Solar Energy Integration Using an Energy Management System

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Background

- The importance of renewable energy sources (RES) like solar energy in reducing carbon emissions and other greenhouse gases has contributed to an increase in integration into the conventional grid.

- The intermittent nature of RES means that an increase in grid penetration would lead to reliability and quality issues.

- **Research Question:** How can we improve solar energy penetration in a reliable and sustainable way?

Aims & Objectives

- Aim is to create an integrated energy management system (IEMS) that combines solar energy forecasting (SEF), generator control (GC), time-of-use (TOU) tariffs and direct load control (DLC), thereby improving the reliability of solar based systems so that they can be integrated into the conventional grid.

- Objectives
  - ➢ To assess different IEMS configurations and determine how individual components increase the reliability of solar-based power systems.
  - ➢ To determine the impact of low-data fusion in combining weather parameters from an on-site weather station and a local weather station to improve solar energy forecasting.
  - ➢ To determine the technical, economic, and environmental impact of the proposed IEMS for both on-grid and off-grid solar applications.
  - ➢ To determine the effect of direct load control for both commercial and residential applications.

Methodological Approach - 1

- Literature review to identify research gaps

- Model development and validation: Solar Forecasting Approach

- Develop IEMS Algorithm

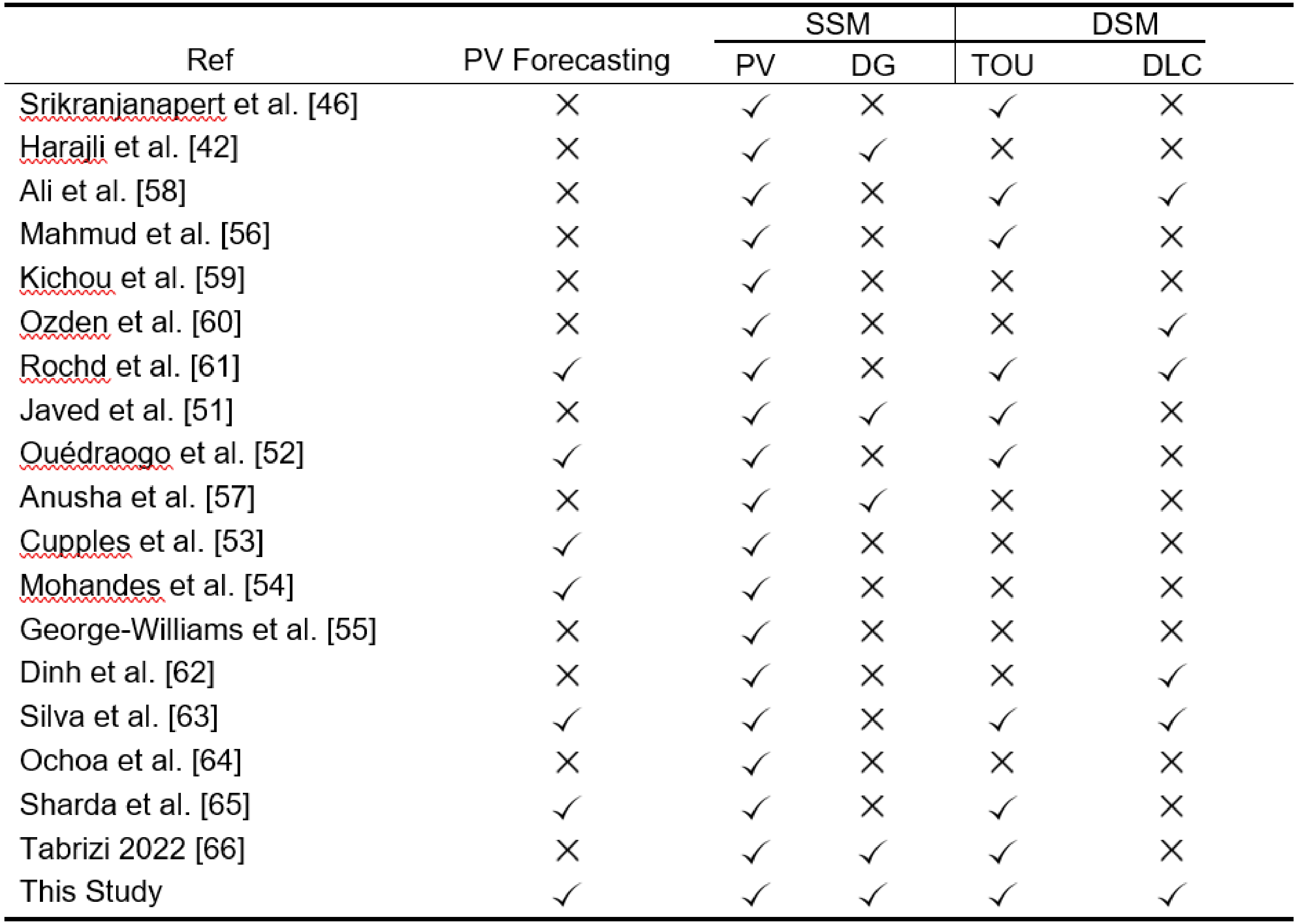
- Techno-economic Analysis of IEMS
    - ➢Levelized Cost of Energy (LCoE), Net Present Value (NPV) etc.

- Optimisation of IEMS model using Performance Ratio Method

- Validate DLC

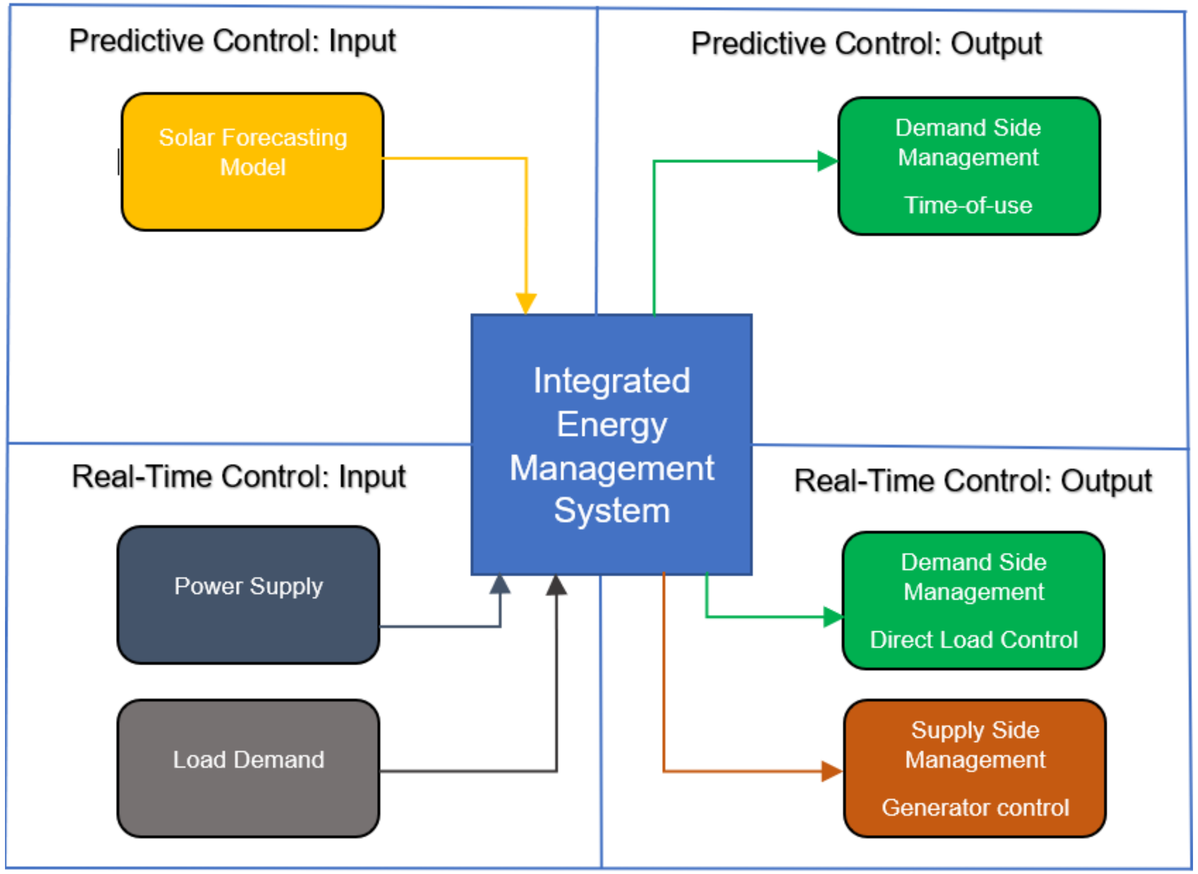
Key Findings 1 – IEMS Definition and Research Gap

IEMS is a system that leverages advancement in technology and communication (particularly through the internet-of-things), integrating predictive and real-time controls to initiate both supply and demand responses in balancing the load and power supply in the grid.



Ref	PV Forecasting	SSM		DSM	
		PV	DG	TOU	DLC
Srikranjanapert et al. [46]	✗	✓	✗	✓	✗
Harajli et al. [42]	✗	✓	✓	✗	✗
Ali et al. [58]	✗	✓	✗	✓	✓
Mahmud et al. [56]	✗	✓	✗	✓	✗
Kichou et al. [59]	✗	✓	✗	✗	✗
Ozden et al. [60]	✗	✓	✗	✗	✓
Rochd et al. [61]	✓	✓	✗	✓	✓
Javed et al. [51]	✗	✓	✓	✓	✗
Ouédraogo et al. [52]	✓	✓	✗	✓	✗
Anusha et al. [57]	✗	✓	✓	✗	✗
Cupples et al. [53]	✓	✓	✗	✗	✗
Mohandes et al. [54]	✓	✓	✗	✗	✗
George-Williams et al. [55]	✗	✓	✗	✗	✗
Dinh et al. [62]	✗	✓	✗	✗	✓
Silva et al. [63]	✓	✓	✗	✓	✓
Ochoa et al. [64]	✗	✓	✗	✗	✗
Sharda et al. [65]	✓	✓	✗	✓	✗
Tabrizi 2022 [66]	✗	✓	✓	✓	✗
This Study	✓	✓	✓	✓	✓

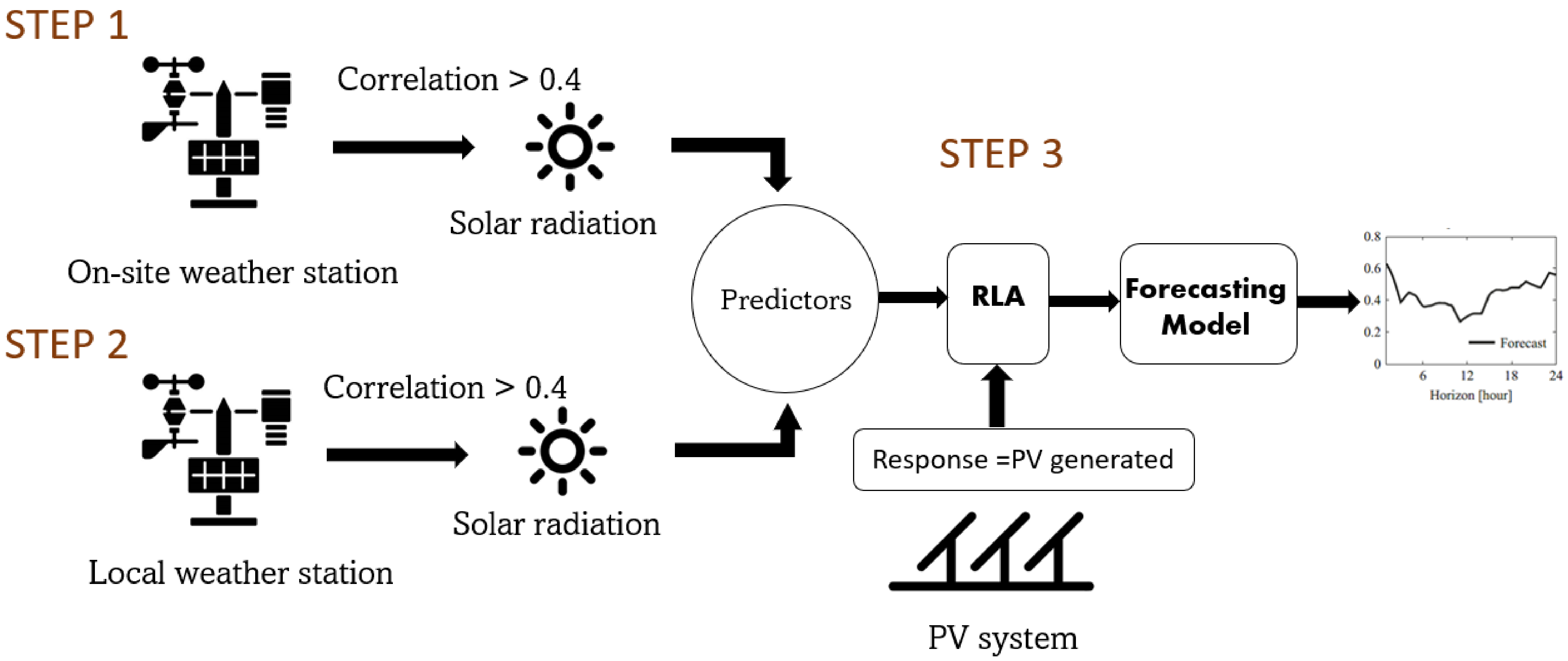
Key Findings 2 –IEMS Framework and Forecasting Approach



Current IEMS Framework

Key Findings - 3

- A novel three-step weather data solar forecasting architecture



STEP 1

Correlation > 0.4

Solar radiation

On-site weather station

STEP 2

Correlation > 0.4

Solar radiation

Local weather station

STEP 3

Predictors

RLA

Forecasting Model

Response =PV generated

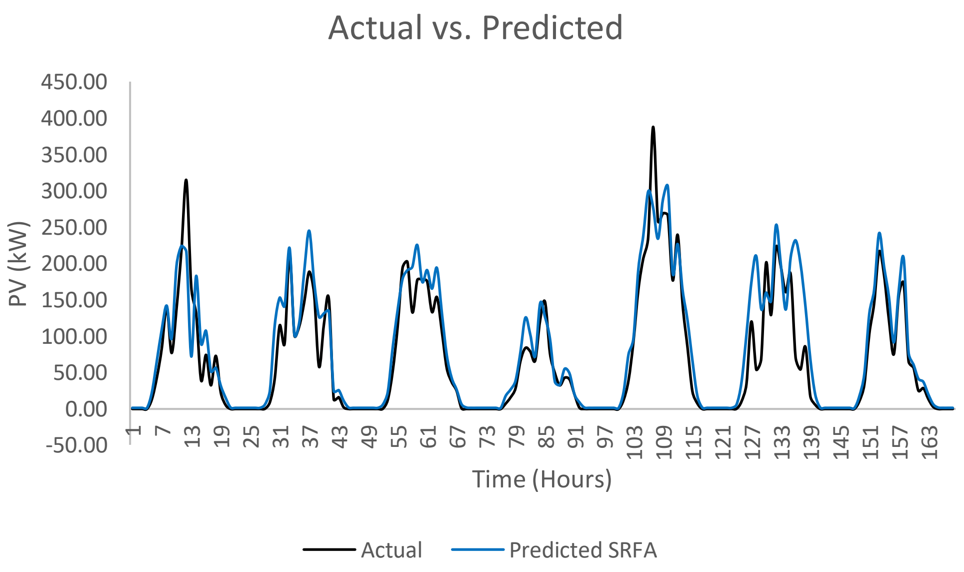
PV system

Key Findings - 3

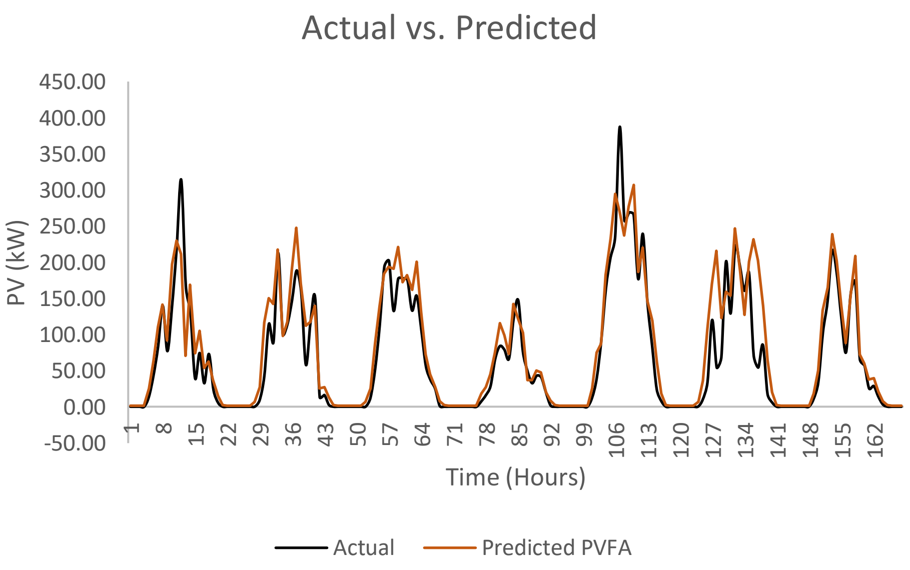
- Photovoltaic power is an equal and strong alternative to solar radiation and can be used as reference parameter in predicting next-day SE generation.

	Training				Testing			
MODEL	RMSE	MSE	MAE	R^2	RMSE	MSE	MAE	R^2
Boosted Trees	0.1042	0.0109	0.0571	0.82	0.0859	0.0074	0.0448	0.84

	Training				Testing			
MODEL	RMSE	MSE	MAE	R^2	RMSE	MSE	MAE	R^2
Boosted Trees	0.1059	0.0112	0.0578	0.81	0.0864	0.0075	0.0448	0.84



One-week Prediction Using Solar Radiation (SRFA)



One-week Prediction Using Photovoltaic Generation (PVFA)

Key Findings - 4

- The three-step weather data solar forecasting approach was validated for lower capacity PV systems in three other buildings with 8.26 kWp, 10.45 kWp and 15 kWp arrays.

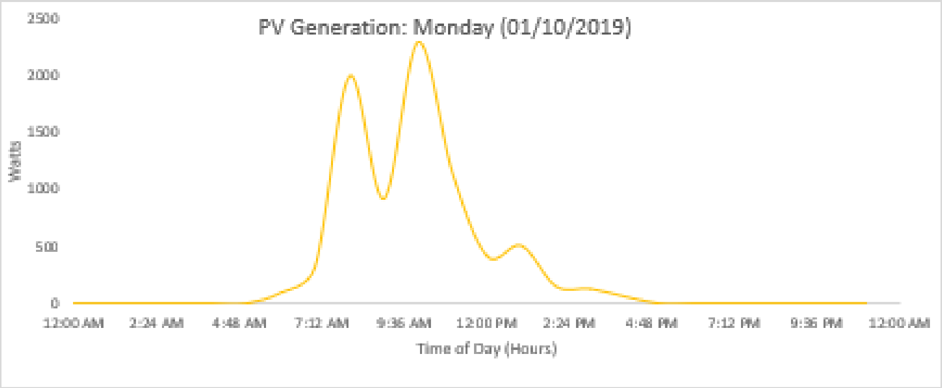
15 kWp	**SRFA**				**PVFA**			
MODEL	RMSE	MSE	MAE	R^2	RMSE	MSE	MAE	R^2
Boosted Trees	0.0885	0.0078	0.0499	0.68	0.0922	0.0085	0.0522	0.65
8.26 kWp	**SRFA**				**PVFA**			
MODEL	RMSE	MSE	MAE	R^2	RMSE	MSE	MAE	R^2
Boosted Trees	0.0984	0.0097	0.0547	0.67	0.1002	0.0100	0.0559	0.65
10.45 kWp	**SRFA**				**PVFA**			
MODEL	RMSE	MSE	MAE	R^2	RMSE	MSE	MAE	R^2
Boosted Trees	0.1425	0.0203	0.0811	0.52	0.1406	0.0198	0.0794	0.53

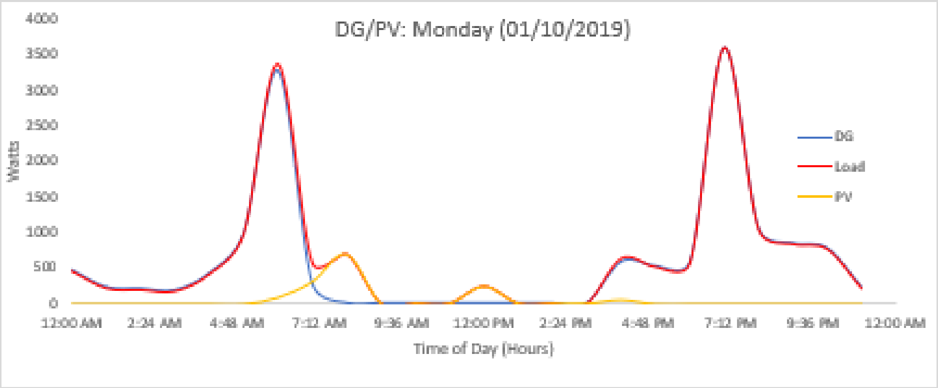
Case Study

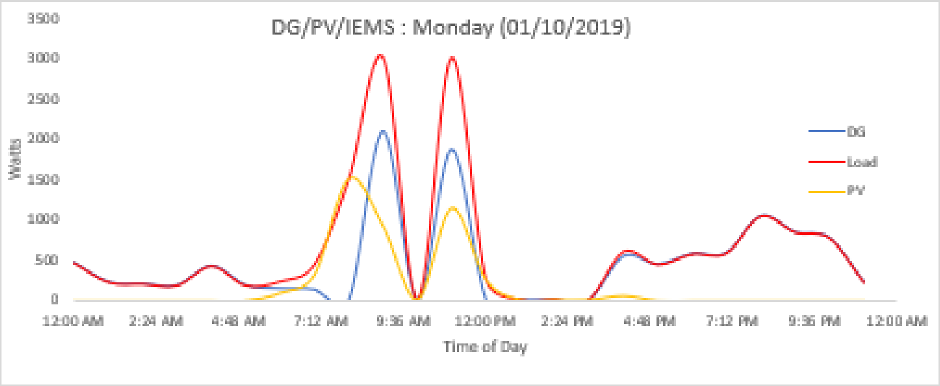
- Perform a techno-economic analysis for a 7.5kVA/10kW dg-solar hybrid configuration using the IEMS framework.

- Compare 2 configurations:
  - ➢DG/PV
  - ➢DG/PV/IEMS

Key Findings 5 – Comparison of DG/PV and DG/PV/IEMS Configurations





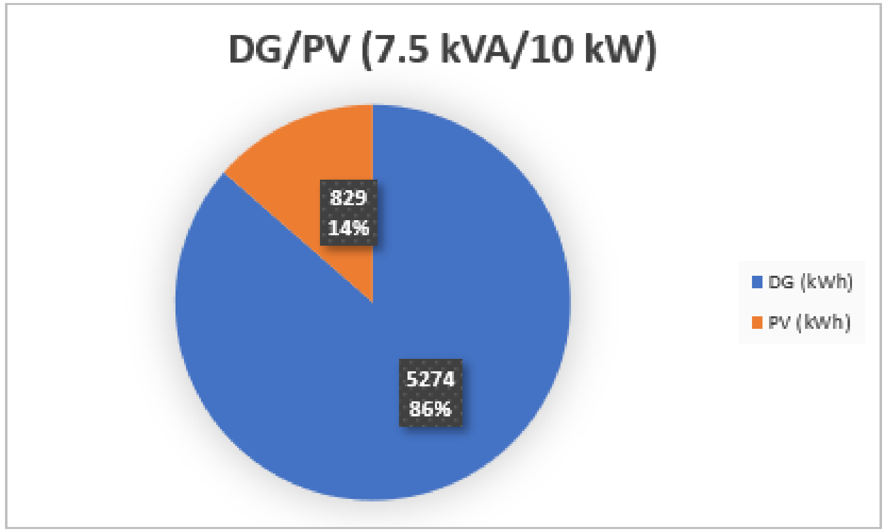


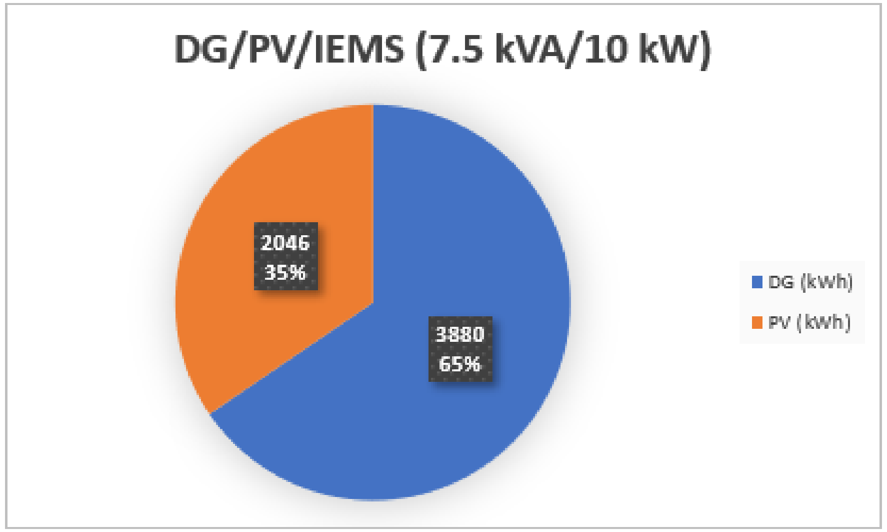
Key Findings 6 – Techno-economic Analysis of IEMS

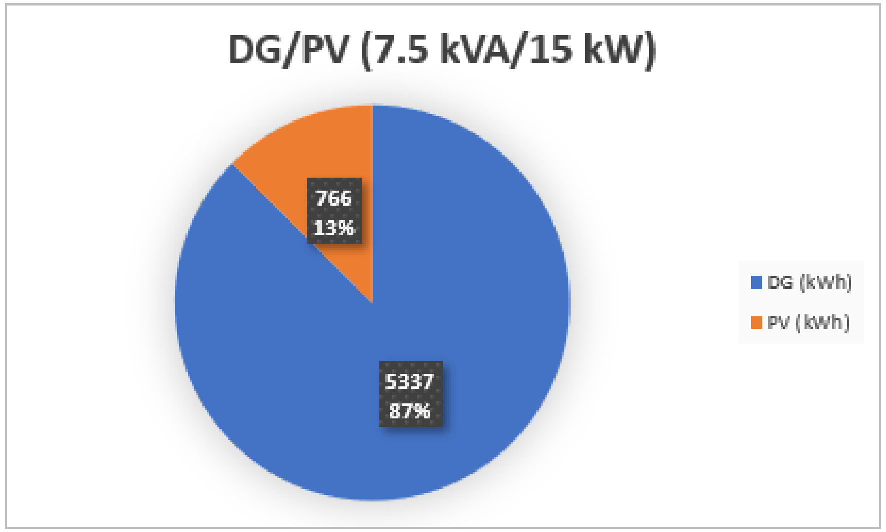
			Performance	
	DG/PV	**DG/PV/IEMS**	**DG/PV**	**DG/PV/IEMS**
Lifetime expenditure	£333,584.23	£328,355.17		✓
Lifetime net income	£138,816.17	£143,153.41		✓
Lifetime net electricity generation	152,664 kWh	124,916 kWh	✓	
PP	2.23 years	2.47 years	✓	
NPV	£123,316.17	£125,453.41		✓
LCCA	£210,268.06	£202,901.76		✓
CBR	2.51	2.42		✓
LCoE	£2.19/kWh	£2.63/kWh	✓	
CO2 Emissions	489,187 kg CO2e	478,471 kg CO2e		✓

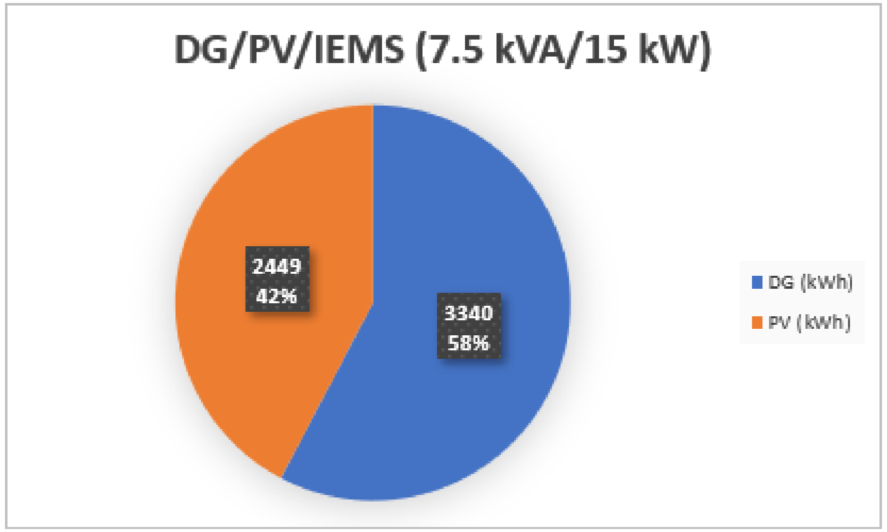
Condition	**Definition**	**Result**
NPV > 0	Investment adds value	Project may be accepted
NPV < 0	Investment subtracts value	Project should be rejected
NPV = 0	Investment neither gains nor loses value	Project will break-even. Other criteria needed for decision
$IRR_2 > IRR_1$	Project 2 has a higher IRR than project 1	Project 2 is more desirable
LCCA > 0	Fails to generate net income	Project may be rejected
LCCA < 0	Generates net income	Project should be accepted
LCCA = 0	Breaks even	Adds no monetary value. Other criteria needed for decision
CBR > 1	Cost exceeds benefit	Project may be rejected
CBR < 1	Benefit exceeds cost	Project should be accepted
CBR = 1	Benefit equals cost	Adds no monetary value. Other criteria needed for decision
$PP_2 > PP_1$	Project 2 has a longer PP than project 1	Project 1 could be more desirable
Cost > LCoE	Electricity cost exceeds LCoE	Greater return on capital
Cost < LCoE	LCoE exceeds electricity cost	Lower return and a possible loss

Key Findings 7 – PV Size Optimization Analysis


DG/PV (7.5 kVA/10 kW)


DG/PV/IEMS (7.5 kVA/10 kW)


DG/PV (7.5 kVA/15 kW)


DG/PV/IEMS (7.5 kVA/15 kW)

Limitations

- Research was limited to grid-tie configurations without a focus on batteries.
- Limited data from on-site weather station
- DLC data analysis yet to be completed

Conclusion

- IEMS that integrates solar energy forecasting (SEF), generator dispatch control (GC) as a SSM technique, time-of-use tariffs (TOU) and direct load control (DLC) as DSM techniques, is a viable solution and one that if successfully implemented can support solar integration.