Decentralised Integration of Renewable Energy Sources Through Smart Grid Technologies (DIRECT)

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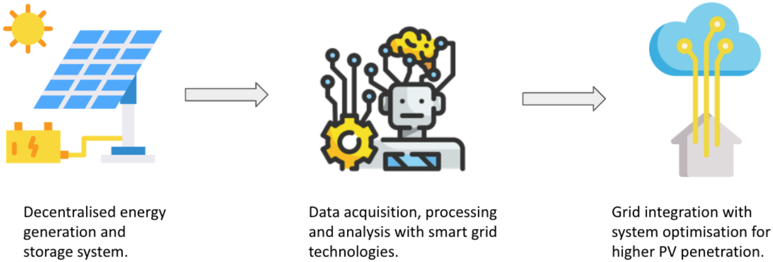

Figure 1: Fundamental areas of DIRECT Project.

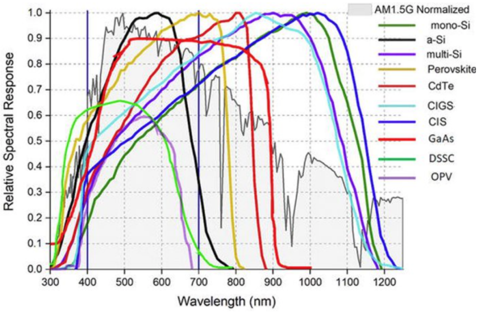

Figure 2: Spectral response per material

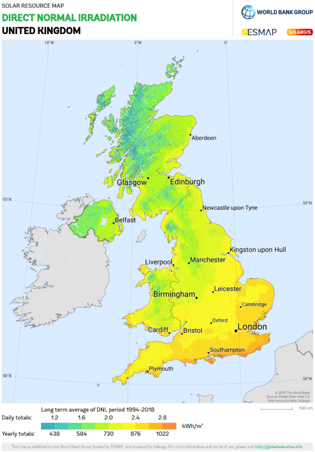

Figure 3: Annual irradiance distribution in the United Kingdom

PV Single Diode Modeling

- The Single Diode method defines the I-V (current-voltage) curve for a single-cell P-N junction as:[1]

$$I = I_L - I_o(e^{\frac{q(V+IR_s)}{nkV_{th}}} - 1) - \frac{V + IR_s}{R_{sh}} \tag{1a}$$

where I_L is the light current generated by the solar cell, I_o the diode reverse saturation current, R_s series resistance, R_{sh} shunt resistance. N_s is the number of series-connected cells, q electron charge, k Boltzmann's constant, n is the ideality factor and T_c is the cell temperature.

- I_L can be calculated as:

$$I_L = \frac{S}{S_{ref}}(I_{L,ref} + \alpha_{I_{sc}}(T_c - T_{c,ref})) \tag{1b}$$

[1] W. De Soto, S. A. Klein, and W. A. Beckman, “Improvement and validation of a model for photovoltaic array performance,” *Solar energy*, vol. 80, no. 1, pp. 78–88, 2006

PV Power Output from Single Diode Method

- For any given traditional Silicon PV parameters evaluted with Eq. 1a, the maximum power output would be calculated as:

$$P^t_{SI-PV}(S, T_c) = V_{mpp}(S, T_c) I_{mpp}(S, T_c) \tag{2}$$

where V_{mpp}, I_{mpp} are the calculated voltage and current maximum power points in the I-V curve respectively for S and T_c at given time t.

PV Power Output from Single Diode Method

- **Low-Light Enghanced PV** Low-Light Enhanced PV (LLE-PV) output power is calculated based on Si-PV power output using Eq. 2. The power output of LLE-PV is determined as:

$$P^t_{LLE-PV}(S, T_c) = P^t_{SI-PV}(S, T_c) \cdot \delta_{mat}(S, T_c) \tag{3}$$

where δ_{mat} is the potential PCE increase and decrease from irradiance and temperature based on the material characteristics.

PV Power Output from Single Diode Method

- **Calculating δ_{mat}:**
  This coefficient is determined by the expected temperature and irradiance impact on the material from 1 Sun to 0.01 Sun.

$$\delta_{mat}(S, T_c) = \frac{\Phi(S) + B(T_c)}{PCE^{max}_{LLE-PV}} \tag{4}$$

where PCE_{STC} is the PCE at STC from chosen PV characteristics. $\Phi(S)$, $B(T_c)$ are linear functions behaviour of light impact in PCE expected from the material in analysis respectively. $\Phi(S)$ can be determined as:

$$\Phi(S) = \frac{PCE^{max}_{LLE-PV} - PCE^{min}_{LLE-PV}}{S_{ref}}(S) + PCE^{max}_{SI-PV} \tag{5}$$

where PCE^{max}_{LLE-PV}, PCE^{min}_{LLE-PV} are the expected PCE at 1000 W/m^2 and 1 W/m^2 respectively. Similarly, the temperature function $B(T_c)$ can be calculated as:

$$B(T_c) = \begin{cases} T_c \cdot |\beta_{SI-PV} - \beta_{LLE-PV}| & \text{if } \beta_{SI-PV} > \beta_{LLE-PV} \\ 1 & \text{if } \beta_{SI-PV} = \beta_{LLE-PV} \\ T_c \cdot (\beta_{LLE-PV} - \beta_{SI-PV}) & \text{otherwise} \end{cases} \tag{6}$$

where β_{SI-PV}, β_{LLE-PV} is the %/°C of power efficiency decrease from Si-PV and LLE-PV respectively.

Self-Consumption model

- The power consumed from the grid or provided to the grid, later shown as grid to house (G2H) or house to grid (H2G) respectively, are described by P_H^t and is calculated as:
$$P_H^t = P_{load}^t - P_{PV}^t - P_{bat}^t \tag{7}$$
where P_{load}^t is the power consumption of the house, P_{PV}^t is the power generated by PV system and P_{bat}^t is the power taken or given to the battery at time t respectively. P_{bat}^t can be calculated as:
$$P_{bat}^t = \begin{cases} max(P_{PV}^t - P_{load}^t, P_r^t, P_d^{max}) & \text{if } P_{load}^t > P_{PV}^t \\ min(P_{PV}^t - P_{load}^t, P_a^t, P_c^{max}) & \text{if } P_{load}^t < P_{PV}^t \end{cases} \tag{8}$$
where P_r, P_a are the power required and power available in battery states respectively, P_c^{max}, P_c^{max} are the charging and discharging maximum rating.

Self-Consumption model

- Power required and available can be determined as:

$$P_r = (SoC^{t-1} - SoC^{min}) \cdot C_{bat} \cdot \eta_c \tag{9}$$

$$P_a = \frac{(SoC^{max} - SoC^{t-1}) \cdot C_{bat}}{\eta_d} \tag{10}$$

The State of Charge (SoC) of the battery system is given by SoC^t and is calculated as:

$$SoC^t = \frac{SoC^{t-1} + (\eta_c)^{Z_{bat}} (\eta_d)^{Z_{bat-1}} \cdot P_{bat}^t \cdot \Delta t}{E_{cap}} \cdot 100\% \tag{11}$$

where SoC^{t-1} is the previous state of charge in the battery, η_c and η_d are the battery charging and discharging efficiency coefficients respectively.

Results

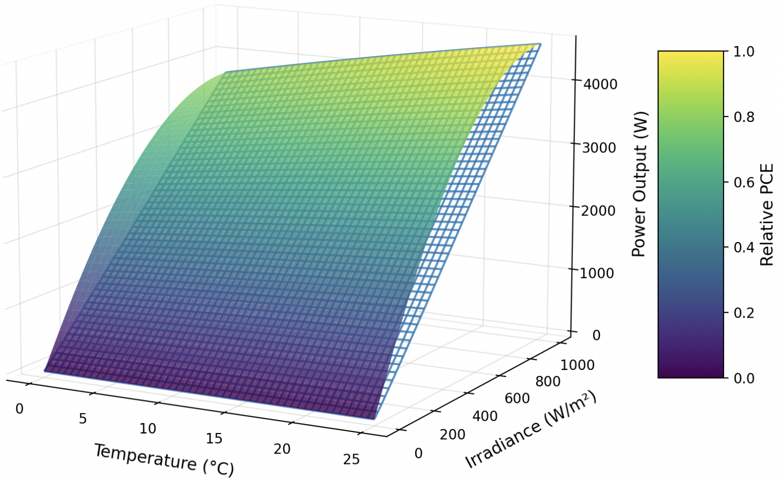

Figure 4: Power generation from 1 to 2 δ_{mat}

Results

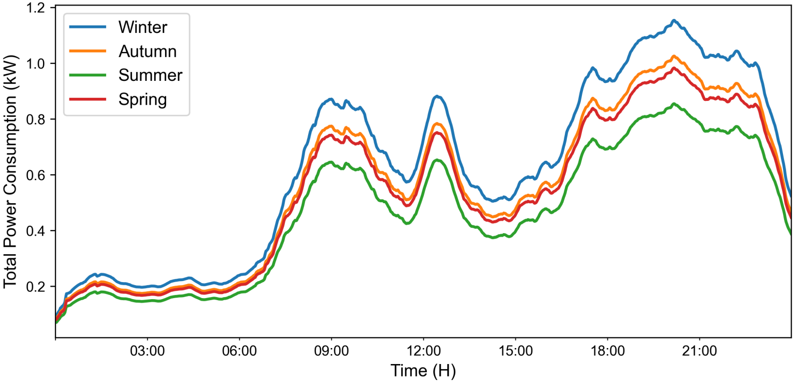

Figure 5: Load utilised for calculating self-consumption accounting for season energy consumption increase

Results

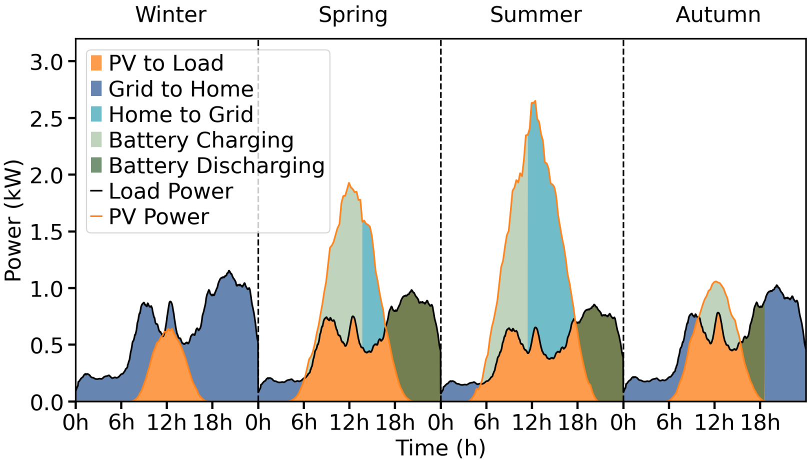

Figure 6: Power generation by Silicon technology per season

Results

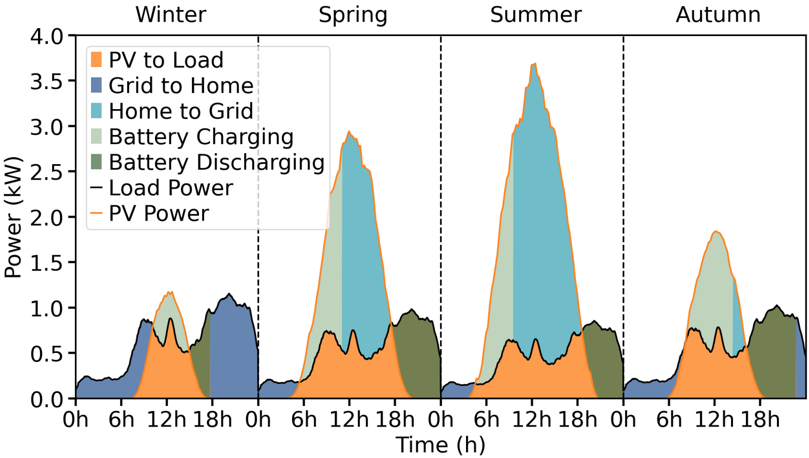

Figure 7: Power generation by LLE technology per season

Results

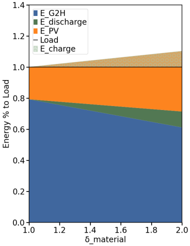

Figure 8: Winter

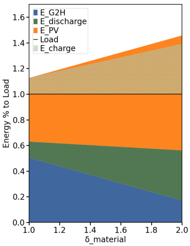

Figure 9: Autumn

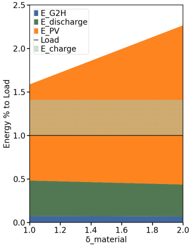

Figure 10: Spring

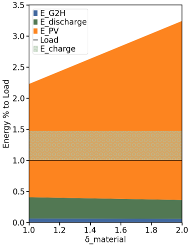

Figure 11: Summer

Thank you for your attention.