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FORMULATION OF PERFORMANCE OF INVERTERS FOR SOLAR PHOTOVOLTAIC POWER PLANTS – INDIAN CASE STUDY

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Research Question

- To formulate weighting factors for calculation of PV inverters efficiency for the identified climatic zones across India that will help the users in selection of inverters for that particular location based on representative efficiency.
- The weighting factors are calculated according to the standards being followed .

Reference Weighted Average Efficiency

The performance of the inverters worldwide has been characterized using two methods: European Efficiency and CEC efficiency.

The weighting factors were defined by Hotopp on the base of measured irradiance data in a single reference year at the location Trier, Germany [1].

The European efficiency is characterized by the following formulae:

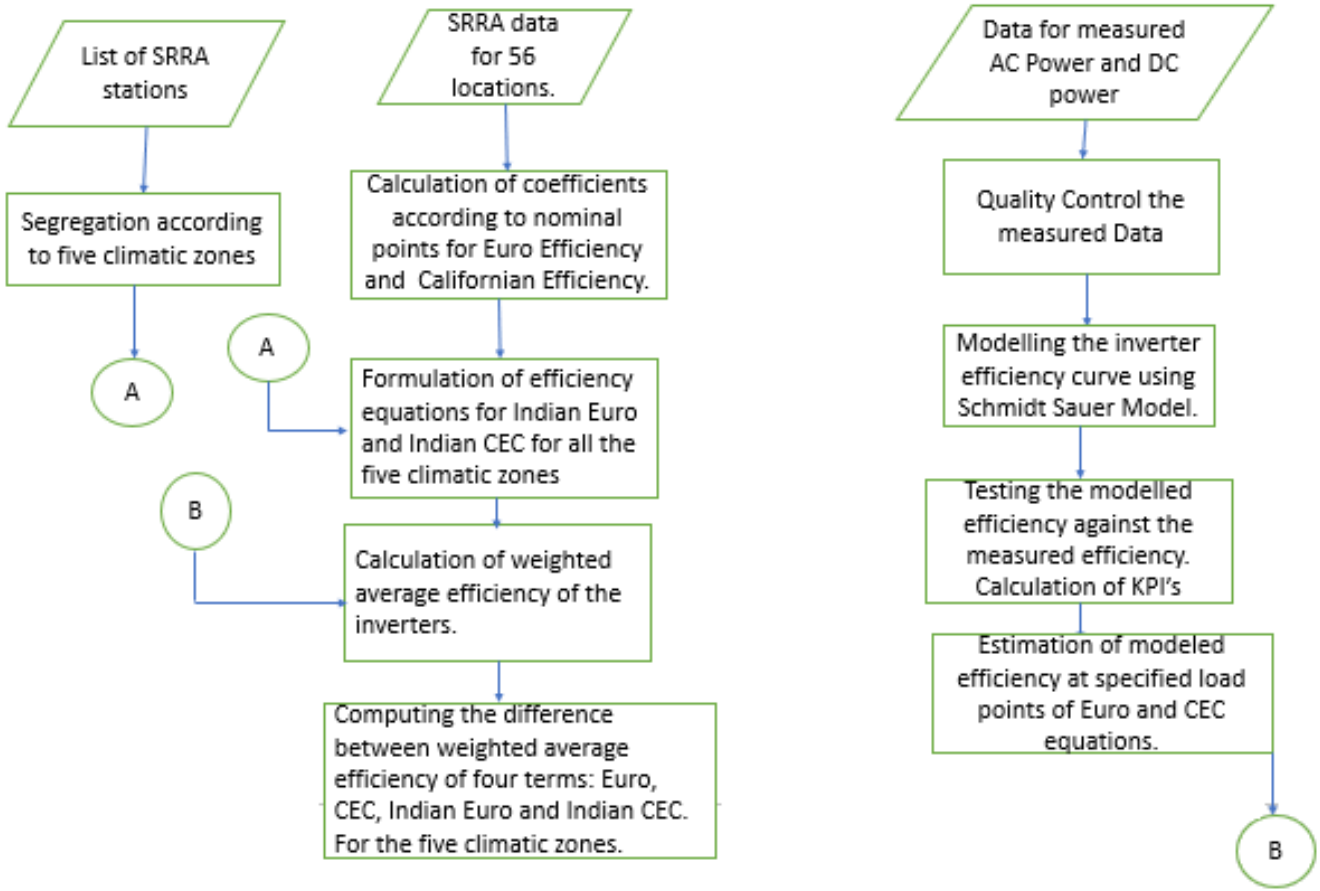
$$\eta_{Euro} = 0.03 * \eta_{5\%} + 0.06 * \eta_{10\%} + 0.13 * \eta_{20\%} + 0.10 * \eta_{30\%} + 0.48 * \eta_{50\%} + 0.2 * \eta_{100\%}$$

Reference Weighted Average Efficiency (contd…)

- The CEC Efficiency has been defined by the California Energy Commission (2006), it was calculated for the Typical Meteorological Year (TMY) for Sacremento. Compared to the European Efficiency a different set of nominal points is used.
- The CEC efficiency is characterized by the following formula:

$$\eta_{CEC} = 0.04 * \eta_{10\%} + 0.05 * \eta_{20\%} + 0.12 * \eta_{30\%} + 0.21 * \eta_{50\%} + 0.53 * \eta_{75\%} + 0.05 * \eta_{100\%}$$

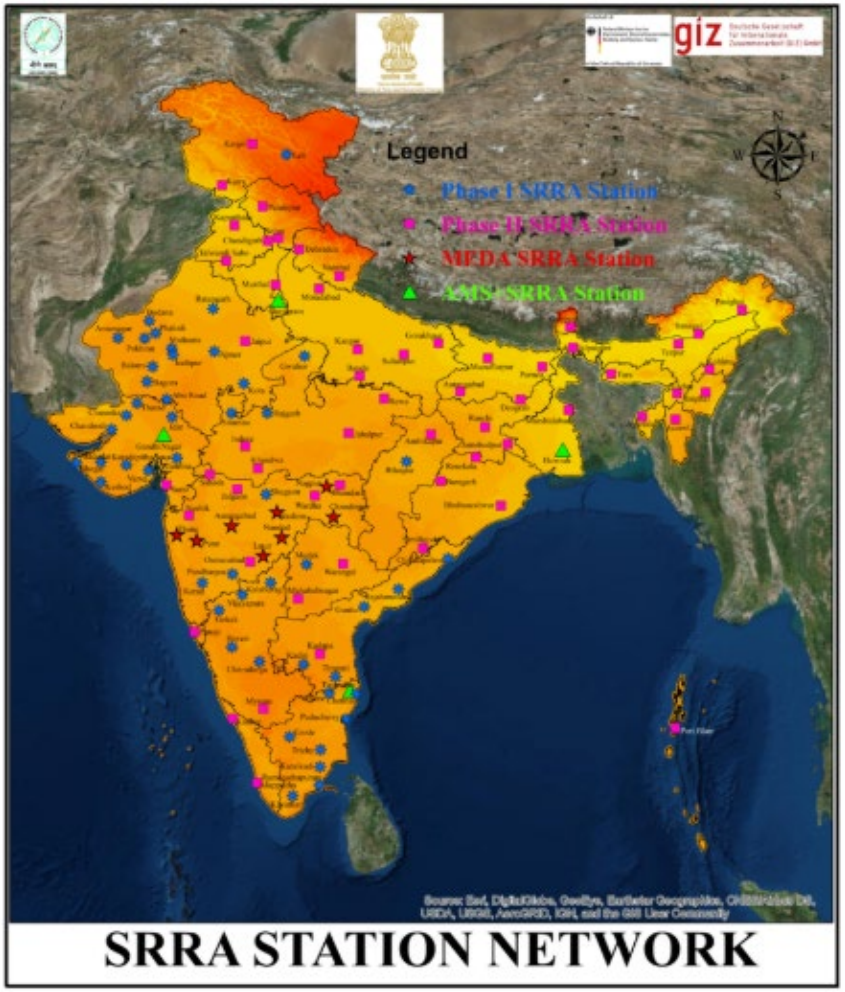
Flow Chart for the methodology carried out in this work



SRRA DATA

- Solar Radiation Resource Assessment (SRRA) is a large scale project involving measurement and collection of data from 125 SRRA stations spread across India.
- The field solar and meteorological data collected is archived in central receiving station.
- A typical SRRA station consists of two towers 1.5m and 6m tall.
  - 1.5m tower – solar tracker, pyrheliometer and two pyranometers with and without shading disk to measure direct , diffuse and global irradiance
  - 6m tower- sensors for measuring temperature, relative humidity , atmospheric pressure, wind speed and direction.

Map with Locations of SRRA stations



Weighted average efficiency Equation

- The weighted average efficiency – mathematical representation –

$$\eta_{WeightedAv} = \sum_{i=1}^{n} K_i * \eta_i$$

where Ki is the weighting co-efficient corresponding to the ith input power level,

- ηi is the effcicency of the inverter at the ith input power level
- ηWT is the weighted average inverter efficiency.
- The weighting co-efficient for a particular DC input power level of the inverter is derived from the below equation
- $$Ki = \frac{\sum energy\ yield\ within\ the\ range\ considered}{total\ energy\ yield\ over\ the\ time\ frame\ considered}$$

Weighted efficiency co-efficients value for ηEURO and ηCEC

% NOMINAL (P_{MPP}/P_{STC} , NOMINAL POINTS	5%	10%	20%	30%	50%	75%	100%
EURO	0.03	0.06	0.13	0.10	0.48		0.2
CEC		0.04	0.05	0.12	0.21	0.53	0.05

Table 1. co-efficients value for η_{EURO} and η_{CEC}

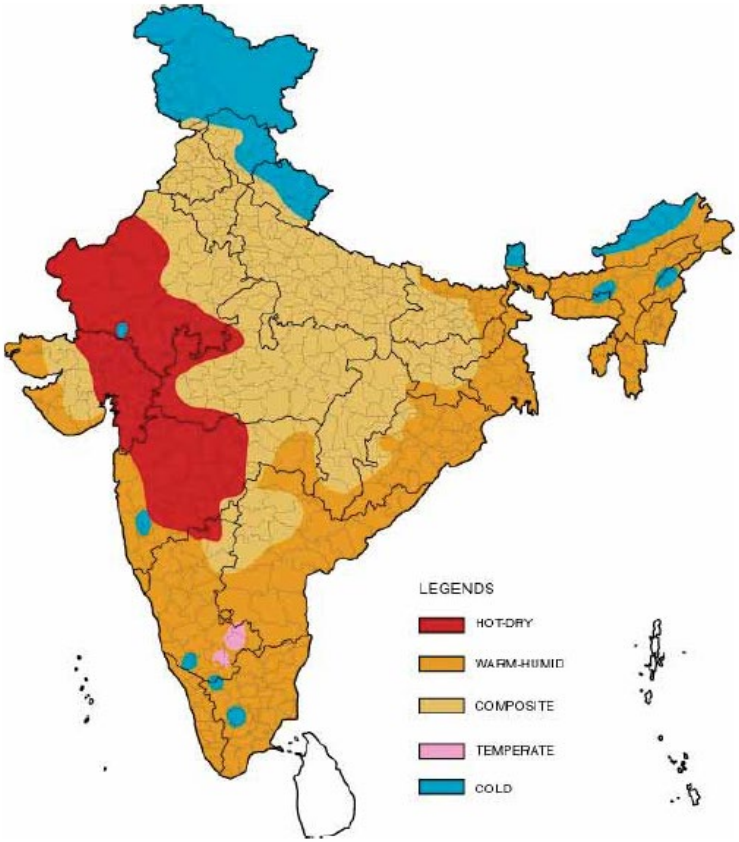
- **Euro Efficiency** = 0.03 x η5% + 0.06 x η10% + 0.13 x η20% + 0.1 x η30% + 0.48 x η50% + 0.2 x η100%.
- **CEC Efficiency** = 0.04 x η10% + 0.05 x η20% + 0.12 x η30% + 0.21 x η50% + 0.53 x η75%. + 0.05 x η100%

Data period Used

- 1st January 2016 to 1st January 2017.
- Data which has passed the quality control test and has been flagged as good is segregated and used for this analysis.
- The one min data was averaged to 15 minute interval and used.

Climatic zones Identified

The climatic zones were identified into 5 different categories as per the map shown below [8].



- Indian Euro Weighted Average efficiency is defined by the following [8]

$$\eta_{Indian\_Euro} = \alpha_1 * \eta_{5\%} + \alpha_2 * \eta_{10\%} + \alpha_3 * \eta_{20\%} + \alpha_4 * \eta_{30\%} + \alpha_5 * \eta_{50\%} + \alpha_6 * \eta_{100\%}$$

- Indian CEC weighted average efficiency is defined by the following [8]:

$$\eta_{Indian\_CEC} = \alpha_1 * \eta_{5\%} + \alpha_2 * \eta_{10\%} + \alpha_3 * \eta_{20\%} + \alpha_4 * \eta_{30\%} + \alpha_5 * \eta_{50\%} + \alpha_6 * \eta_{100\%}$$

- Here: α1, α2, α3, α4, α5, α6 are weighted coefficient factors which are to be calculated for individual locations and then averaged for different Indian climatic zones specified.

RESULTS

- Computed Weighing Coefficients for euro efficiency radiation ranges for the identified locations (averaged as per climatic zone) is given in the table below:

	% NOMINAL (PMPP/PSTC , NOMINAL POINTS)					
Weighting Coefficients for identified climatic zones	5%(α1)	10%(α2)	20%(α3)	30%(α4)	50%(α5)	100%(α6)
Euro	0.03	0.06	0.13	0.1	0.48	0.2
Cold	0.0369	0.0684	0.1171	0.2028	0.3839	0.1903
Composite	0.0558	0.0447	0.0779	0.1312	0.4895	0.2012
Hot and dry	0.0153	0,0290	0.0501	0.1201	0.5149	0.2703
Temperate	0.0161	0.0319	0.0615	0.1388	0.5132	0.2382
Warm and humid	0.0147	0.0295	0.0547	0.1308	0.4785	0.2914

RESULTS (Contd…)

- Weighing Coefficients calculated for CEC efficiency radiation ranges for the identified locations (averaged as per climatic zone) are given in the table below:

	% NOMINAL (PMPP/PSTC , NOMINAL POINTS)					
Weighting Coefficients for identified Locations	10%(α1)	20%(α2)	30%(α3)	50%(α4)	75%(α5)	100%(α6)
CEC	0.04	0.05	0.12	0.21	0.53	0.05
Cold	0.1053	0.1171	0.2028	0.2723	0.2053	0.0964
Composite	0.1004	0.0779	0.1312	0.3125	0.3145	0.063
Hot and dry	0.0443	0.0501	0.1201	0.3052	0.3877	0.0921
Temperate	0.0481	0.0615	0.1388	0.3174	0.3533	0.0805
Warm and humid	0.0443	0.0547	0.1308	0.2763	0.4091	0.0844

Inverter efficiency modelling

- The inverter η is modelled using the measured instantaneous DC and AC of the power plant which is quality controlled using Schmidt sauer model [12].
- Quality controlled measured power plant data is taken from two power plants:
  - 10 MW power plant located in Rajasthan (six months data considered).
  - Single Inverter data from Power plant located in Tamil Nadu (1.25MW capacity inverter).

Schmidt Sauer Model (contd…)

- The parameters are found by fitting the DC power and AC power data of the power plant where the measurements were available.

$$Ploss = Pself + Vloss.Pout + rloss.P^2out$$

when rloss is positive:

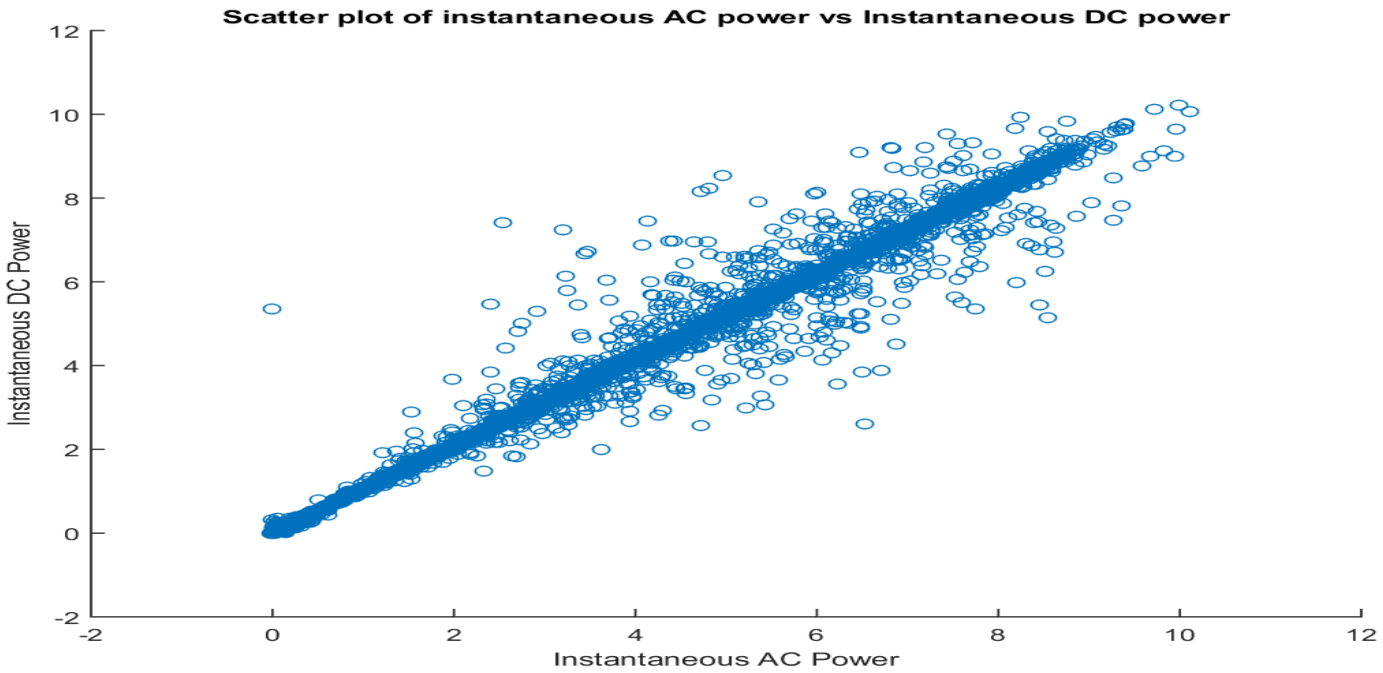
$$\eta* = -\frac{1+v*_{loss}}{2.r_{loss}.p_{in}} + \sqrt{\frac{(1+v*_{loss})^2}{(2.r*_{loss}.p_{in})^2} + \left(\frac{p_{in}-p*_{self}}{r*_{loss}.p_{in}^2}\right)}$$

when rloss is negative:

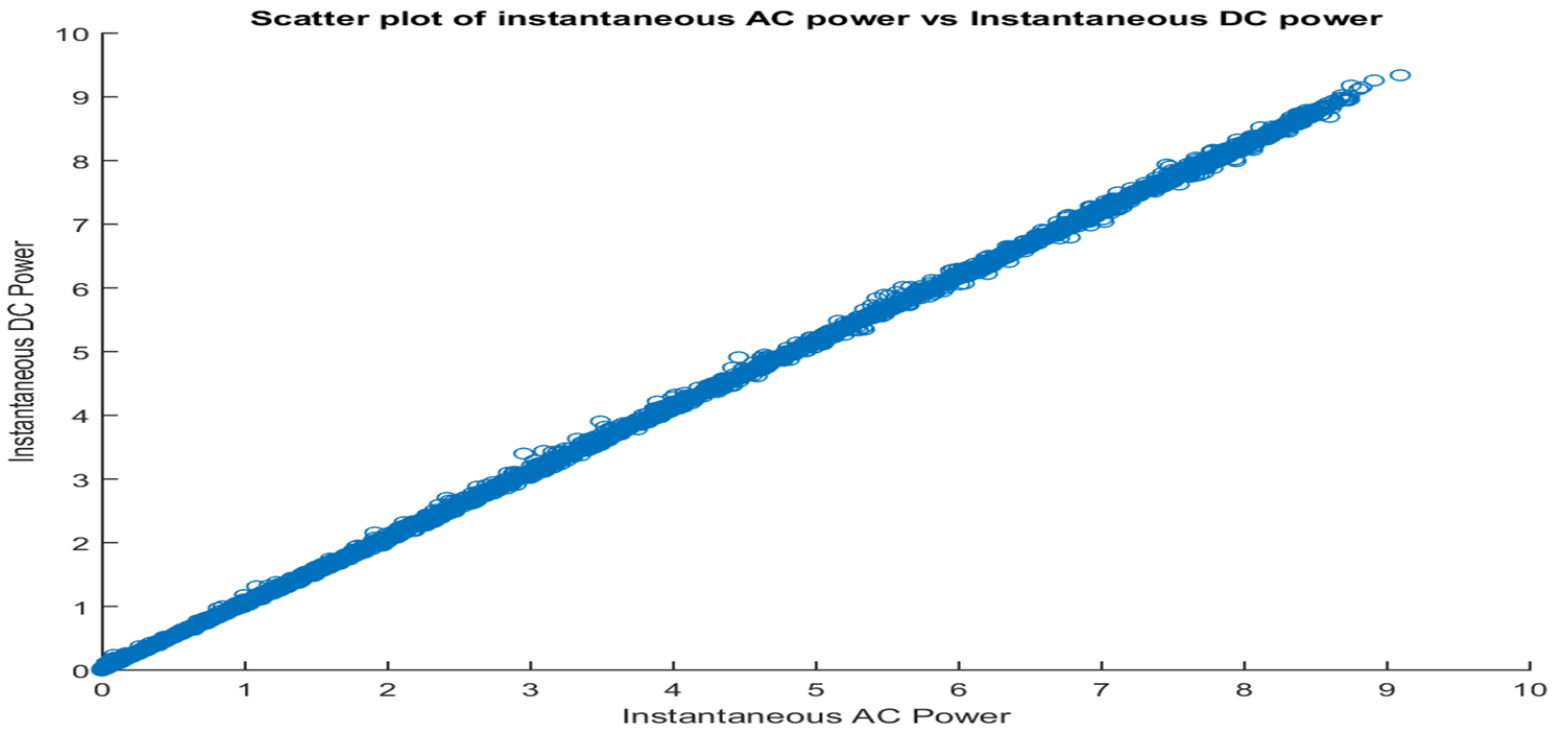
$$\eta* = -\frac{1+v*_{loss}}{2.r_{loss}.p_{in}} - \sqrt{\frac{(1+v*_{loss})^2}{(2.r*_{loss}.p_{in})^2} + \left(\frac{p_{in}-p*_{self}}{r*_{loss}.p_{in}^2}\right)}$$

Inverter efficiency model - Rajasthan

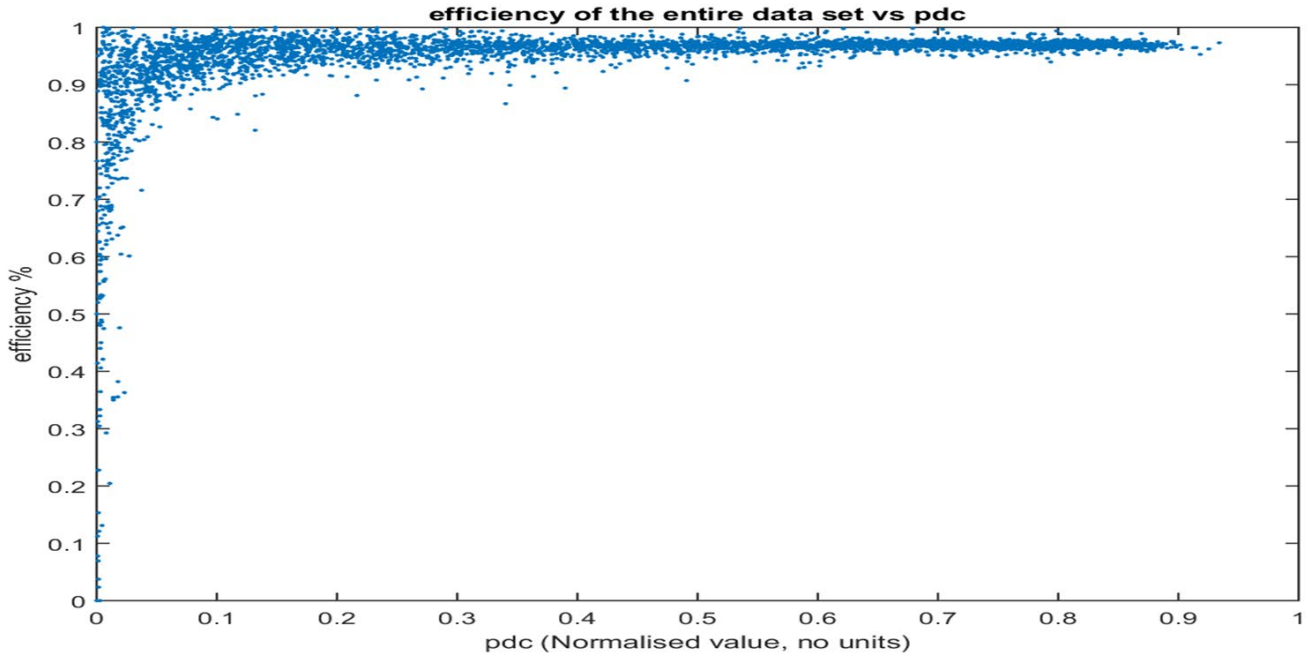
Scatter plot of the instantaneous AC power vs instantaneous DC power



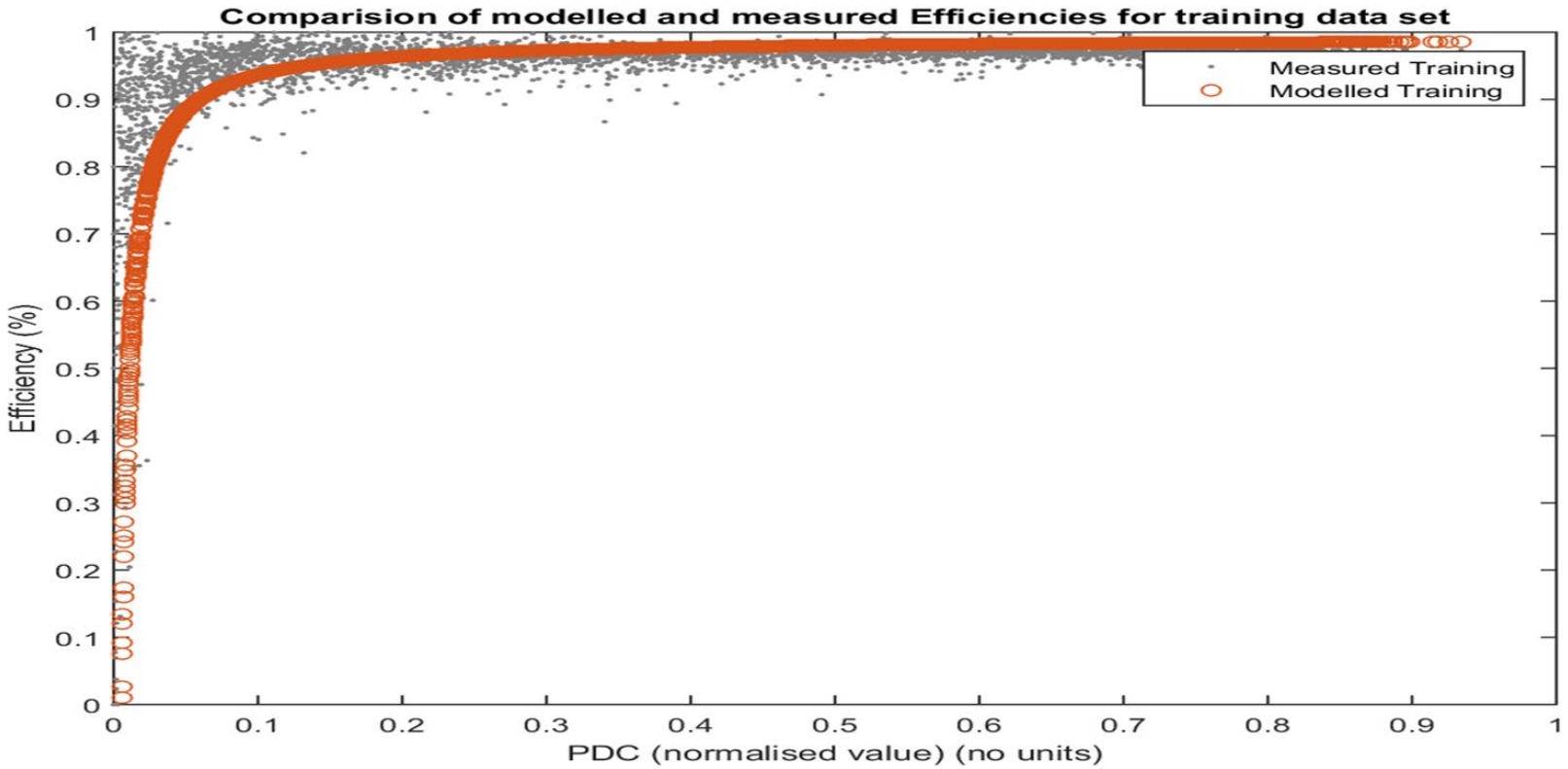
Scatter plot after quality control of AC and DC instantaneous power



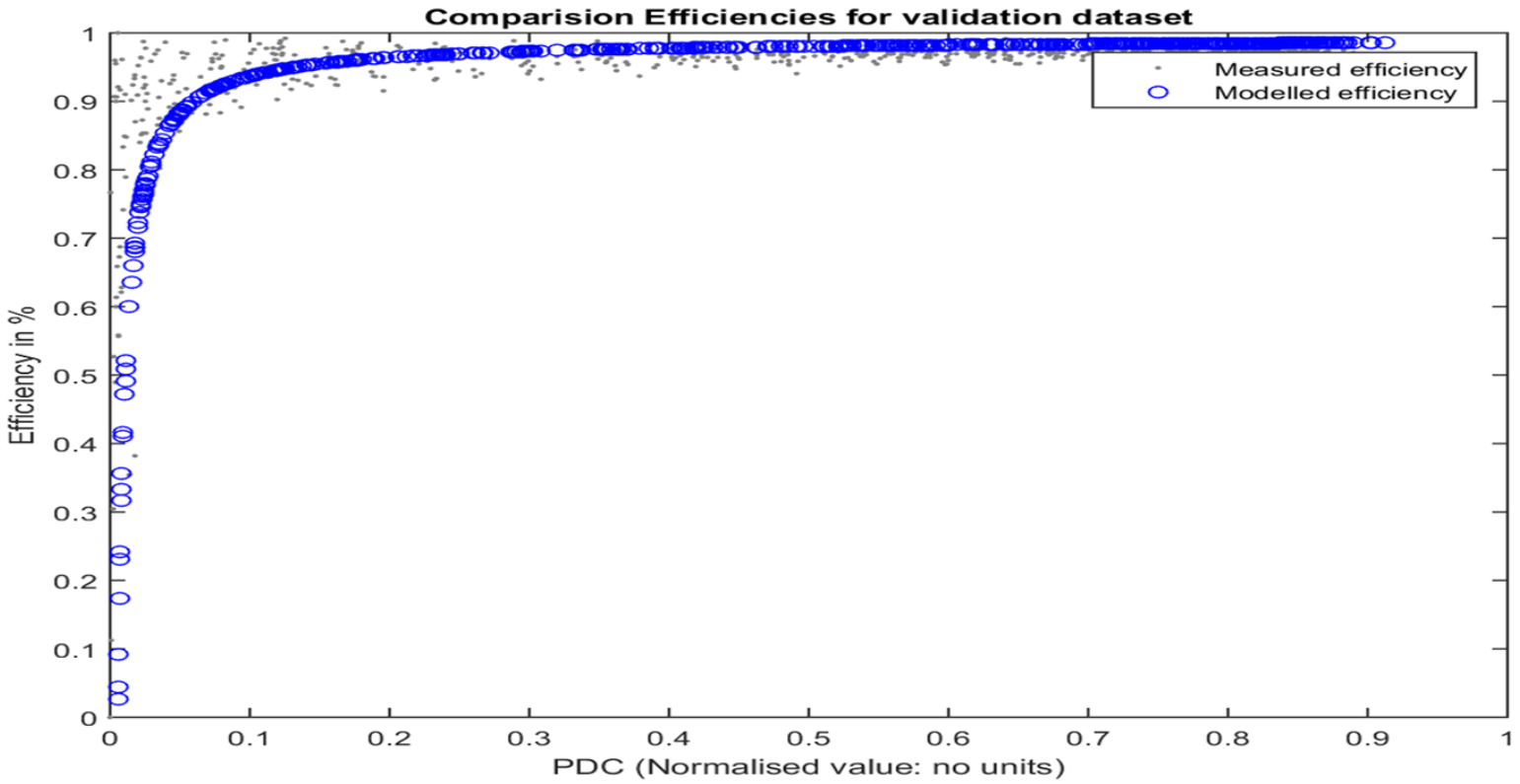
Efficiency plot of the entire Data set



Efficiency plot of the training Data set



Efficiency plot of the validation Data set



RESULTS (contd…)

- The KPI's of the model is calculated and shown the following table:

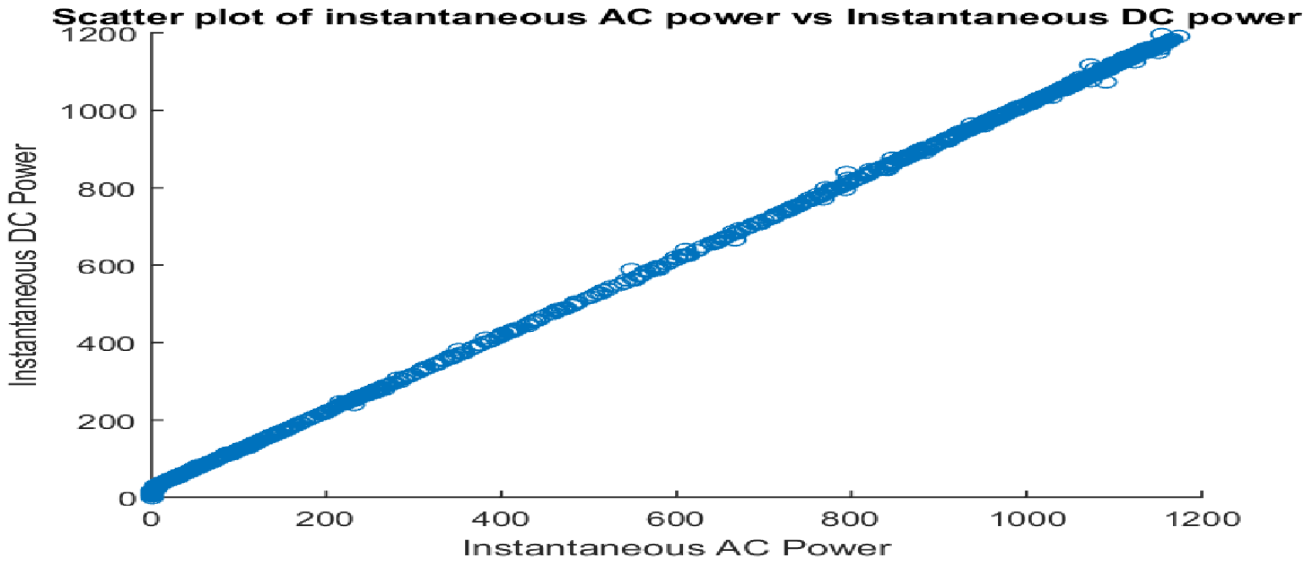
NRMSE (%)	NMAE (%)	NBIAS (%)
0.9	0.7	0.6

- The efficiency at different nominal points according to the developed model is depicted in the following:

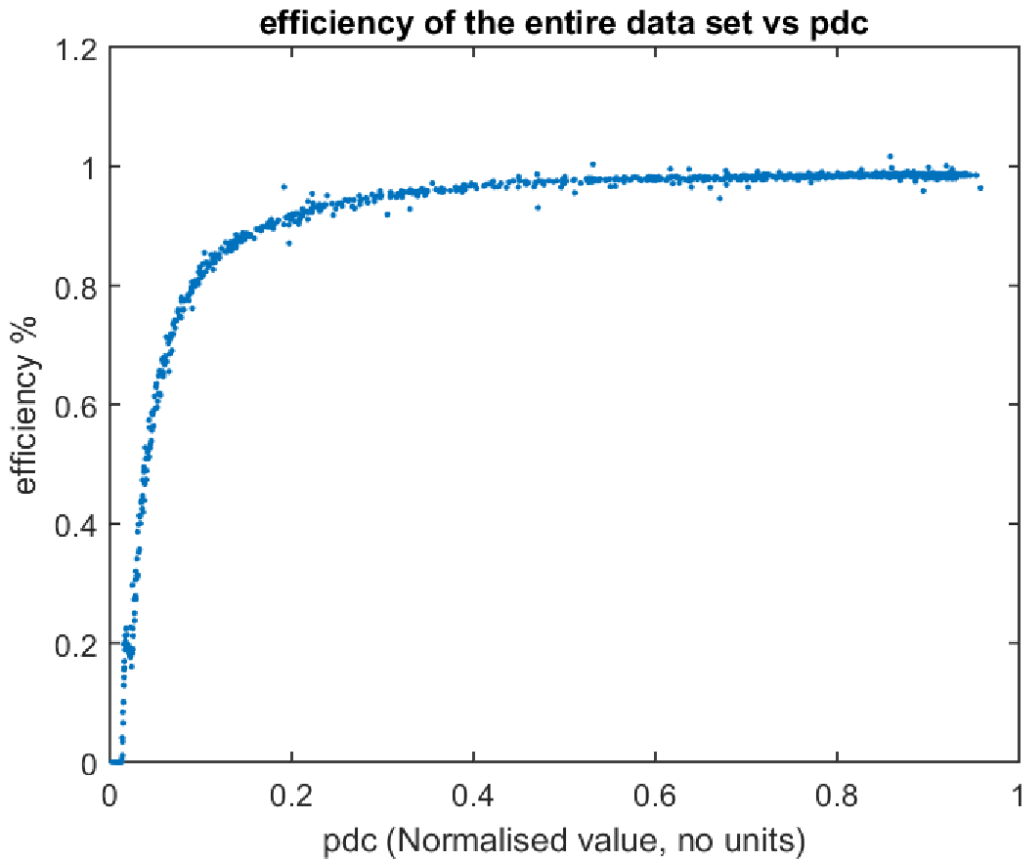
% NOMINAL (PMPP/PSTC , NOMINAL POINTS	5%	10%	20%	30%	50%	75%	100%
ηEURO	0.88	0.93	0.96	0.97	0.98		0.99
ηCEC		0.93	0.96	0.97	0.98	0.98	0.99

RESULTS for Inverter Modelling_ Tamil Nadu Power plant

- Quality controlled measured power plant data is taken from power plant located in Tamil Nadu with 1.25MW capacity (total capacity 50MW – 40 inverters).



Measured Efficiency Curve for the entire Data Set



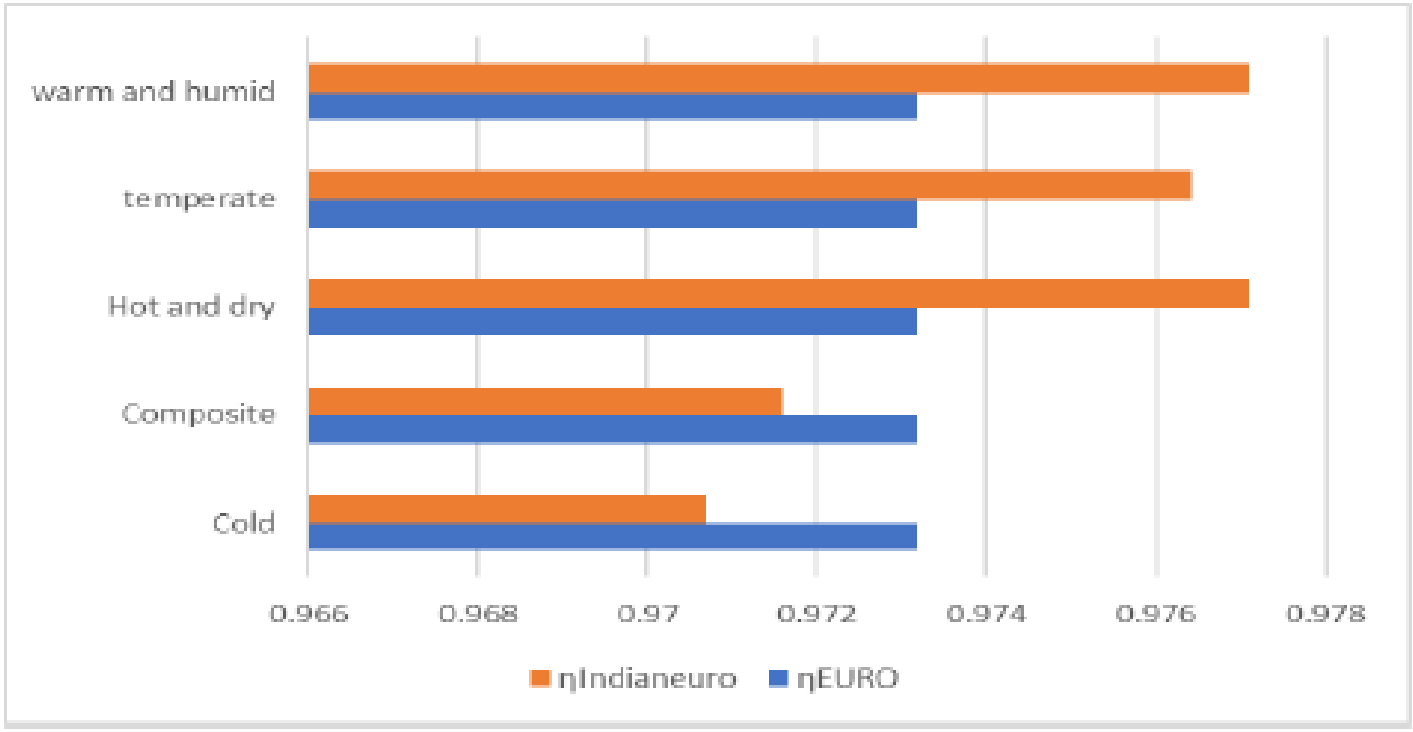
RESULTS (contd…)

- **η of the inverter at different input power level is shown in the table below:**

% NOMINAL (PMPP/PSTC , NOMINAL POINTS	5%	10%	20%	30%	50%	75%	100%
ηEURO	0.82	0.90	0.94	0.96	0.97		0.985
ηCEC		0.90	0.94	0.96	0.97	0.98	0.985

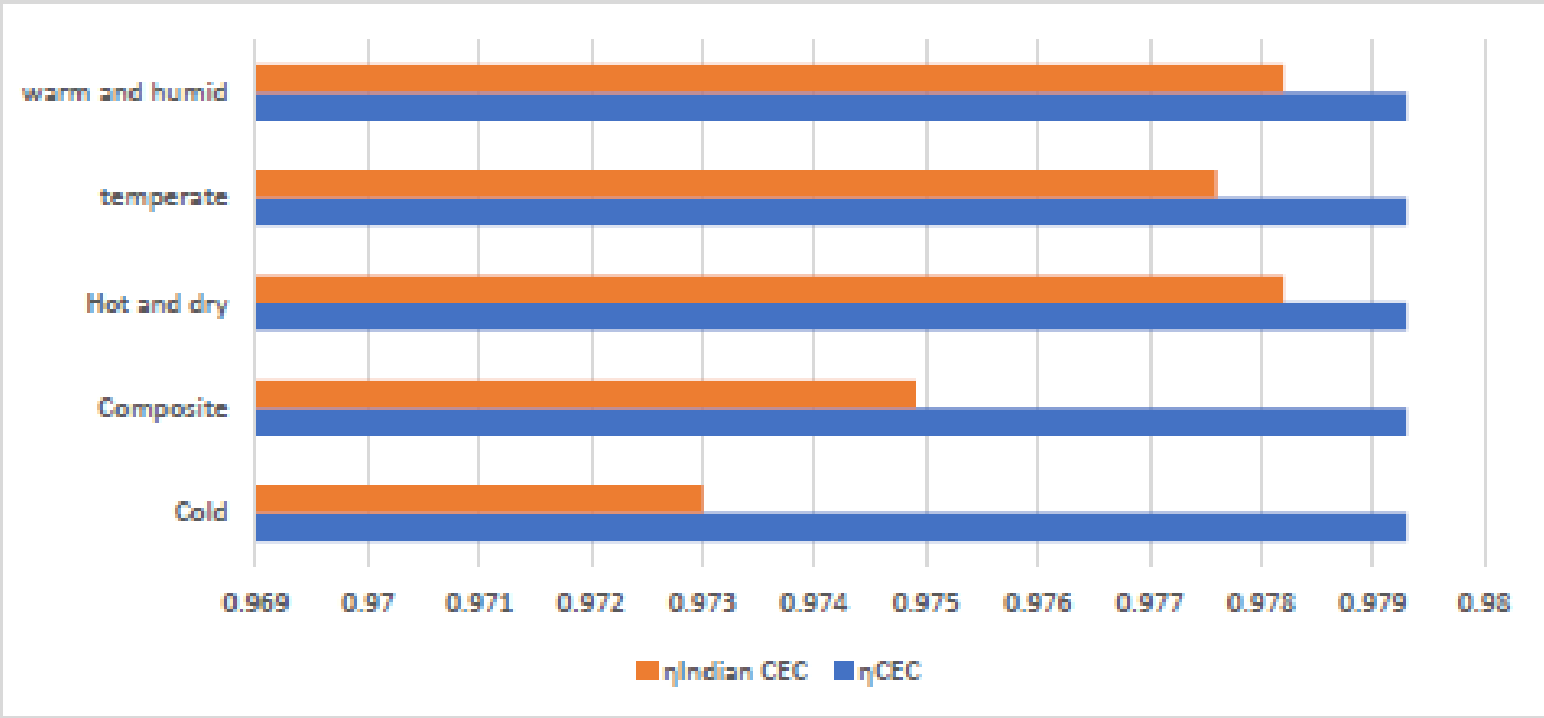
RESULTS (contd…)

- The Overall weighted average Indian Euro efficiency according to the inverter efficiency values in Rajasthan is shown in the figure below:



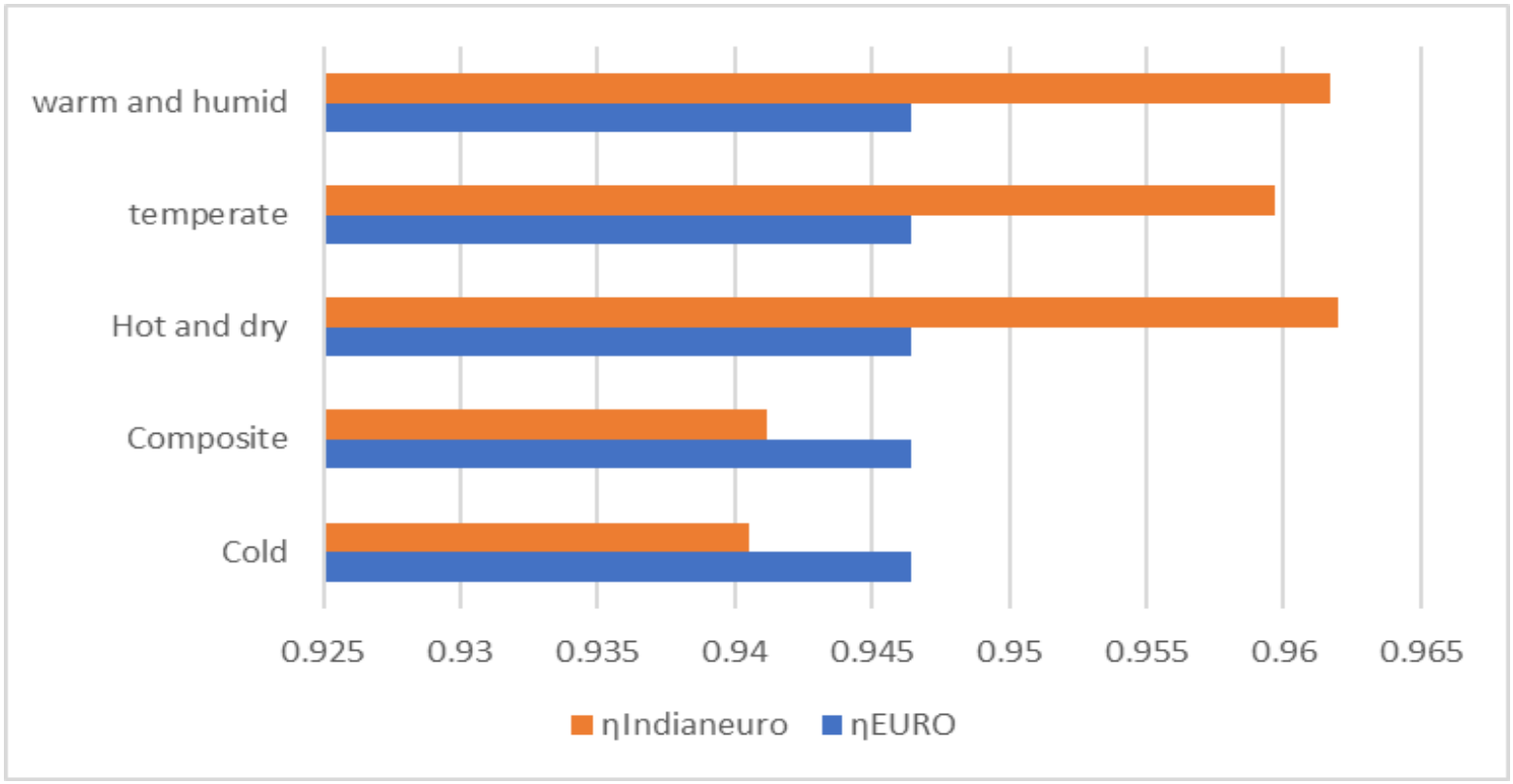
RESULTS (contd…)

- The Overall weighted average Indian Californian efficiency according to the inverter efficiency values in Rajasthan is shown in the figure below:



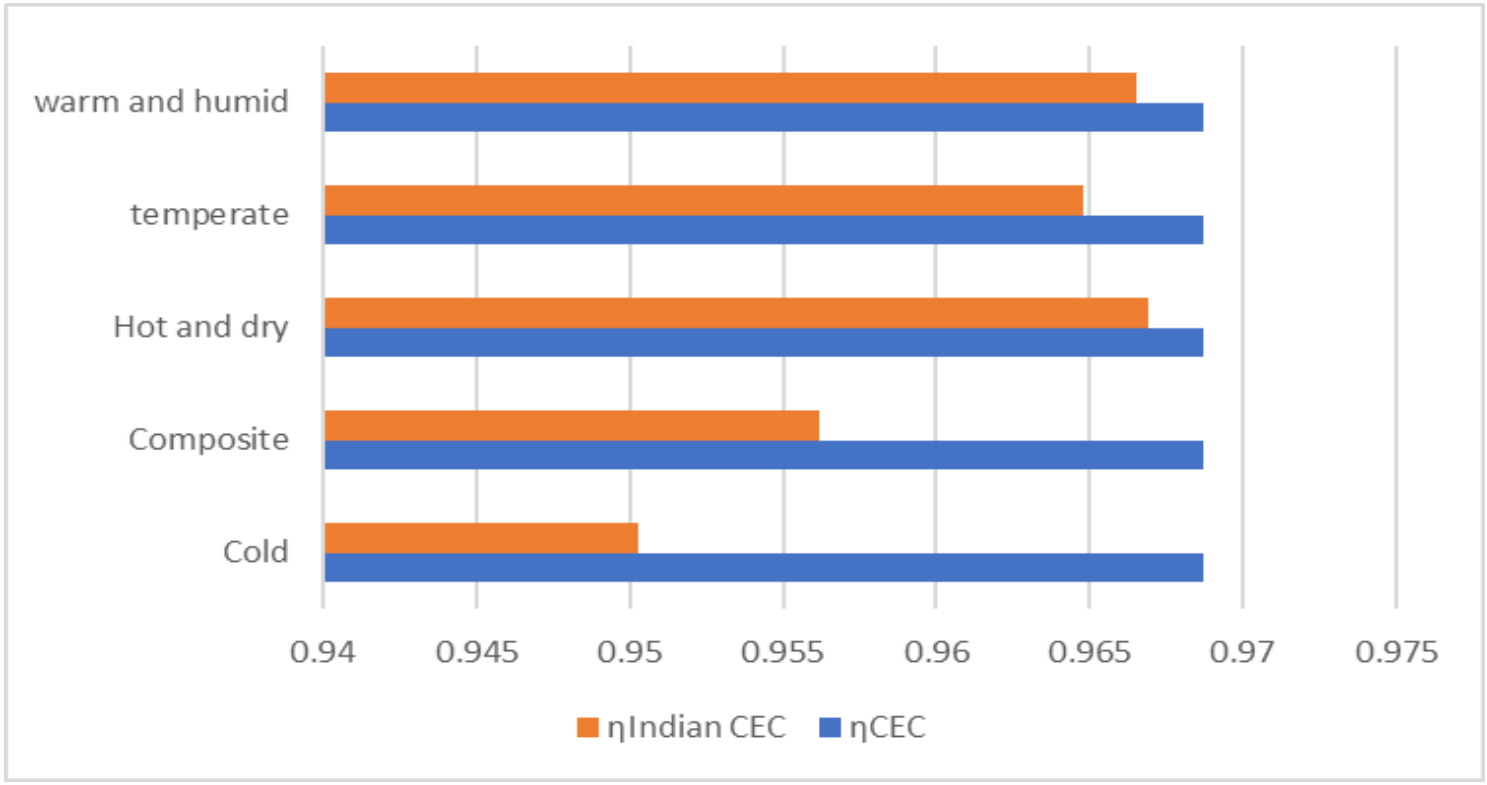
RESULTS (contd…)

- The Overall weighted average Indian Euro efficiency according to the inverter efficiency values in Tamil Nadu is shown in the figure below:



RESULTS (contd…)

The Overall weighted average Indian Californian efficiency according to the inverter efficiency values in Tamil Nadu is shown in the figure below



Observations

- Value of the euro efficiency is seen to deviate in the range:
  - **Rajasthan plant**
    - -0.2% to 0.3% from the value calculated using location specific irradiation profile.
  - **Tamil Nadu plant**
    - -0.6% to 1.5% from the value calculated using location specific irradiation profile
- Value of the CEC efficiency is seen to deviate in the range:
  - **Rajasthan plant**
    - -0.5% to 1.56% from the value calculated using location specific irradiation profile.
  - **Tamil Nadu plant**
    - -2% to -0.18% from the value calculated using location specific irradiation profile.

Observations (contd…)

- In the results for Euro Efficiency:
  - For warm and humid, Temperate, hot and dry, Indian Euro Efficiency is overestimating with reference to standard.
  - For Composite and cold climate, its over determining with respect to standard Euro efficiency.
- In the results of CEC efficiency:
  - For all climatic zones, Indian-CEC efficiency values are under-estimating with respect to standard efficiency.

CONCLUSION

- Performance of the same inverter is observed to be different in different climatic zones within India.
- On account of not using location specific equation for determining the efficiency it leads to underestimating or overestimating the performance of the inverter in that location.

FUTURE/ ONGOING WORK

- Validation with measured energy values.
- Considering more SRRA sites for analysis.
- Doing sensitivity analysis for nominal points of the inverter.

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