Experiment-6

Study of the solar PV plant installed at IIT Kharagpur

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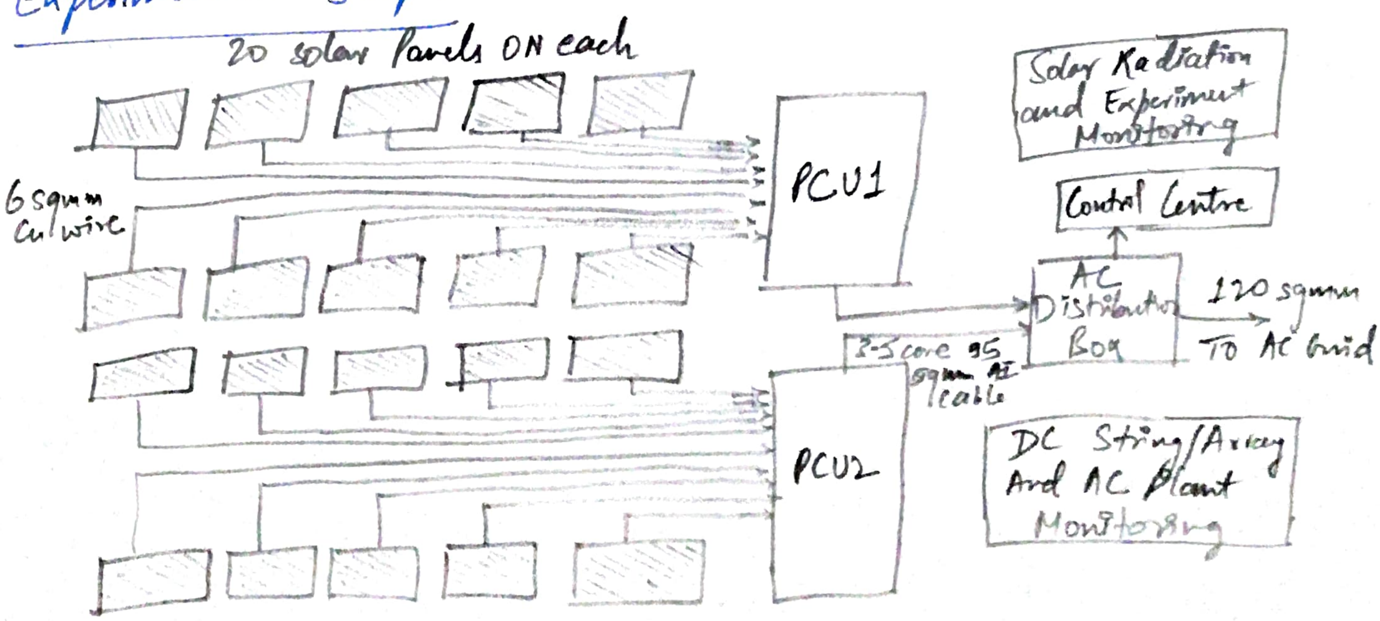
Objective:

1. To familiarize with the 100 kW grid-connected solar PV plant installed at the rooftop of the LLR hall of residence, IIT Kharagpur.
2. To understand the procedure to access performance data of the solar PV plant from metrocontrol website.
3. To calculate the following techno-economic performance indices of the PV plant using the performance data.
   - Technical performances indices
     Performance ratio
     Capacity factor
   - Economic performance indices
     Payback period
     Net present value

Experimental Setup:



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Techno-Economic performance indices used for Performance analysis

The IEC standard 61724 specifies the following performance indices for PV plant.

→ Technical performance indices.

- Annual energy yield
- Capacity Factor (CF)
- Performance Ratio (PR)

→ Economical performance indices

- Payback period
- Net present value

for this, we will use the 2019 annual data.

Annual Energy yield $(E_{AC}) = 127,174.74$ kWh

Installed capacity $(P_{ac}) = 99.84$ kW

$$\text{Capacity factor} = \frac{E_{ac}}{P_{ac} \times 8760} = \frac{127,174.74}{99.84 \times 8760} = 0.1454 \simeq 14.54\%$$

Total isolation $(G) = 16,60,548.328\ \mathrm{Wh/m^2} = 1660.548\ \mathrm{kWh/m^2}$

PV module efficiency $(\eta_{PV}) = 15.27\%$

Area of the plant $(A) = 627\ \mathrm{m^2}$

$$\text{Performance Ratio } (PR) = \frac{E_{ac}}{G \times A \times \eta_{PV}}$$

$$= \frac{127,174.74}{1660.548 \times 627 \times 0.1527} = 0.80 \simeq 80\%$$

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Typical data with respect to Solar Plant are

Cost of solar PV modules (a) = 99.84 kW × Rs 30,000/kW
= INR 29.95 lakhs

Cost of fixed axis structures (b) = 99.84 kW × 6,000 INR/kW
= INR 5.99 lakhs

Cost of Central Inverter (c) = INR 8 lakhs

Balance of System & Installation cost (d) = 99.84 kW × 10,000 INR/kW
= INR 9.984 Lakhs

Total Initial Cost (C_{int}) = a + b + c + d
= INR 53.92 lakhs

Operation & maintenance cost in first year (C_{om}) =
99.84 kW × 1000 INR/kW = INR 0.99 lakhs

Inflation Rate (f) = 6%

Interest Rate (i) = 10%

Expected life of Project (N) = 25 years

Present value of annual maintenance charges (C_{pe})

$$= \left(\frac{C_{om}}{f-i}\right)\left[\left(\frac{1+f}{1+i}\right)^N - 1\right] = \text{INR } 14.95 \text{ lakhs}$$

Total Project Cost (C_{total}) = $C_{int} + C_{pe}$
= INR 68.87 lakhs

Energy Cost = INR 8 per kWh

Annual Savings = E_{ac} × Energy Cost = INR 10.17 Lakhs

Payback Period = $\frac{C_{total}}{\text{Annual Savings}}$ = 6.77 years ≈ 7 years

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Discount Rate (r) = 8% given

Cash inflow for savings (P_n) = Annual Savings $\times \frac{(1+r)^n - 1}{r(1+r)^n}$ =

~~INR 1021.1 Lakhs~~

Net present Value = $-C_{total} + \sum_{n=1}^{N} \frac{P_n}{(1+r)^n}$ = INR 540.47 Lakhs.

Conclusions:

- The Component level and system level study of 100 kW solar PV plant at LLR Hall, IIT Kharagpur is performed in this experiment.
- A step-by-step process to access the data from metrocontrol website is presented through appropriate illustrations
- The techno-economical performance indices calculated for the LLR plant indicate that the plant is performing satisfactorily.
- The payback period in the NPV is larger due to the fact that the time value of money is involved in the NPV calculation

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DISCUSSION

1) Compare the techno-economic performance Indices of the Solar PV plant at LLR hall for the year 2017 & 2019 in tabular form. Also plot the data for graphical comparison.

→ for year 2017,

Annual Energy yield (E_{ac}) = 131,533.96 kWh

Installed Capacity (P_{ac}) = 99.84 kW

Capacity factor (CF) = $\frac{131,533.96 \text{ (kWh)}}{99.84 \text{ (kW)} \times 8760} = 0.1504$ → 15.04 %

Total Isolation (G) = 1642.74 kWh/m^2

PV module efficiency (η_{pv}) = 15.27 %

Area of the plant (A) = 627 m^2

Performance Ratio (PR) = $\frac{131,533.96}{1642.74 \times 627 \times 0.1527}$

= 0.8363 → 83.63%

Total Project Cost (C_{total}) = INR 68.87 lakhs

Energy Cost = INR 8 per kWh (Assuming the same cost as of 2019)

Annual Savings = INR 8 × 131,533.96

= 10.522 lakhs

Payback period = $\frac{68.87}{10.522}$ = 6.54 years.

Discount Rate = 8% (r)

Net present Value = INR 561.57 lakhs

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Year	Technical Performance Indices			Economical Performance Indices	
	Annual Energy Yield (in kwh)	Capacity Factor (%)	Performance Ratio (%)	Payback Period (in Years)	Net Present Value in (INR Lakh)
2017	131,533.96	15.04	83.63	6.54	561.57
2019	127,174.74	14.54	80	6.77	540.47

2) What is the effect of energy degradation over the years on the NPV value of PV plant? State the modified NPV equation considering the energy degradation factor.

→ According to a research, it was observed that modules have inherently differing characteristics which become exacerbated over time. The standard deviation of the short-circuit current increases for modules, indicating differing module performance. This leads to extensive mismatch, a loss of total system output due to different outputs of individual modules on the string. Corrosion of interconnections and gridlines were also observed.

For the modified NPV equation,
three simplified forms of the degradation rate model are generally recommended when modelling system efficiency loss. The most commonly used is the linear model but a general ~~f~~ exponential form can be implemented as well as a variation of the exponential form recommended by NASA JET PROPULSION LABORATORY :—

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$D(t) = P_0(1-\alpha t)$

$D(t) = P_0 e^{-bt}$

$D(t) = P_0 e^{-bt^c}$

where $D(t)$ is the degraded performance at time "t"
P_0 is the initial power output at time 0
a, b and c are model parameters

3) Describe any two additional techno-economical criteria along with their associated equations for the performance assessment of a solar PV plant.

→ Technical Criteria:-

Thermal loss: The thermal behaviour of a module is calculated in PVsyst in thermal balance :-

$$U(T_{module} - T_{amb}) = \alpha_a G_{inc}(1-\eta_m)$$

where U is the thermal loss factor $[W/(m^2 \cdot K)]$, T_{module} is the operating temperature of the module [°C], T_{amb} is the ambient temperature [°C], α_a is the solar irradiation absorption coefficient, G_{inc} is the incident solar irradiance $[W/m^2]$ and η_m is the module efficiency.

Economical Criteria:

Profitability index:

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It is also known as benefit-cost ratio. It gives the present value of future benefits, computed at the required rate of return on the initial investment.

$$PI = 1 + \frac{NPV}{\text{Initial Investment Cost}}$$

If $PI > 1$, then accept the project, but if $PI < 1$, reject the project.

4) Design a Solar PV plant at your home rooftop and calculate period and NPV values taking actual rooftop area and electricity tarrif of your home. Assume remaining as

- One Solar Panel of 300W & 2 sq.mt area
- Complete Solar plant initial Cost = 50 Rs/W.
- O & M cost = 100 Rs/kW, $n = 25$ years, $f = 6\%$, $i = r = 10\%$
- Assume, if you need any other data & mention it.

→ Area of roof top = 15 ft × 15 ft = 225 sq.ft = 20.903 sq.mt
= ~~23.69 sq.mt~~
≃ 21 sq.mt.

Installed Capacity (P_{ac}) = $\frac{300}{2} \times 21$ W = 3150 W

Typical data w.r.t Solar plant are

Total Initial Cost (C_{int}) = Rs. 50 × 3150
= Rs. 157500

Operation and maintenance cost in first year (C_{om}) =
Rs. 100 × 3.15 = Rs. 315

Inflation Rate (f) = 6%
Interest Rate (i) = 10%
Expected life (N) = 25 years
(given)

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Present Value of annual maintenance charges (C_{pe})

$$= \frac{C_{om}}{f-i}\left[\left(\frac{1+f}{1+i}\right)^N - 1\right] = 15.096 \times \text{Rs. } 315$$

$$= \text{Rs. } 4755.24$$

Total Project Cost (C_{total}) = $C_{int} + C_{pe}$

= Rs. ~~20505~~ 162255.24

≃ Rs. 1,62,256

Energy Cost = INR 8 per kwh (assumption)
(for my electricity tarrif at home)

Annual Savings = $(\underbrace{4139.1 \text{ kwh}}_{\text{Annual Energy yield (assumed with 15\% efficiency)}} \times \text{Rs } 8/\text{kwh})$

= Rs 33113

Payback Period = $\frac{C_{total}}{\text{Annual Savings}}$

$= \frac{162256}{33113} = 4.9$ years

≃ 5 years

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Discount rate $(r) = 10\%$ (given)

Cash inflow for savings (P_n) = Annual Savings $\times \frac{(1+r)^n - 1}{r(1+r)^{2n}}$

Net present value $= -C_{total} + \sum_{n=1}^{N} \frac{P_n}{(1+r)^n}$

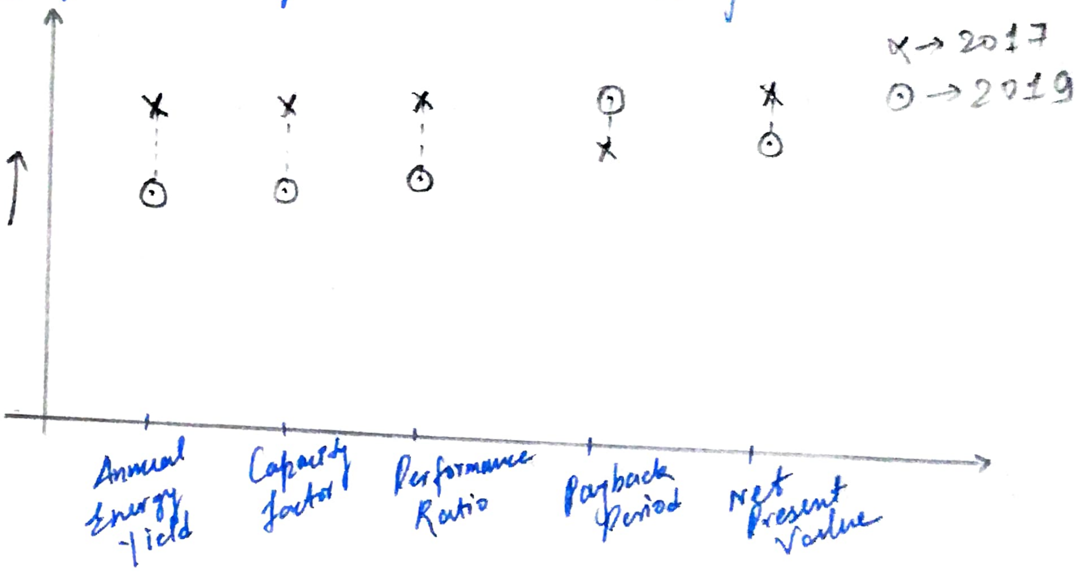
$= -C_{total} + \left(\sum_{n=1}^{N} \frac{(1+r)^n - 1}{r(1+r)^{2n}} \right) \times$ Annual Savings

$=$ Rs $(-1,62,256 + 43.556 \times 33113)$

$\simeq$ Rs. 1280014

$\simeq$ Rs. 12.8 lakhs

Q1) Graphical Analysis. Pratyush Jaiswal, 18EE30021



So, it can be seen that 2017 has been more effective in every aspect as compared to 2019.