# DESIGN, ANALYSIS, SIMULATION, AND CONTROL OF A COST-OPTIMIZED HYBRID POWER SYSTEM FOR URBAN PAKISTAN


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(FACULTY OF ENGINEERING AND APPLIED SCIENCE)
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# PRESENTATION OUTLINE

# INTRODUCTION

## Background

- Global energy demand rising; IEA projects **1000 TWh** annual growth.
- Rising global energy prices and **supply chain disruptions** impact developing economies.
- Pakistan faces severe energy shortages due to growing demand and limited local resources.
- Heavy reliance on imported fossil fuels worsens with **exchange rate** volatility.
- **Subsidy removals** and **additional taxes** have sharply increased electricity costs.
- Frequent, severe floods cause widespread economic damage and displacement..
- Power outages of up to **12 hours** daily disrupt life and economic activity.
- Independent Power Projects (IPPs) increase electricity costs for citizens through capacity payments even when the requirement is low.

# INTRODUCTION

## Why Renewable Energy ?

- Burning fossil fuels releases **greenhouse gases** and causes **environmental damage** leading to global warming and exreme weather events. e.g severe floods
- **Frequent, severe floods** in Pakistan cause widespread economic damage and displacement, highlighting the urgent need for sustainable energy solutions.
- Fossil fuel reserves are **finite**. If we do not reduce cosumption, the may deplete in our life span.
- Air pollution from fossil fuels results in adverse **health impacts** such as respiratory problems and lead to increased healthcare costs.

**key takeaway:** Transitioning to renewable energy is imperative for a cleaner, sustainable, and more secure future

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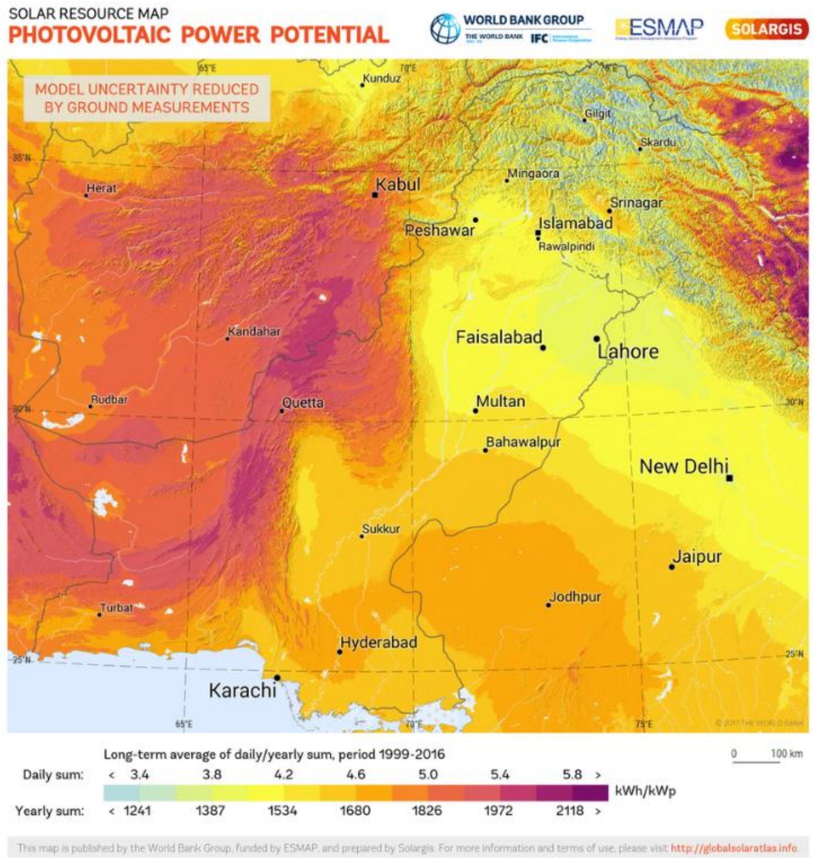
# INTRODUCTION

## Pakistan's Solar Potential

- Pakistan benefits from favorable climatic conditions, with an average of 8 to 9 hours of sunlight per day.
- The country's solar radiation levels range between 4 and 7 $kWh/m^2/day$, making it highly suitable for solar energy deployment.



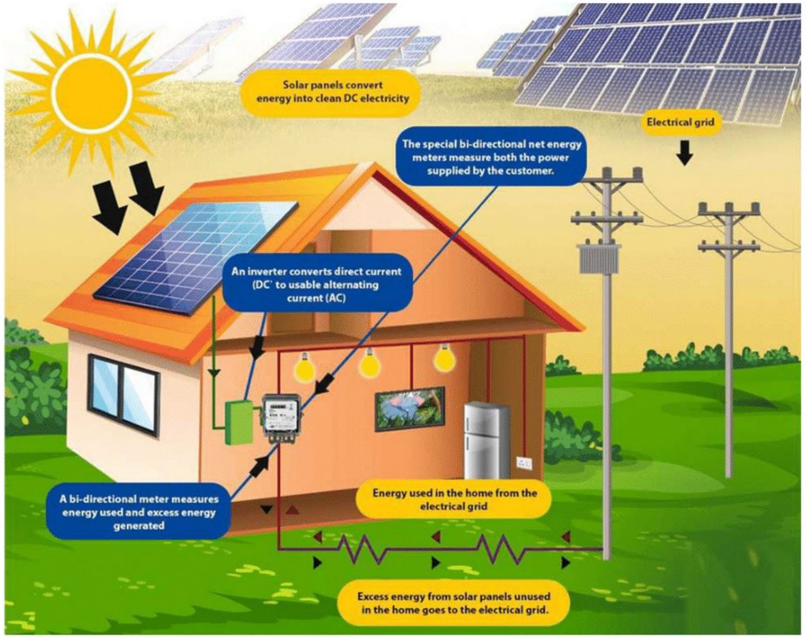
## INTRODUCTION

# Types of PV Systems

- **Grid-Tied (On-Grid) Systems:**
  - Connected directly to the utility grid.
  - Supply electricity to properties and export surplus via net metering.
  - Do not operate during grid outages unless paired with batteries.
  - Recent change in net-metering policies.

- **Off-Grid Systems:**
  - Operate independently of the grid using battery banks for energy storage.
  - Ideal for remote/rural areas with no grid access.
  - Require higher initial costs and battery maintenance.

- **Hybrid Systems:**
  - Combine solar with other energy sources (e.g., diesel generators, wind).
  - Include battery storage for enhanced reliability.
  - Ensure uninterrupted power during low solar availability or grid outages.

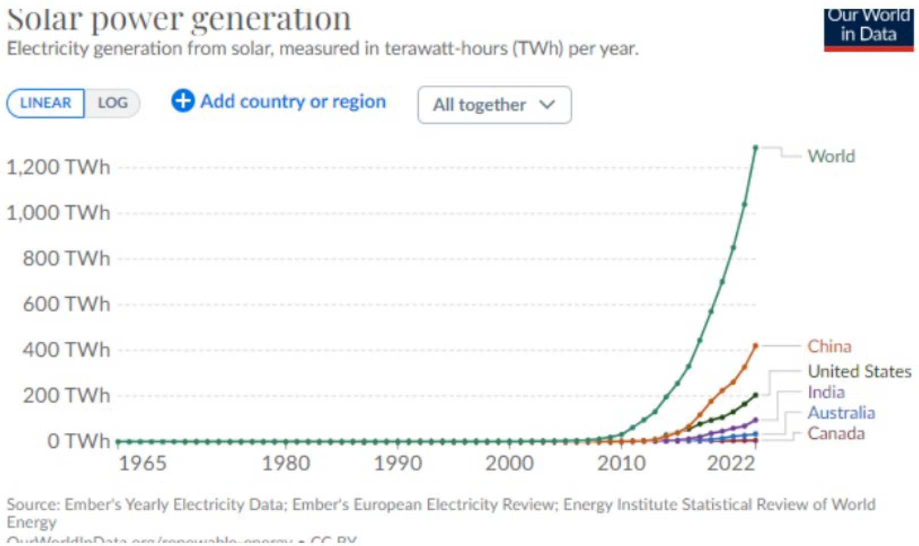


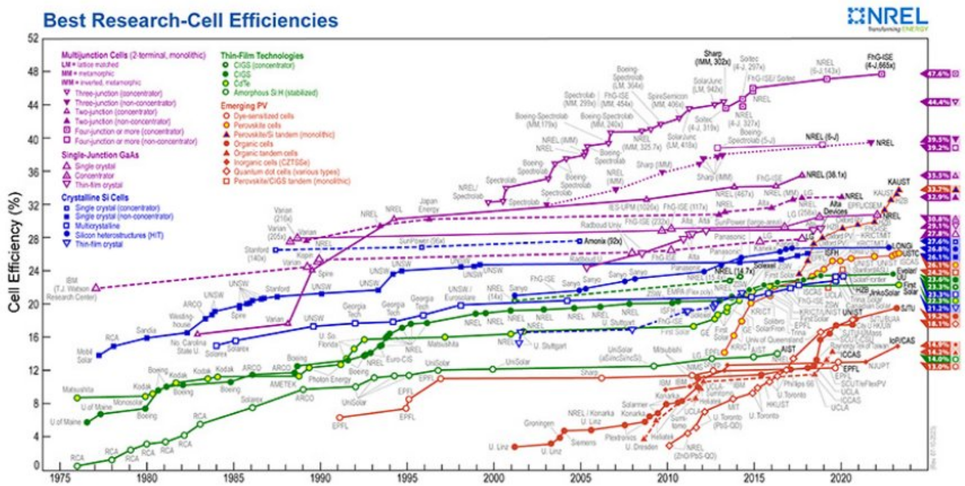
# INTRODUCTION

## The Current State of Solar Energy & PV Technology

- The 'Our World in Data' website report presents solar energy production data up to 2022, highlighting China as the global leader in solar energy production.

- NREL data highlights the advancement of solar panel efficiency from 1975 to 2023, with the highest achieved efficiency of 47.6% in multi-junction solar cells.

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# RESEARCH OBJECTIVES

- Address Pakistan’s energy crisis marked by frequent load shedding, rising costs, and heavy reliance on imported fossil fuels.
- Design a cost-effective, grid-independent hybrid energy system tailored for urban residential neighborhoods.
- Conduct techno-economic optimization using HOMER Pro to identify the most feasible system configuration under local constraints.
- Perform dynamic modeling and simulation in MATLAB/Simulink to analyze system stability, load-following capability, and response to variable operating conditions.
- Develop advanced control strategies for intelligent load sharing, efficient battery management, and diesel generator coordination to ensure reliable and autonomous operation.

# LITERATURE REVIEW

| Reviewed Paper | Description |
|---|---|
| Ozogbuda & Iqbal (2021) | Designed a DC microgrid for a Nigerian community using HOMER Pro. Optimized PV–battery system for nine houses with varying loads and analyzed system performance under different solar conditions. |
| Al-Wakeel (2020) | Studied Iraq's reliance on neighborhood diesel generators due to unreliable grids. Highlighted environmental and economic issues and proposed rooftop solar PV as a sustainable alternative. |
| Muskan & Channi (2023) | Designed a PV–diesel hybrid system in India using HOMER Pro, achieving LCOE of $0.428/kWh. |
| Shang et al. (2020) | Proposed an improved MPPT strategy with faster response under varying irradiance in MATLAB. |
| Aziz et al. (2022) | Developed a PV–diesel–battery system in Iraq with improved dispatch, reducing NPC and emissions. |

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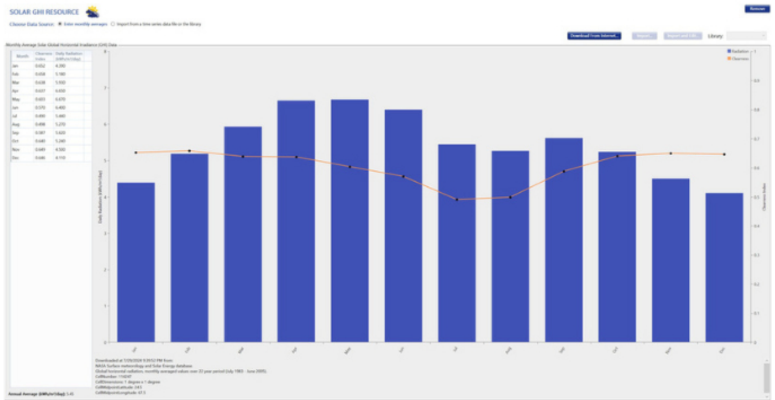
## Site Location

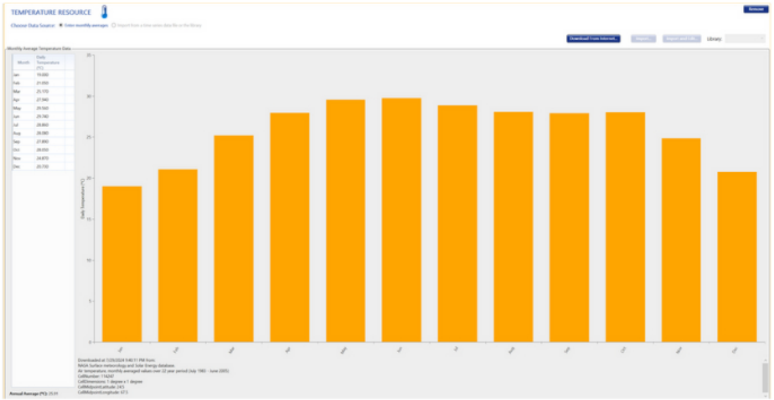
- Study site: Urban neighborhood in Karachi with seven closely located houses.
- Geographical coordinates: 24.9199ºN, 67.1455ºE.
- Flat rooftops, free from shading, ideal for solar PV systems.

## Weather and Solar Potential at Site

- Average solar irradiance: 5.45–5.6 kWh/m²/day, peaking in May and lowest in December.

- Average temperature: 19°C in January and 29.7°C in June, with summer highs reaching 40–45°C.

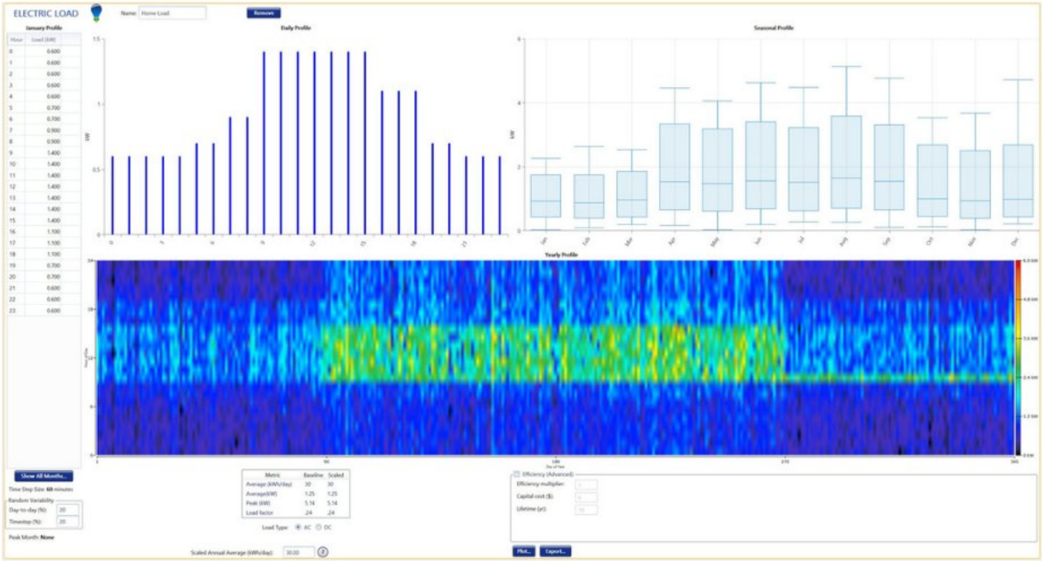




# Electric Load Profile in the Neighborhood

- Energy loads for seven houses range from 15–45 kWh/day, with House 1 (baseline) consuming 30 kWh/day due to varied occupant lifestyles and usage patterns.

- Peak demand occurs during May–September, driven by air conditioning use, with higher daytime consumption from non-essential activities to align with solar availability.

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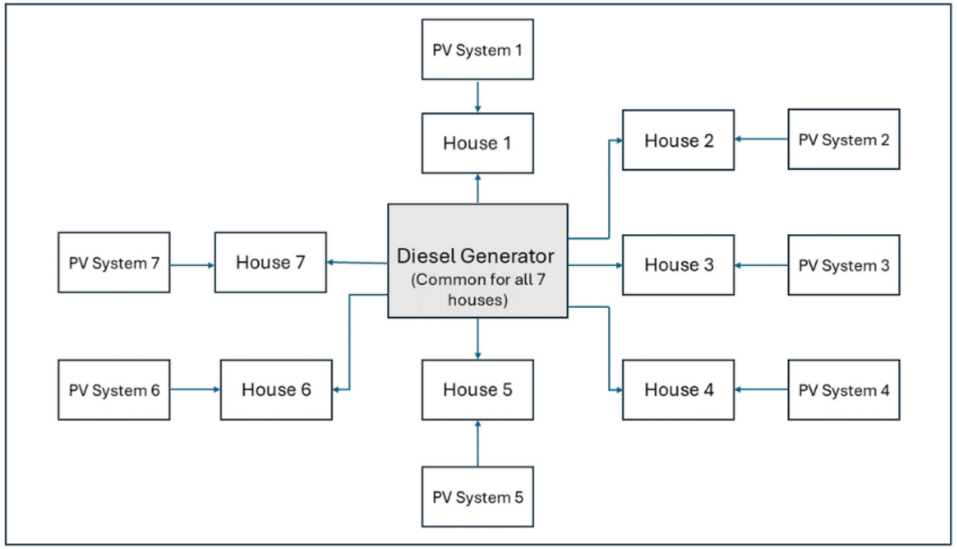
## Proposed System Block Diagram

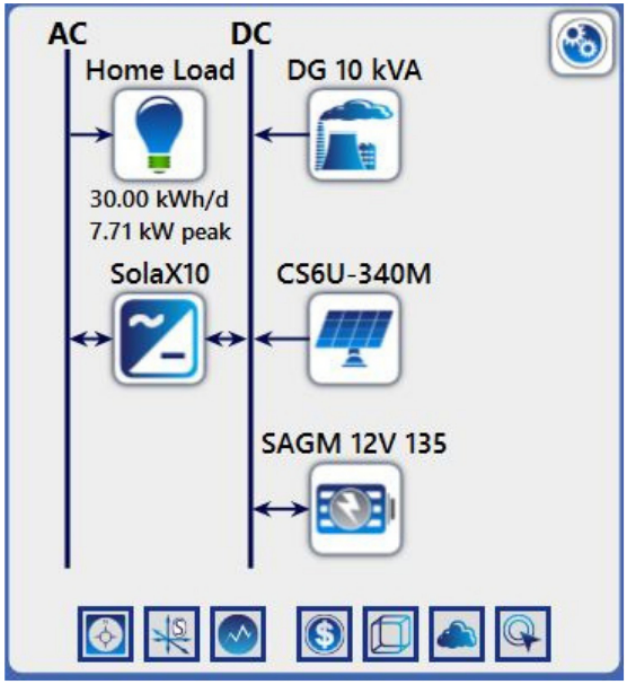
- Key components: PV systems, batteries, converters, shared diesel generator.
- Each house equipped with its own PV system and connected to the diesel generator via a DC bus.
- Separate meters installed in each house to monitor diesel generator usage.
- Diesel generator provides backup during low solar or high demand periods.



## System Design

- This hybrid energy system consists of individual solar power system for each house, battery storage, and a shared diesel generator.

- Key components include solar PV panels (CS6U-340M), a battery storage unit (SAGM 12V 135), a 10 kVA diesel generator (DG), and a SolaX10 inverter



## System Design and Sensitivty Analysis

- Seven off-grid PV systems sized for 15 to 45 kWh/day loads, supported by a shared 2 kW diesel generator for battery charging.
- Sensitivity analysis: Assessed performance under ±10% solar irradiance variations to account for weather fluctuations.
- Cycle Charging (CC) dispatch chosen for efficiency and reduced generator runtime vs. Load Following (LF).

| Sensitivity | | Architecture | | | | Cost | | | | DG 10kVA | | | | | SAGM 12V 135 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Home Load Scaled Average (kWh/d) | Solar Scaled Average (kWh/m²/day) | CS6U-340M (kW) | DG 10kVA (kW) | SAGM 12V 135 (#) | Dispatch | NPC ($) | LCOE ($/kWh) | Operating cost ($/yr) | CAPEX ($) | Hours | Production (kWh) | Fuel (L) | O&M Cost ($/yr) | Fuel Cost ($/yr) | Autonomy (hr) | Annual Throughput (kWh/yr) |
| 15.0 | 4.23 | 11.6 | 2.00 | 8 | CC | $15,488 | $0.300 | $598.35 | $7,752 | 27.0 | 35.5 | 11.5 | 21.6 | 21.3 | 17.2 | 2,031 |
| 15.0 | 4.70 | 7.61 | 2.00 | 12 | CC | $15,563 | $0.296 | $553.54 | $8,407 | 48.0 | 68.5 | 21.9 | 38.4 | 40.7 | 25.8 | 2,115 |
| 15.0 | 5.17 | 7.41 | 2.00 | 8 | CC | $14,807 | $0.287 | $612.86 | $6,884 | 66.0 | 92.5 | 29.6 | 52.8 | 55.1 | 17.2 | 2,078 |
| 20.0 | 4.23 | 12.3 | 2.00 | 12 | CC | $20,263 | $0.294 | $813.90 | $9,742 | 78.0 | 87.0 | 28.9 | 62.4 | 53.7 | 19.3 | 2,752 |
| 20.0 | 4.70 | 8.72 | 2.00 | 12 | CC | $20,438 | $0.298 | $886.94 | $8,972 | 154 | 183 | 60.1 | 123 | 112 | 19.3 | 2,778 |
| 20.0 | 5.17 | 9.02 | 2.00 | 12 | CC | $19,637 | $0.288 | $820.93 | $9,025 | 113 | 129 | 42.8 | 90.4 | 79.5 | 19.3 | 2,760 |
| 25.0 | 4.23 | 16.7 | 2.00 | 12 | CC | $25,444 | $0.282 | $1,102 | $11,198 | 99.0 | 136 | 43.6 | 79.2 | 81.1 | 15.5 | 3,507 |
| 25.0 | 4.70 | 15.0 | 2.00 | 16 | CC | $24,792 | $0.276 | $967.47 | $12,285 | 54.0 | 67.0 | 21.8 | 43.2 | 40.6 | 20.6 | 3,531 |
| 25.0 | 5.17 | 14.1 | 2.00 | 16 | CC | $24,500 | $0.271 | $958.34 | $12,111 | 56.0 | 66.1 | 21.8 | 44.8 | 40.5 | 20.6 | 3,548 |
| 30.0 | 4.23 | 16.6 | 2.00 | 20 | CC | $28,952 | $0.283 | $1,138 | $14,242 | 77.0 | 94.1 | 30.8 | 61.6 | 57.3 | 21.5 | 4,155 |
| 30.0 | 4.70 | 18.3 | 2.00 | 16 | CC | $28,392 | $0.275 | $1,176 | $13,185 | 65.0 | 82.0 | 26.7 | 52.0 | 49.6 | 17.2 | 4,127 |
| 30.0 | 5.17 | 18.3 | 2.00 | 16 | CC | $28,005 | $0.274 | $1,150 | $13,140 | 57.0 | 67.0 | 22.1 | 45.6 | 41.0 | 17.2 | 4,082 |
| 35.0 | 4.23 | 18.4 | 2.00 | 20 | CC | $33,940 | $0.283 | $1,463 | $15,032 | 157 | 204 | 66.0 | 126 | 123 | 18.4 | 4,867 |
| 35.0 | 4.70 | 19.1 | 2.00 | 20 | CC | $32,653 | $0.272 | $1,353 | $15,165 | 86.0 | 115 | 37.1 | 68.8 | 69.1 | 18.4 | 4,839 |
| 35.0 | 5.17 | 18.5 | 2.00 | 20 | CC | $32,115 | $0.269 | $1,322 | $15,020 | 83.0 | 98.6 | 32.4 | 66.4 | 60.3 | 18.4 | 4,800 |
| 40.0 | 4.23 | 29.5 | 2.00 | 20 | CC | $38,983 | $0.285 | $1,648 | $17,678 | 86.0 | 115 | 37.2 | 68.8 | 69.1 | 16.1 | 5,420 |
| 40.0 | 4.70 | 28.8 | 2.00 | 24 | CC | $39,278 | $0.286 | $1,567 | $19,015 | 72.0 | 84.8 | 27.9 | 57.6 | 51.9 | 19.3 | 5,419 |
| 40.0 | 5.17 | 17.9 | 2.00 | 20 | CC | $37,690 | $0.272 | $1,727 | $15,366 | 224 | 286 | 92.8 | 179 | 173 | 16.1 | 5,561 |
| 45.0 | 4.23 | 35.2 | 2.00 | 20 | CC | $43,841 | $0.285 | $1,902 | $19,251 | 106 | 118 | 39.2 | 84.8 | 72.9 | 14.3 | 6,047 |
| 45.0 | 4.70 | 29.3 | 2.00 | 20 | CC | $42,761 | $0.278 | $1,913 | $18,037 | 158 | 187 | 61.5 | 126 | 114 | 14.3 | 6,105 |
| 45.0 | 5.17 | 29.6 | 2.00 | 20 | CC | $41,840 | $0.273 | $1,839 | $18,068 | 112 | 130 | 42.8 | 89.6 | 79.5 | 14.3 | 6,087 |

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# Specifications of system components

### PV Module Specifications

| Parameter | Values |
|---|---|
| Model | CS6U–340M |
| Manufacturer | Canadian Solar |
| Panel Type | Monocrystalline |
| Nominal Maximum Power(*Pmax*) | 340 W |
| Operating Voltage (*Vmp*) | 37.8V |
| Operating Current (*Imp*) | 8.87A |
| Operating Temperature | -40°C ~ +85°C |
| Cell Arrangement | 72 cells(6x12) |
| Module Efficiency | 17.49 % |
| Junction box rating | IP 67 |
| Weight | 22.4 kg |

### Battery Specifications

| Parameter | Values |
|---|---|
| Model | CS6U–340M |
| Manufacturer | Canadian Solar |
| Panel Type | Monocrystalline |
| Nominal Maximum Power(*Pmax*) | 340 W |
| Operating Voltage (*Vmp*) | 37.8V |
| Operating Current (*Imp*) | 8.87A |
| Operating Temperature | -40°C ~ +85°C |
| Cell Arrangement | 72 cells(6x12) |
| Module Efficiency | 17.49 % |
| Junction box rating | IP 67 |
| Weight | 22.4 kg |

### Diesel Generator Specifications

| Parameter | Values |
|---|---|
| Fuel Type | Diesel |
| Minimum Load Ratio | 25 % |
| Life of operation | 12 Years |
| Capacity Factor | 1.9 % |
| Governor Type | Mechanical |
| Engine Compression Ratio | 23:1 |
| Displacement | 1.1 litre |
| Mean Electrical Efficiency | 32.9 % |

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# Specifications of system components

## DG Fuel Consumption

| Parameter | Values |
|---|---|
| Net fuel consumption | 81.6 L |
| Fuel consumption per day(avg) | .22 L |
| Specific fuel consumption | 0.309 L/kWh |
| Fuel curve intercept | 0.5 L/hr |
| Fuel curve slope | 0.273 L/hr/kW |
| Lower heating value | 43.2 MJ/kg |
| Density | 820 kg/m3 |

## DG Expected Emissions

| Parameter | Values |
|---|---|
| Carbon Monoxide | 16.34 g/L |
| Unburned Hydrocarbons | 0.72 g/L |
| Particulate matter | 0.098 g/L |
| Fuel sulfur converted to PTM | 2.2 % |
| Nitrogen Oxides | 15.359 g/L |

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## Electrical Generation Analysis

Simulation Results

| | |
|---|---|
| System Architecture: | Trojan SAGM 12 135 (3.00 strings) |
| CanadianSolar MaxPower CS6U-340M (7.61 kW) | SolaX X3-hybrid10 (0.576 kW) |
| DG (2.00 kW) | HOMER Cycle Charging |

Scaled Average (15.00 kWh/d)

| | |
|---|---|
| Total NPC: | $15,562.55 |
| Levelized COE: | $0.2959 |
| Operating Cost: | $553.54 |

Cost Summary | Cash Flow | Compare Economics | Electrical | Fuel Summary | DG | Renewable Penetration | Trojan SAGM 12 135 | CanadianSolar MaxPower CS6U-340M | SolaX X3-hybrid10 | Emissions

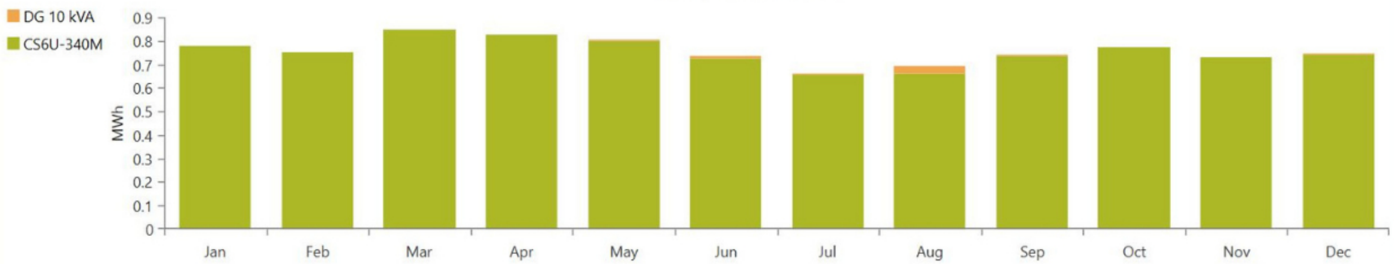
| Production | kWh/yr | % |
|---|---|---|
| CanadianSolar MaxPower CS6U-340M | 9,017 | 99.2 |
| DG | 68.5 | 0.754 |
| Total | 9,085 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 4,069 | 100 |
| DC Primary Load | 0 | 0 |
| Deferrable Load | 0 | 0 |
| Total | 4,069 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 4,550 | 50.1 |
| Unmet Electric Load | 1,406 | 25.7 |
| Capacity Shortage | 1,784 | 32.6 |

| Quantity | Value | Units |
|---|---|---|
| Renewable Fraction | 98.3 | % |
| Max. Renew. Penetration | 16,755 | % |

Monthly Electric Production




Simulation Report | Time Series Plot | Other...

## Cost Summary

Simulation Results

System Architecture: Trojan SAGM 12 135 (3.00 strings)
CanadianSolar MaxPower CS6U-340M (7.61 kW) SolaX X3-hybrid10 (0.576 kW)
DG (2.00 kW) HOMER Cycle Charging

Scaled Average (15.00 kWh/d)

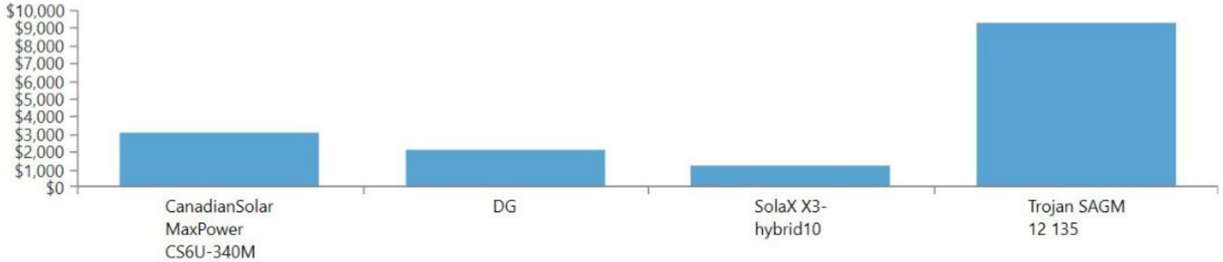
Total NPC: $15,562.55
Levelized COE: $0.2959
Operating Cost: $553.54

Emissions

Cost Summary | Cash Flow | Compare Economics | Electrical | Fuel Summary | DG | Renewable Penetration | Trojan SAGM 12 135 | CanadianSolar MaxPower CS6U-340M | SolaX X3-hybrid10

Cost Type
- Net Present
- Annualized

Categorize
- By Component
- By Cost Type




| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| CanadianSolar MaxPower CS6U-340M | $1,576.29 | $0.00 | $1,476.63 | $0.00 | $0.00 | $3,052.92 |
| DG | $1,300.00 | $0.00 | $496.42 | $525.78 | -$264.47 | $2,057.72 |
| SolaX X3-hybrid10 | $1,210.35 | $0.00 | $0.00 | $0.00 | $0.00 | $1,210.35 |
| Trojan SAGM 12 135 | $4,320.00 | $5,107.35 | $775.65 | $0.00 | -$961.44 | $9,241.56 |
| System | $8,406.64 | $5,107.35 | $2,748.70 | $525.78 | -$1,225.91 | $15,562.55 |

Simulation Report | Time Series Plot | Other...

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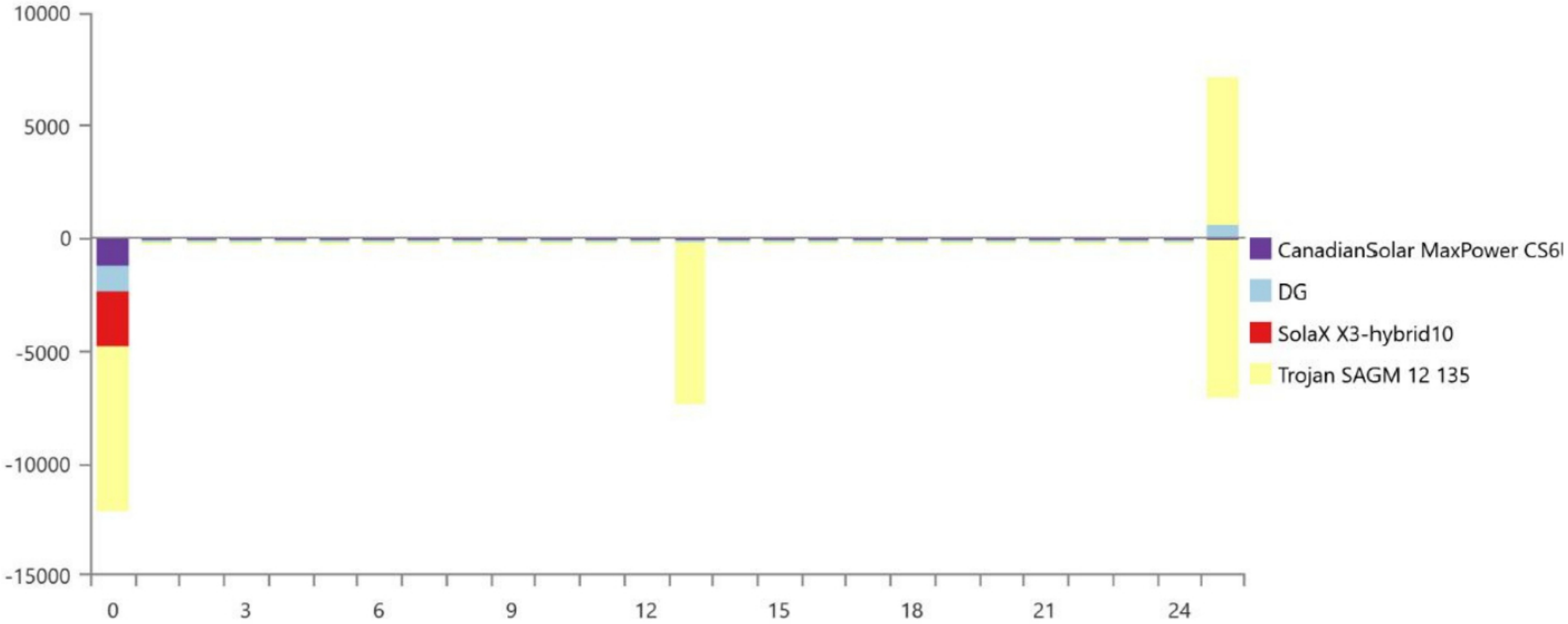
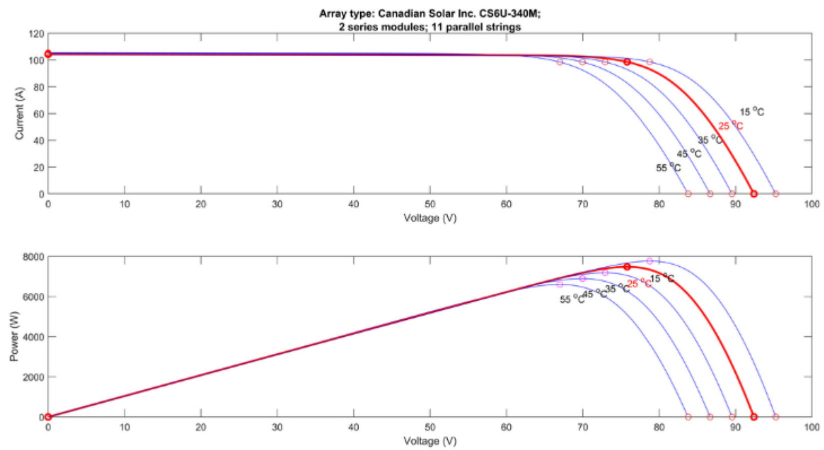
## Cash Flow


10000
5000
0
-5000
-10000
-15000
0
3
6
9
12
15
18
21
24
CanadianSolar MaxPower CS6I
DG
SolaX X3-hybrid10
Trojan SAGM 12 135

# Dynamic Modeling and Simulation of Proposed System in MATLAB/Simulink

# PV CHARACTERSTICS

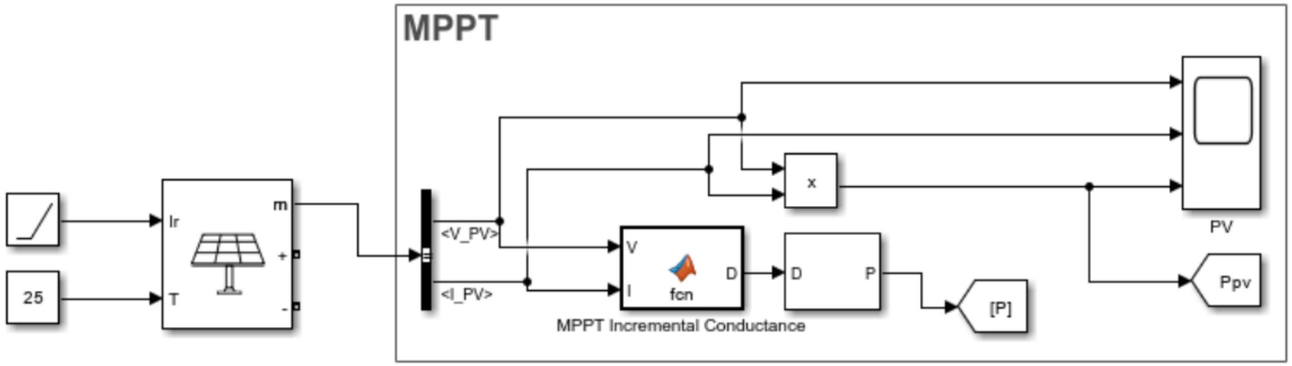
- House 1 was selected for the simulation with a daily energy requirement of 15 kWh.
- Canadian Solar CS6U-340M modules are used with 17.49% efficiency, Operating Current (Imp) of 8.97 A, and Operating Voltage (Vmp) 37.9V.




I-V and P-V curves of the PV Array

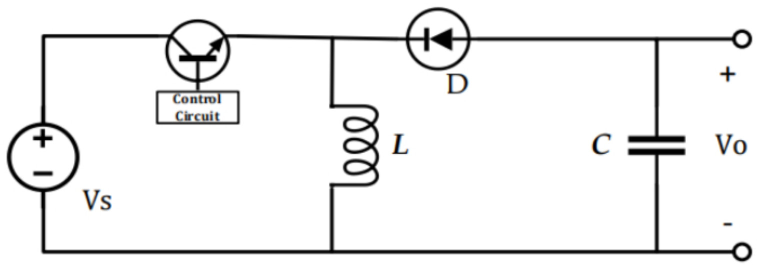
# MPPT ALGORITHM

- Ensures maximum power extraction from the PV array by continuously adjusting to the optimal operating point based on irradiance and temperature.
- The Incremental Conductance (INC) algorithm was chosen; it dynamically adjusts the duty cycle of the DC-DC converter based on real-time changes in power and voltage.
- Reduces power loss and improves system efficiency by consistently operating near the Maximum Power Point (MPP).



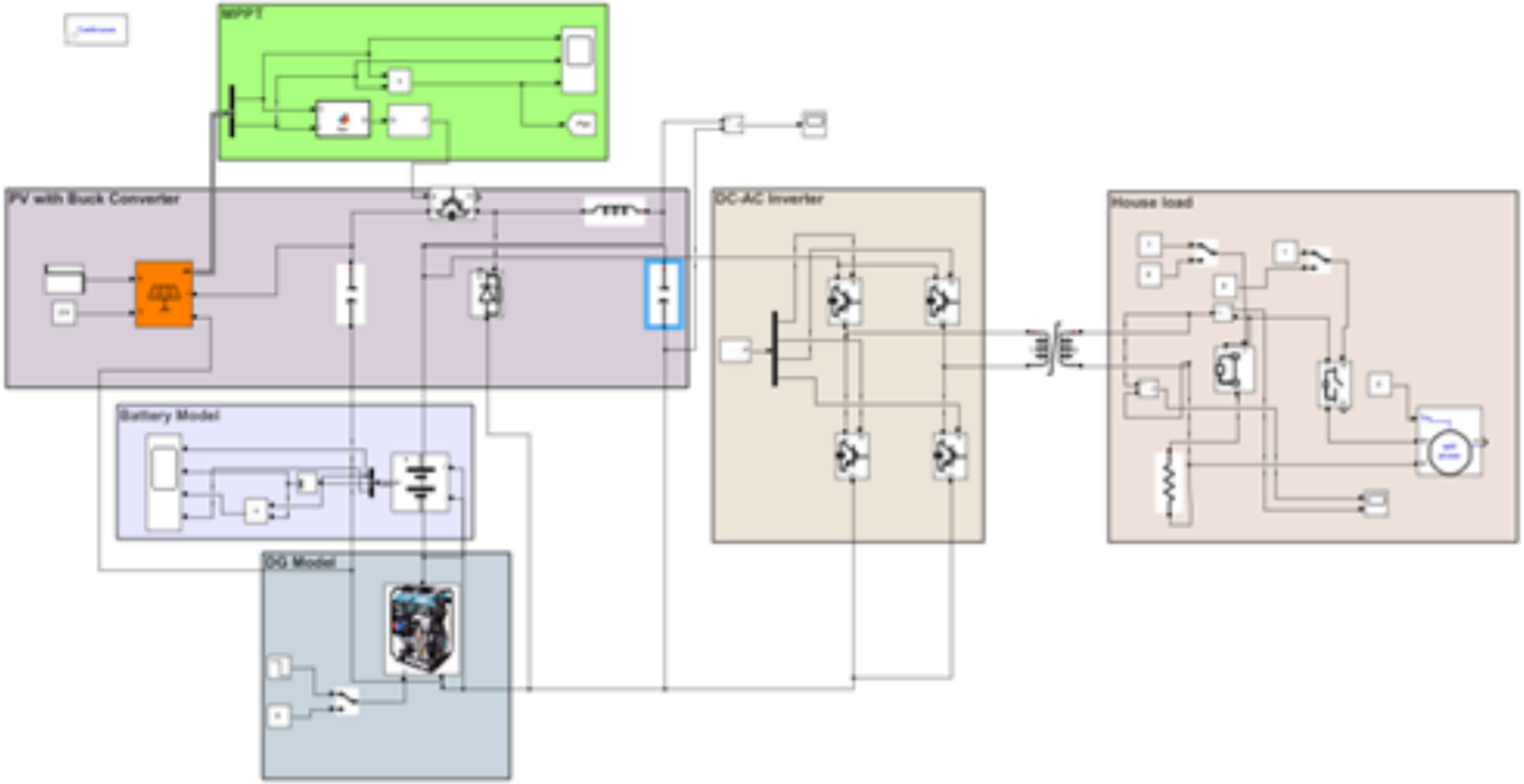
# BUCK CONVERTER

- The buck converter steps down the PV array voltage to meet the system's DC link voltage requirement of 48V.
- The duty cycle of the IGBT switch is dynamically adjusted through MPPT controller to control the voltage, with an LC filter ensuring smooth and stable output.
- The converter's design calculations yield an inductor value of 2.2 mH and a capacitor value of 19.55 μF, optimized for stable and efficient operation in the system.

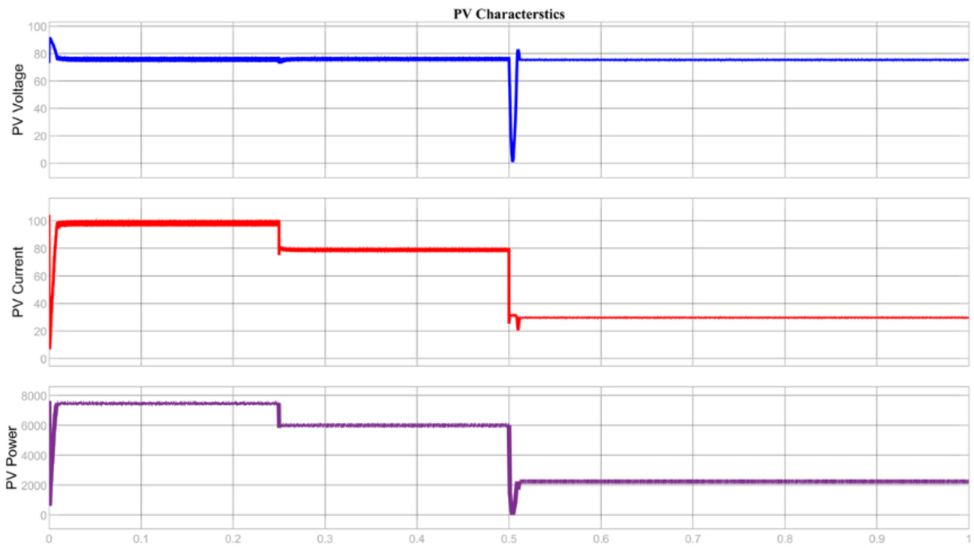


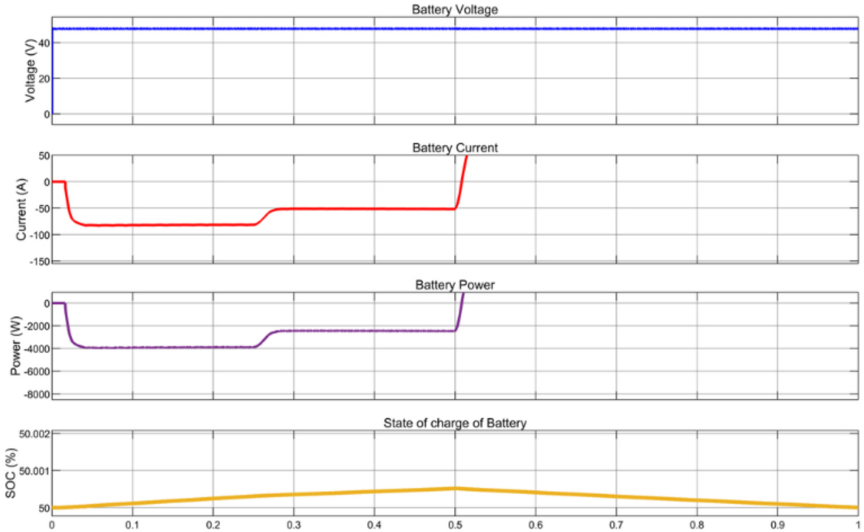

DC - DC Buck Converter

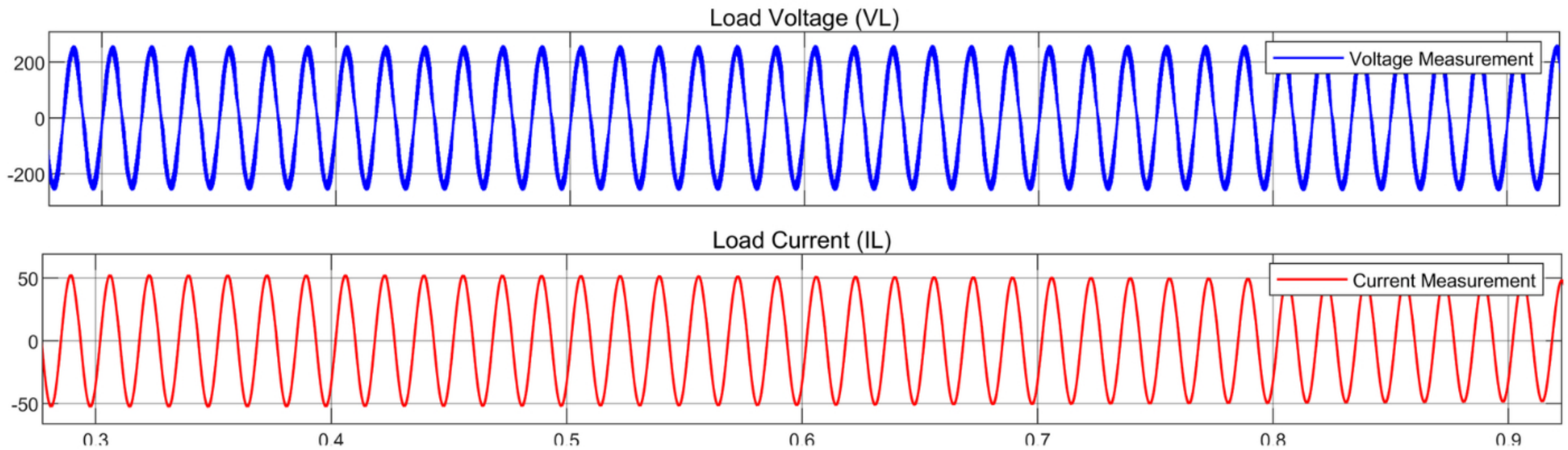
# COMPLETE SYSTEM MODEL IN MATLAB SIMULINK



# SIMULATION RESULTS




220 V, 50 Hz

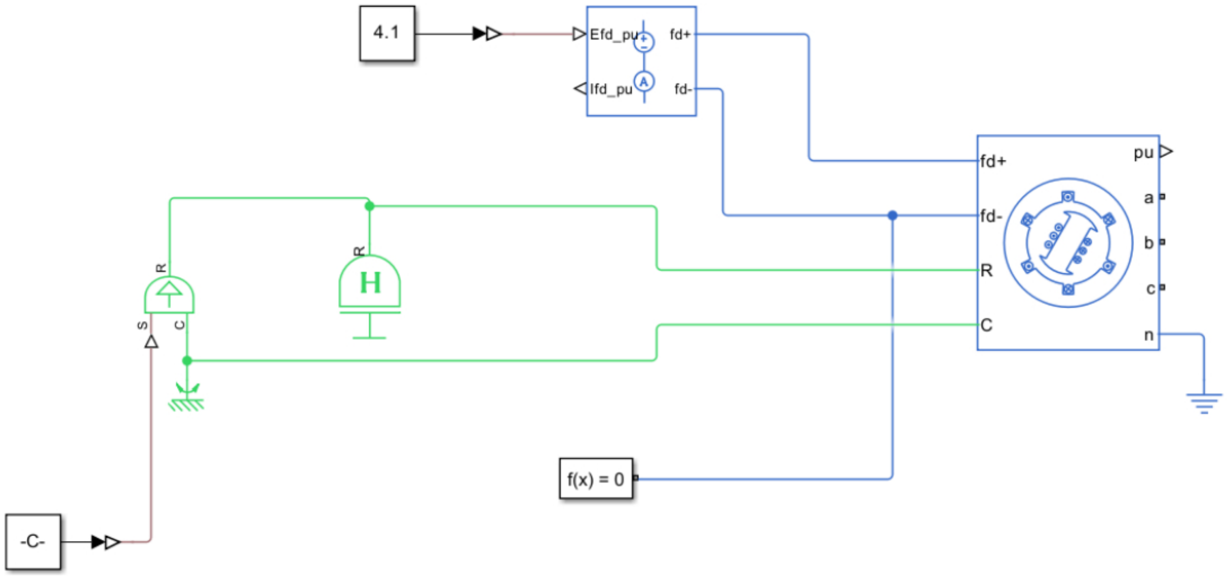
# Control Strategies for Shared Diesel Generator in Hybrid Power System

# DIESEL GENERATOR MODELING AND DYNAMICS

- A four-pole, 50 Hz synchronous generator is rigidly coupled to a diesel engine via a mechanical shaft, ensuring synchronized mechanical and electrical angular displacement.
- Diesel engine converts fuel energy into mechanical torque; engine inertia mitigates torque pulsations and provides a kinetic energy buffer for transient stability.
- Generator excitation current of 32 A produces a rotating magnetic field at 1500 rpm, inducing three-phase voltages for real and reactive power supply.
- Active power regulated by fuel input control; reactive power controlled through excitation current to field winding.
- Dynamic response shaped by direct-axis (Xd) and quadrature-axis (Xq) reactances and their time constants (T′d0, T″q0), critical for voltage stability and damping.

# DIESEL GENERATOR MODELING AND DYNAMICS

- The model simulates mechanical and electrical dynamics, enabling studies on start-up, load changes, fault conditions, and control strategy optimization.



# CONTROL STRATEGY FOR AC LOAD SUPPLY

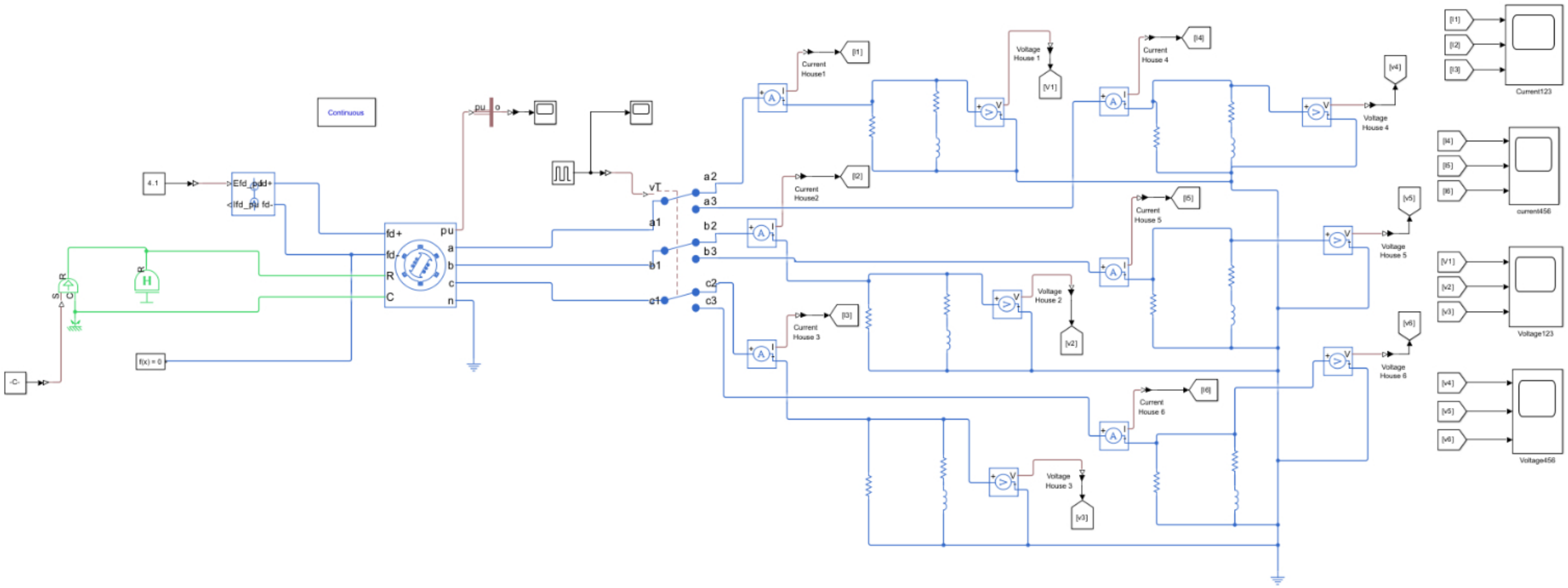
- Diesel generator supplies AC loads during low PV output periods such as nighttime or extended cloudy days.
- Load sharing prevents overloading by alternating power delivery between two groups of houses using a time-sharing scheme.
- Three-phase output dynamically routed via SPDT switches:

1. Phase A alternates between Houses 1 and 4
2. Phase B alternates between Houses 2 and 5
3. Phase C alternates between Houses 3 and 6 (with House 7 combined with House 6).

- Only half of the total neighborhood load is connected at any time, keeping generator current within safe limits.
- Household loads modeled as equivalent impedance networks with resistive and inductive branches i.e approx. 2 kW per house at 220 V, PF ≈ 0.95.

# CONTROL STRATEGY FOR AC LOAD SUPPLY

- Output waveforms confirm stable operation and generator current below rated capacity under this strategy.

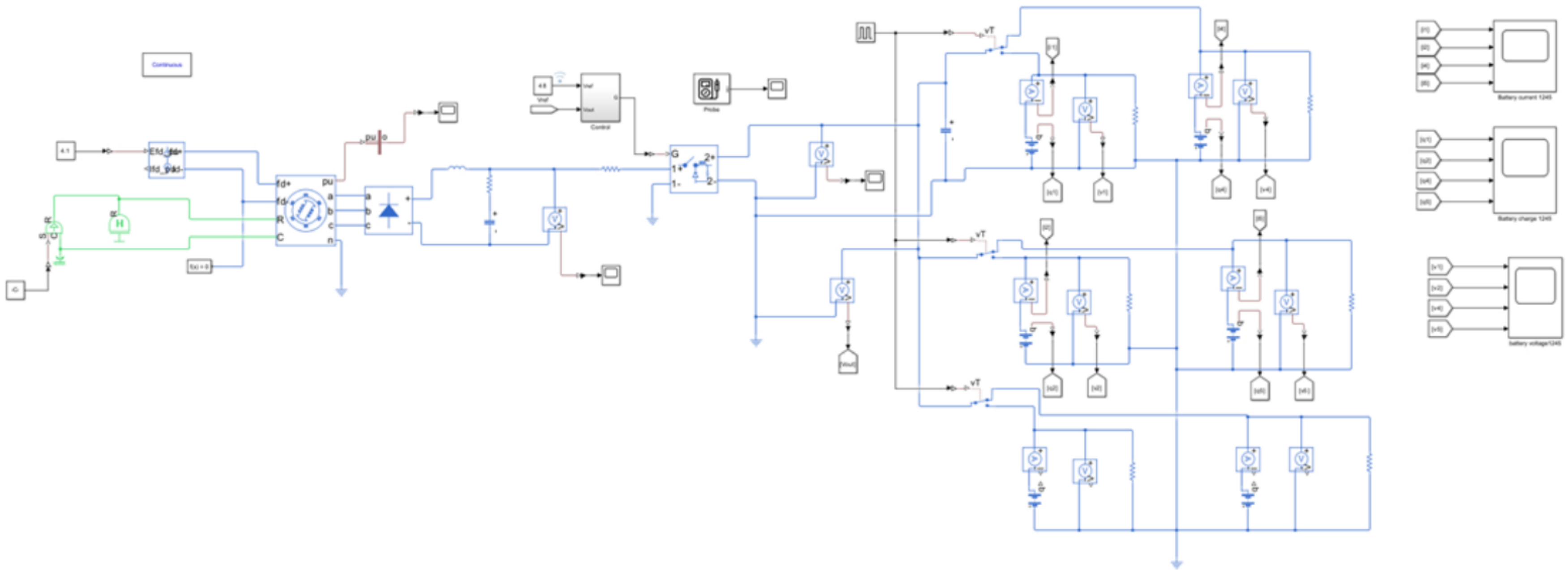


# CONTROL STRATEGY FOR BATTERY CHARGING

- Operates during low solar periods (nighttime, extended cloudy days) to recharge all seven battery banks.
- Diesel generator's three-phase AC output is rectified using a six-pulse diode bridge, then stepped down to 48 V DC via a buck converter.
- Buck converter uses IGBT switches and PWM control at 10 kHz, regulated by a PI controller to maintain stable 48 V DC output.
- All battery banks connected in parallel to the regulated DC bus for simultaneous charging with ideal load sharing in the simulation.
- Centralized AC–DC conversion enables efficient multi-bank charging, outperforming sequential charging methods in both time and energy efficiency.

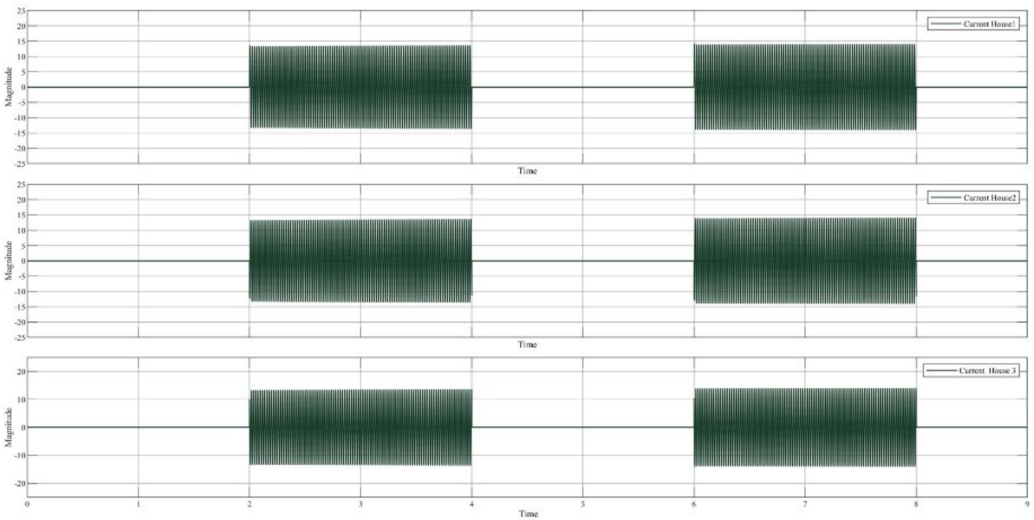
# CONTROL STRATEGY FOR FOR BATTERY CHARGING

- Ensures batteries are replenished to maintain off-grid autonomy during periods of insufficient photovoltaic generation.

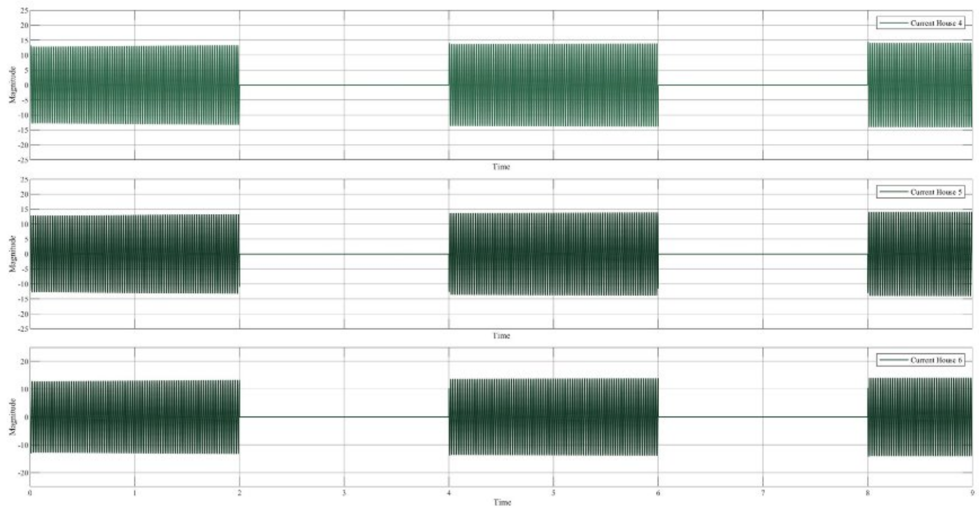


# SIMULATION RESULTS

- Diesel generator supplies 9.65 A RMS per phase for 2 kW loads (resistive 6.81 A, inductive 2.84 A).
- Time-sharing alternates power between two house groups, preventing overload.
- Generator speed remains stable at 1500 rpm with minor transient droops promptly corrected.
- Current waveforms sinusoidal and distortion-free, confirming steady-state operation.



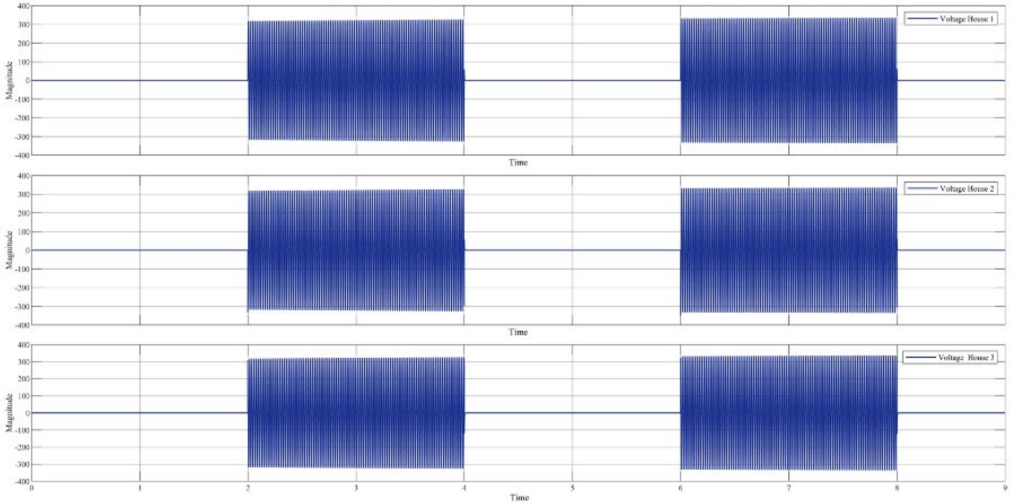

Load current waveforms for House 1, 2 & 3



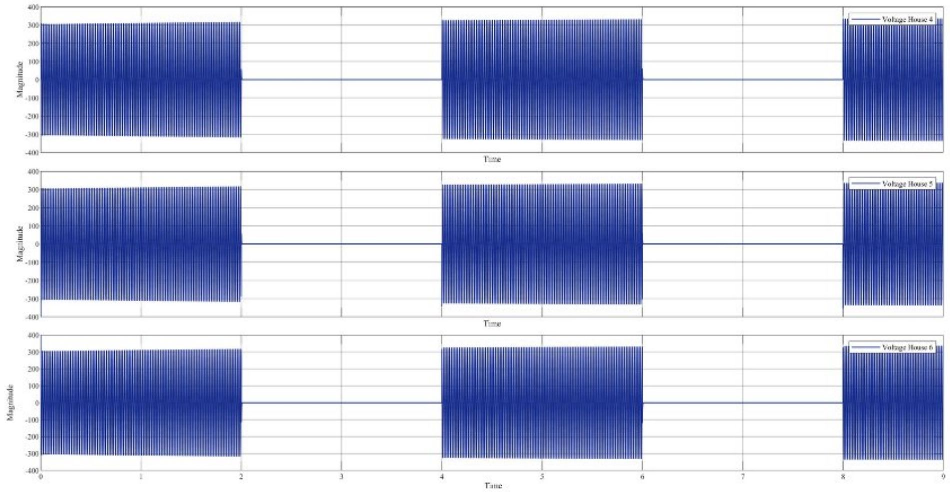

Load current waveforms for House 4, 5 & 6

## SIMULATION RESULTS

- Voltage regulated at ~220 V RMS (311 V peak-to-peak), within ±10% of nominal for Pakistani appliances.
- Minor voltage dips during switching are rapidly corrected by the excitation system and generator inertia.
- Slight phase shift from inductive loads does not impact power quality.



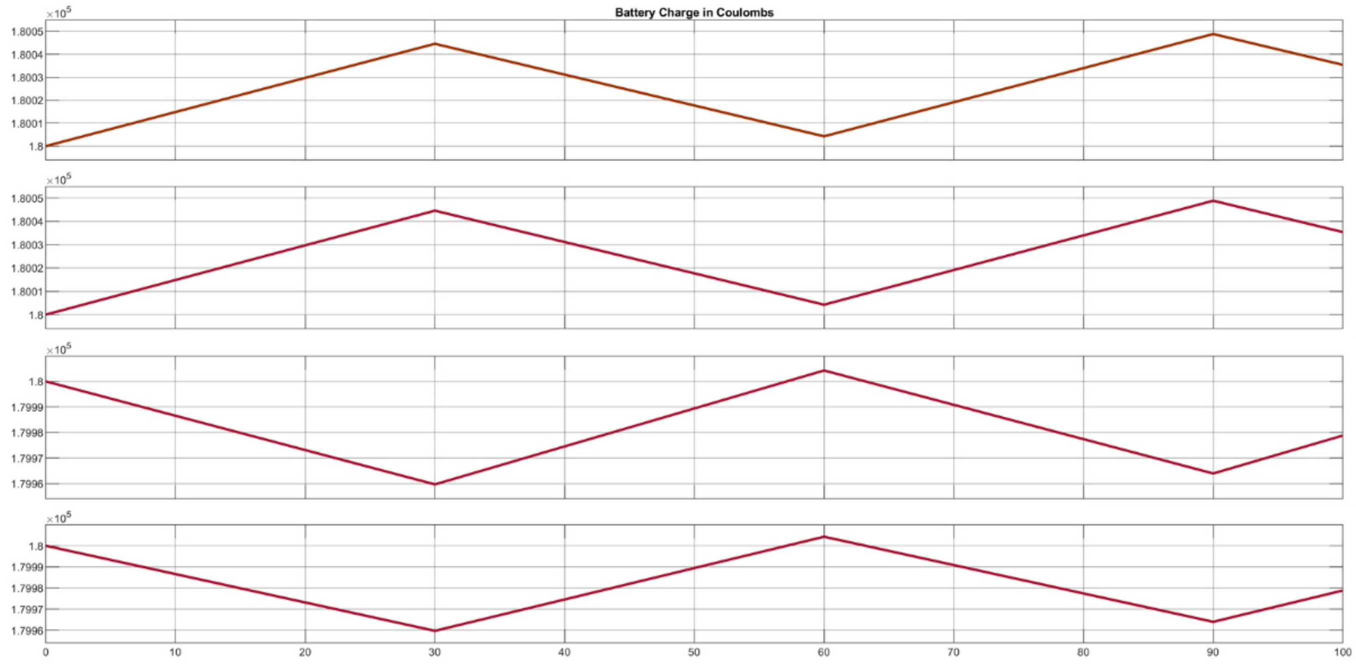

Load Voltage waveforms for House 1, 2 & 3




Load Voltage waveforms for House 4, 5 & 6

# SIMULATION RESULTS

- Centralized 48 V DC bus provides balanced, simultaneous charging of all battery banks.
- Initial high charge rates decrease as batteries approach full capacity, reflecting constant-voltage charging.
- Smooth and stable charge waveforms confirm effective voltage regulation and system autonomy.




Battery charging profile

## CONCLUSION

- This thesis presents a hybrid PV–battery–diesel system designed for urban neighborhoods in Karachi to address energy shortages, grid unreliability, and rising electricity costs.
- Techno-economic analysis using HOMER Pro identified an optimal system configuration, achieving an LCOE of $0.2959/kWh and a 25-year NPC of $15,562.55 while reducing greenhouse gas emissions.
- Dynamic modeling and simulation in MATLAB/Simulink validated system stability, with robust voltage and frequency control under variable solar and load conditions.
- Advanced control strategies were implemented for time-shared load management and centralized battery charging, ensuring efficient resource utilization and preventing generator overloading.
- The proposed system offers a scalable, cost-effective, and sustainable solution for urban energy resilience, supporting Pakistan's transition toward clean and reliable power systems.

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## FUTURE WORK

- **Advanced PV and Storage Technologies:** Explore high-efficiency panels such as bifacial, heterojunction, and perovskite, along with next-generation batteries including lithium-ion, sodium-ion, and flow batteries to enhance performance and reduce lifecycle costs.
- **Enhanced Control Strategies:** Develop Model Predictive Control, artificial intelligence, and machine learning-based controllers for adaptive operation and efficient resource utilization.
- **IoT and SCADA Integration:** Design real-time monitoring and control platforms with smart alerts via SMS or email and automated fault detection to improve system resilience.
- **Optimization Under Uncertainty:** Apply stochastic and multi-objective optimization techniques to manage variability in weather and household energy demand effectively.
- **Hardware Demonstration:** Conduct hardware-in-the-loop testing and field trials to validate control strategies in practical operating conditions.

## LIST OF PUBLICATIONS

- **Kashif, M.; Iqbal, M. T.; Jamil, M.**, Optimal Design of an Off-Grid Solar Energy System Integrated With a Diesel Generator for Urban Areas in Pakistan, J. Electron. Electric. Eng. 2024, 3, 445–459.
- **Kashif, M.; Iqbal, M. T.; Jamil, M.**, "Dynamic Modeling and Simulation of an Isolated Hybrid Power System Designed for Urban Areas in Pakistan, Presented at the 33rd IEEE NECEC Conference, 2024, St. John's, NL.
- **Kashif, M.; Iqbal, M. T.; Jamil, M.**, "Control Strategies for a Shared Diesel Generator in an Off-Grid Hybrid Power System for Urban Areas in Pakistan", European Journal of Electrical Engineering and Computer Science (Accepted, July 2025).
- **Kashif, M.; Iqbal, M. T.; Jamil, M**, "A Case Study: Design, Analysis, and Cost Effectiveness of a Residential 20kW Grid-Connected Photovoltaic System", Presented at the 32nd IEEE NECEC Conference, 2023, St. John's, NL.

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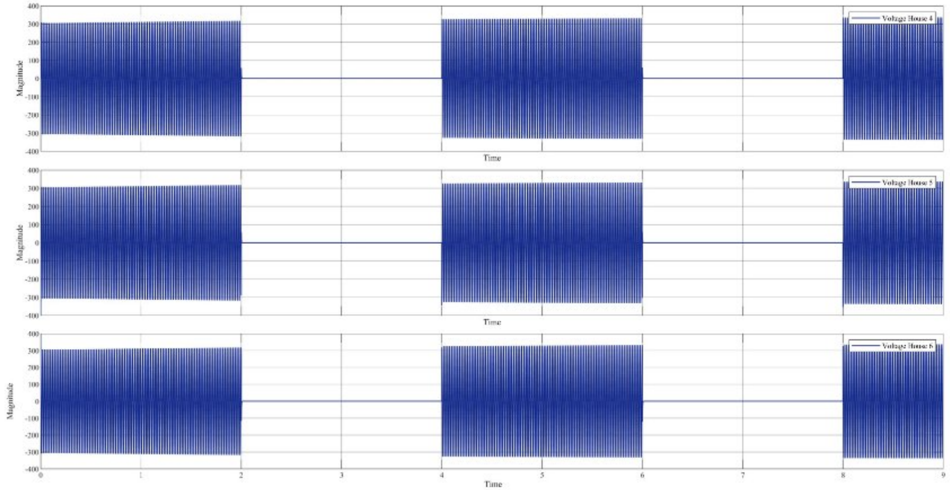


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# Thank you!

If you have any queries, please contact me at

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ANY
QUESTIONS