SINGAPORE INSTITUTE OF TECHNOLOGY
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Electrical Power Engineering

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A Microgrid Approach to Energy Cost Reduction and Emission Reduction for Sustainable Port Operations

INTRODUCTION

This project is dedicated to the research and development of an energy management system for Jurong Port in Singapore, aiming to optimize energy cost savings and reduce carbon emissions. The energy management system algorithm will be designed using Python. The optimization will be based on data including electrical tariff rates, energy consumption, solar PV generation, and grid network configuration.

Jurong Port

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OBJECTIVE

- To design an optimization algorithm to minimize the total operational cost of the microgrid

Cost of charging/discharging the ESS
Shedding cost

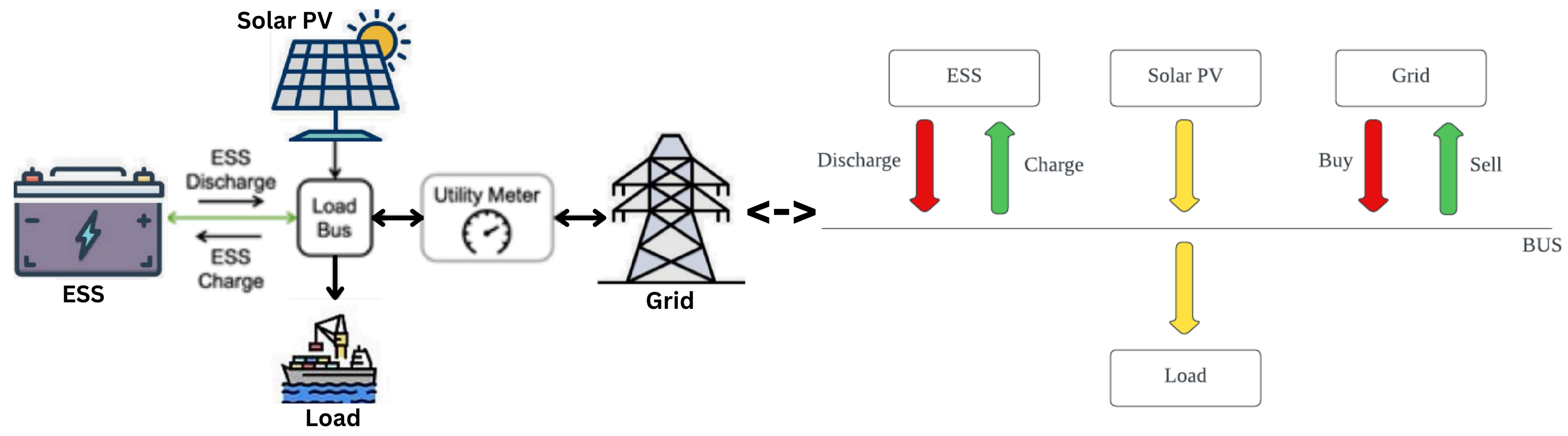
Buying cost of Electricity from grid
Revenue from selling electricity to grid

- To ensure efficient power management & satisfy various operational constraints

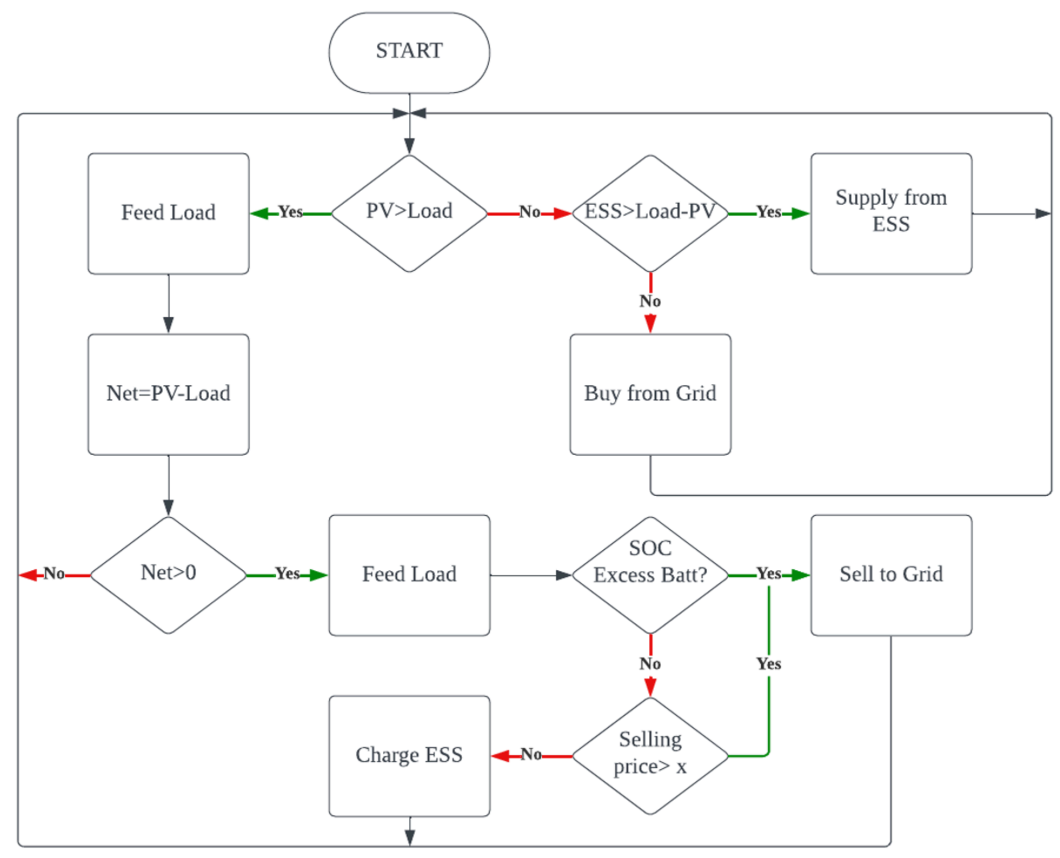
CONSTRAINT

→ Power balance
→ State of Charge (SOC)
→ Power Exchange
→ Power buying/ selling
→ Load shedding
→ Community Distributed Generator (CDG)

SYSTEM CONFIGURATION



WORKFLOW



METHODOLOGY

- **Mixed-Integer Linear Programming (MILP)**

Mathematical optimization approach where the objective function and constraints are linear, but some variables are constrained to be integers.

- **Hierarchical Approach**

Hierarchical optimization involves solving optimization problems in a multi-level or staged manner, where the solution of one level influences the other. This can be particularly useful in complex systems like microgrids where decisions can be made at different levels

→ High-Level Decision	Determine the capacity of ESS
→ Medium-Level Decision	Determine the initial SOC level
→ Lower-Level Decision	Determine the amount of energy to buy/sell to grid in real-time
	Optimize the charging/ discharging cycle
	Implement load shedding strategies during peak demand period

VARIABLES

- Decision Variables

→ Continuous Variables	→ Integer Variables
Price buy/sell	Buying/ Selling Indices
Charge/discharge Power	Charging/ Discharging Indices
Energy in ESS	
Load Shedding Power	

- Objective Function

→ Total Cost $\text{Total Cost} = C_{ex} + C_{ESS} + C_{shed}$

→ Cost of power exchange $C_{ex} = \sum_{i=1}^{n_{grid}} \sum_{j=1}^{T} (P_b[i,j]\, \rho_b[i,j] - P_s[i,j]\, \rho_s[i,j]) \cdot \Delta t$

→ Cost of charging/ discharging power $C_{ESS} = \sum_{i=1}^{n_{bat}} \sum_{j=1}^{T} (P_{ch}[i,j]\, \gamma_{ch}[i] + P_{dis}[i,j]\, \gamma_{dis}[i]) \cdot \Delta t$

→ Cost of load shedding $C_{shed} = \sum_{i=1}^{n_{load}} \sum_{j=1}^{T} P_{shed}[i,j]\, \lambda_{shed}[i] \cdot \Delta t$

i = grid
j = time step

OPTIMIZATION

Import Data →

```
PVdata = pd.read_csv("./JP/PV.csv")
PVdata
```

Variable Input →

```
def C_ex_objective_expr(model):
    return sum(model.Pb[i, j] * model.pb[i, j] - model.Ps[i, j]
```

Constraints →

```
def buy_sell_rule(model, i, j):
    return model.ζb[i,j] + model.ζs[i,j] <= 1
```

Solver →

```
solver = pyo.SolverFactory('glpk')
results = solver.solve(model)
```

Output

RESULTS

- Difference in operational cost with different PV load profiles

→ **Theoretical assumption**

The system with higher power developed by PV should have a lower operational cost

→ **Actual Test results**

PV power(kWh)	Test Results	Avg. Operational Cost (SGD)
300	27/02/23 started. 515.2596887712966 BC test sample 27/02/23 with cost = 515.2596887712966 28/02/23 started. 794.7147886363158 BC test sample 28/02/23 with cost = 794.7147886363158 Test set average cost = 660.698821221058	660.7
500	BC test sample 26/02/23 with cost = -115.81470961157885 27/02/23 started. -1051.387909816315 BC test sample 27/02/23 with cost = -1051.387909816315 28/02/23 started. -1007.7413756078939 BC test sample 28/02/23 with cost = -1007.7413756078939 Test set average cost = -739.5022949552067	-739.5

- **Conclusion**

With all the other elements of the system kept constant, increasing the power generated by PV from 300kWh to 500kWh successfully decreased the daily average operational cost from $660.7 to $-739.5 where the negative sign indicates profit from selling power to the grid.

FUTURE WORK

Current

Microgrid

Future

Microgrid Community

Currently, the designing of the optimization algorithm is focused on catering for a single microgrid. However, with strong fundamental algorithm as a skeleton, forming of a microgrid community could be achieved.

REFERENCES

[1] P. Tian, X. Xiao, K. Wang and R. Ding, "A Hierarchical Energy Management System Based on Hierarchical Optimization for Microgrid Community Economic Operation," in IEEE Transactions on Smart Grid, vol. 7, no. 5, pp. 2230-2241, Sept. 2016, doi: 10.1109/TSG.2015.2470551.
[2] Q. Jiang, M. Xue and G. Geng, "Energy Management of Microgrid in Grid-Connected and Stand-Alone Modes," in IEEE Transactions on Power Systems, vol. 28, no. 3, pp. 3380-3389, Aug. 2013, doi: 10.1109/TPWRS.2013.2244104.
[3] M. D. Ilic, "From hierarchical to open access electric power systems," Proc. IEEE, vol. 95, no. 5, pp. 1060–1084, May 2007.