1412 | 0.1471 | 4.18% | 0.1713 | 0.1722 | 0.525% | 0.0545 | 0.0560 | 2.75% | 0.0583 | 0.0584 | 0.17% |
| 22 | 0.1479 | 0.1968 | 33.1% | 0.1811 | 0.1897 | 4.75% | 0.0571 | 0.0713 | 24.9% | 0.0613 | 0.0621 | 1.31% |
| 30 | 0.1530 | 0.2140 | 39.9% | 0.1886 | 0.1991 | 5.6% | 0.0602 | 0.0798 | 32.6% | 0.0648 | 0.0660 | 1.85% |

| | Dimension = 1, r = 0.1*var(data) | | | Dimension = 2, r = 0.1*var(data) | | | Dimension = 1, r = 0.25*var(data) | | | Dimension = 2, r = 0.25*var(data) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus Location | ApEn (Unfaulted) | ApEn (Faulted @ Fault 2) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 2) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 2) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 2 | % Difference |
| 1 | 0.1397 | 0.1402 | 0.4% | 0.1692 | 0.1691 | -0.06% | 0.0538 | 0.0539 | 0.2% | 0.0575 | 0.0575 | 0.00% |
| 6 | 0.1450 | 0.1476 | 1.8% | 0.1771 | 0.1766 | -0.3% | 0.0562 | 0.0568 | 1.1% | 0.0603 | 0.0603 | 0.00% |
| 9 | 0.1452 | 0.1486 | 2.3% | 0.1775 | 0.1784 | 0.51% | 0.0552 | 0.0561 | 1.6% | 0.0591 | 0.0592 | 0.17% |
| 14 | 0.1453 | 0.1636 | 12.6% | 0.1779 | 0.1794 | 0.84% | 0.0552 | 0.0612 | 10.9% | 0.0591 | 0.0595 | 0.68% |
| 16 | 0.1412 | 0.1449 | 2.62% | 0.1713 | 0.1725 | 0.701% | 0.0545 | 0.0555 | 1.83% | 0.0583 | 0.0587 | 0.69% |
| 22 | 0.1479 | 0.1538 | 4.0% | 0.1811 | 0.1820 | 0.50% | 0.0571 | 0.0599 | 4.9% | 0.0613 | 0.0617 | 0.65% |
| 30 | 0.1530 | 0.1565 | 2.3% | 0.1886 | 0.1896 | 0.5% | 0.0602 | 0.0621 | 3.2% | 0.0648 | 0.0650 | 0.31% |

| | Dimension = 1, r = 0.1*var(data) | | | Dimension = 2, r = 0.1*var(data) | | | Dimension = 1, r = 0.25*var(data) | | | Dimension = 2, r = 0.25*var(data) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus Location | ApEn (Unfaulted) | ApEn (Faulted @ Fault 3) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 3) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 3) | % Difference | ApEn (Unfaulted) | ApEn (Faulted @ Fault 3 | % Difference |
| 1 | 0.1397 | 0.1401 | 0.3% | 0.1692 | 0.1690 | -0.12% | 0.0538 | 0.0539 | 0.2% | 0.0575 | 0.0575 | 0.00% |
| 6 | 0.1450 | 0.1478 | 1.9% | 0.1771 | 0.1763 | -0.5% | 0.0562 | 0.0569 | 1.2% | 0.0603 | 0.0603 | 0.00% |
| 9 | 0.1452 | 0.1470 | 1.2% | 0.1775 | 0.1783 | 0.45% | 0.0552 | 0.0555 | 0.5% | 0.0591 | 0.0592 | 0.17% |
| 14 | 0.1453 | 0.1460 | 0.5% | 0.1779 | 0.1782 | 0.17% | 0.0552 | 0.0552 | 0.0% | 0.0591 | 0.0590 | -0.17% |
| 16 | 0.1412 | 0.1412 | 0.00% | 0.1713 | 0.1712 | -0.058% | 0.0545 | 0.0546 | 0.18% | 0.0583 | 0.0584 | 0.17% |
| 22 | 0.1479 | 0.1493 | 0.9% | 0.1811 | 0.1817 | 0.33% | 0.0571 | 0.0579 | 1.4% | 0.0613 | 0.0616 | 0.49% |
| 30 | 0.1530 | 0.1563 | 2.2% | 0.1886 | 0.1896 | 0.5% | 0.0602 | 0.0619 | 2.8% | 0.0648 | 0.0650 | 0.31% |

# Game Theory and Renewable Energy Market



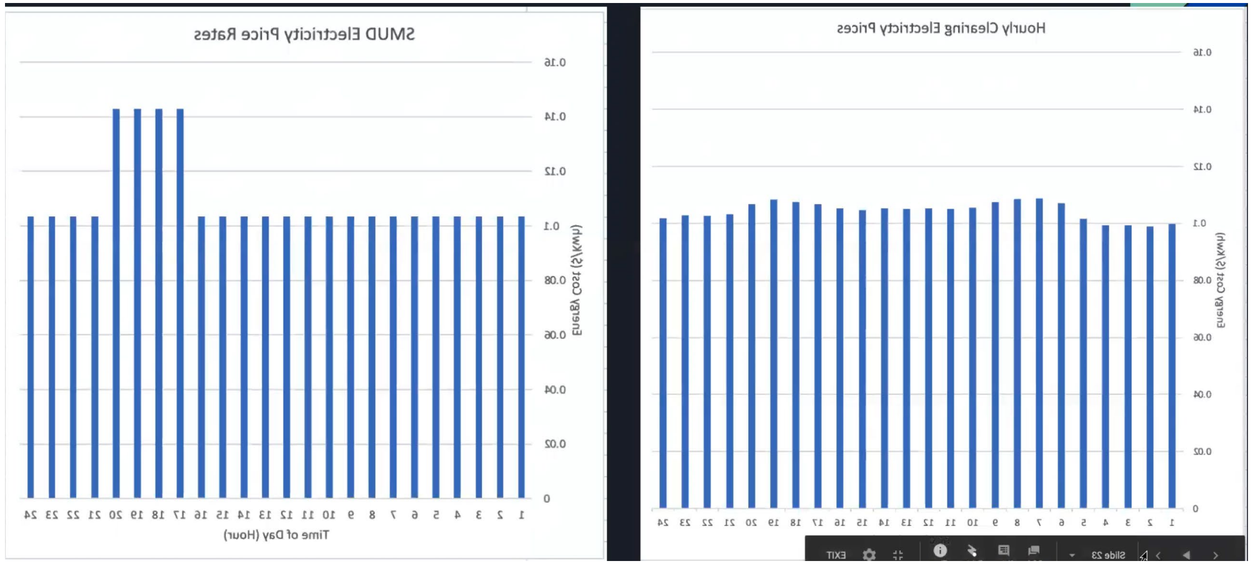

Home Energy Management System sends to and receives signals From Market Operator

The optimum price is calculated by the Market Operator using data and information obtained from players.
The proposed market structure seeks a global solution where all players benefit from participation in the market.
Non-cooperative game theory method, Nash equilibrium and NIRA is used to solve and optimize incentives for players.
H-MG must provide dynamic information and rated capacity of the existing devices, operational constraints, and cost function to the Market Operator.

# Game Theory and Renewable Energy Market

Step 1: Estimate the generation capacity of the renewable sources (photovoltaic & wind turbine) as NDU and NRL for the day ahead using HEMS.
Step 2: Solve each scenario for unit commitment problem.
Step 3: The shortage and excess power for each H-MG is either supplied and bought by the retailers. Retailer submits two separate bids, one for purchasing excess power for H-MGs and the other bids for selling and supplying energy shortage to H-MGs.
Step 4: Primary schedule from steps 1, 2 and 3 are calculated based on local MCEMS operations and NIRA algorithm is used to determine the global optimal schedule of each players.
Step: 5: The market clearing price is calculated based on the Nash equilibrium and the bids submitted by the players using a double sided auction.

Get the best bid for each hour is the optimization problem.
Energy Price Consistent throughout the day.



# THANK YOU