NIWE, CHENNAI

Day Ahead Solar PV Power Forecasting Based on a Combination of Statistical and Physical Modelling Utilizing NWP Data For Solar Parks In India

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GREAT THANKS TO…

INDO – GERMAN COLLABORATION ON GEC

- This work was carried out under the umbrella **of Indo German Energy Programme, Green Energy Corridors project**.
- Joint declaration of Intent between Germany and India on **Indo-German Development Cooperation** regarding the Establishment of Green Energy Corridors was signed on 11th April 2013.

The declaration was signed in the presence of H.E. Dr. Manmohan Singh, Prime minister of the Republic of India, and H.E. Dr. Angela Merkel, Federal Chancellor of the of the Federal Republic of Germany.

GEC, 11th April, 2013

Signing of declaration between India and Germany

Solar Forecasting project initiated 2017 consortium of Overspeed GmbH, University of Oldenburg, Suntrace GmbH and SGS environmental systems was selected on the basis of an international tender

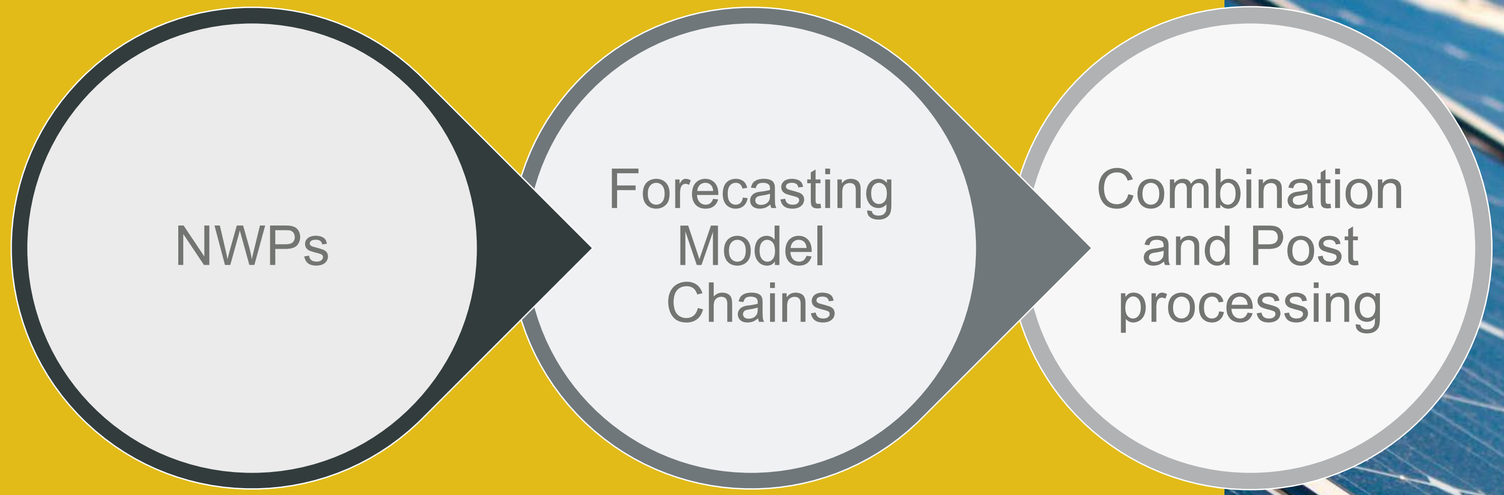
Development of indigenous forecasting chain, project completion 2019

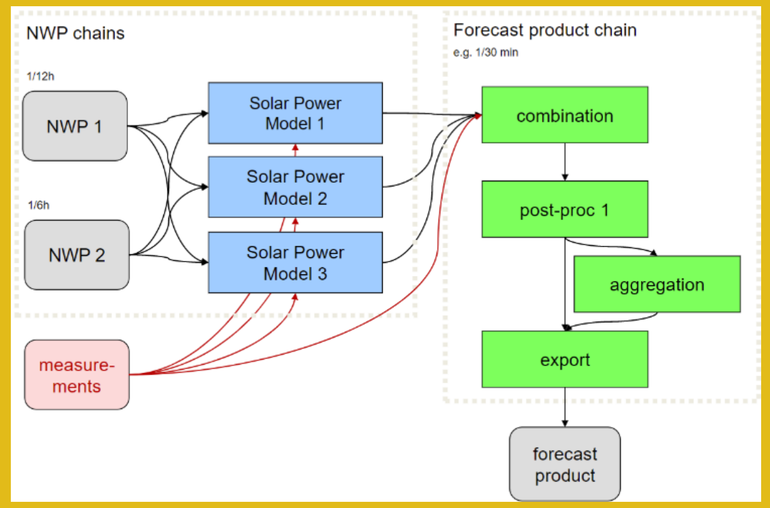
Research Question

To develop a indigenous Day-ahead solar power forecasting system using combination of physical and statistical approach.

WHAT'S INSIDE...

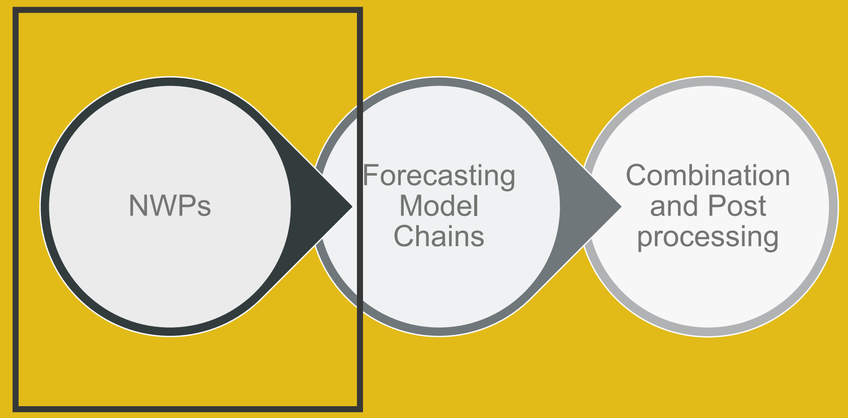
Point Forecasting Process Flow Diagram





MODELLING WEATHER WITH PARTIAL DIFFERENTIAL EQUATIONS...

Numerical Weather Prediction data



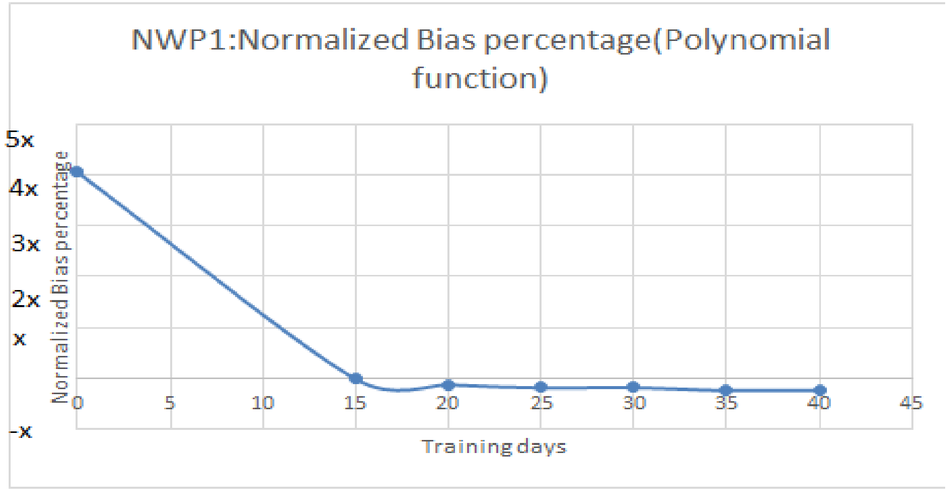
Bias correction is performed by

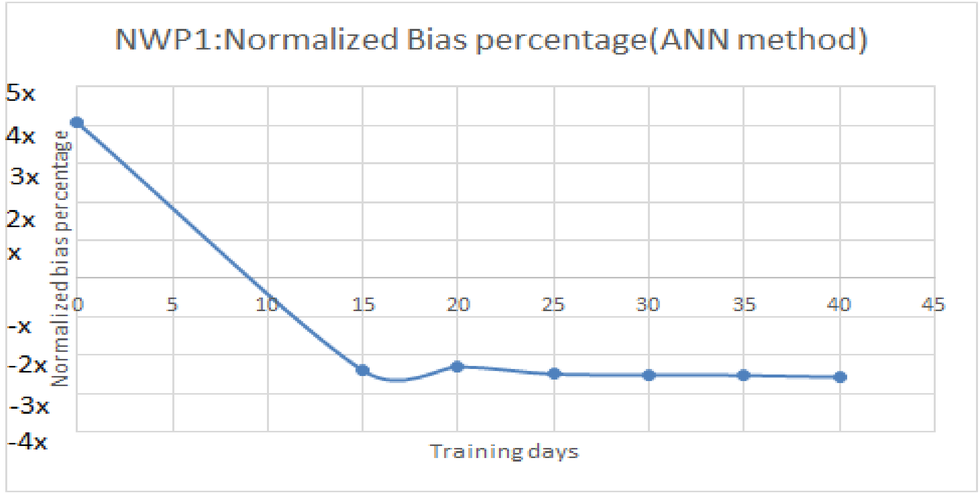
- Standard fourth order polynomial function of clear-sky index and Cosine of Zenith angle,
- Artificial Neural Network with two inputs clear sky index and cosine of zenith angle

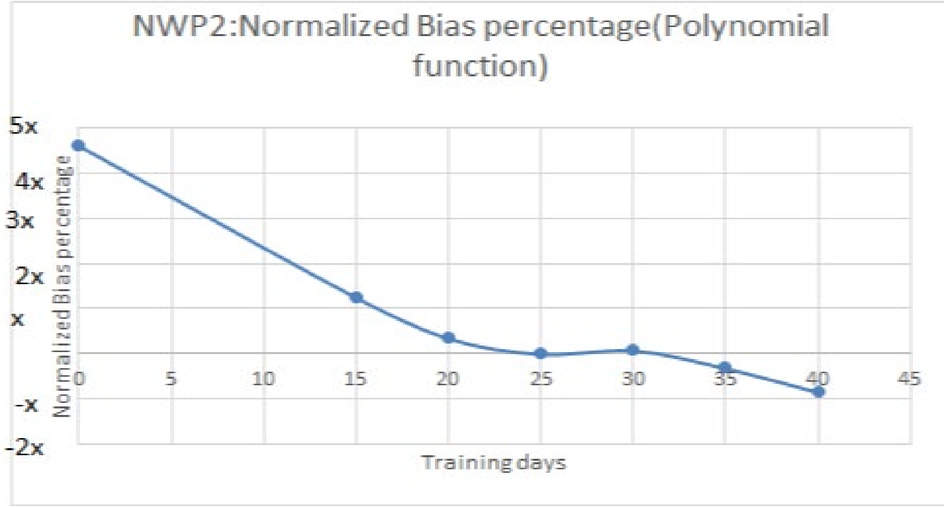
NWP Model Name	Spatial Resolution	Original Temporal resolution	Interpolated Temporal resolution (not given by the provider)
NCMRWF	0.25 degree x 0.25 degree (Approx. 25 km * 25 km)	1 hour	15 minutes
ECMWF	0.25 degree x 0.25 degree (Approx. 25 km * 25 km)	3 hours	15 minutes

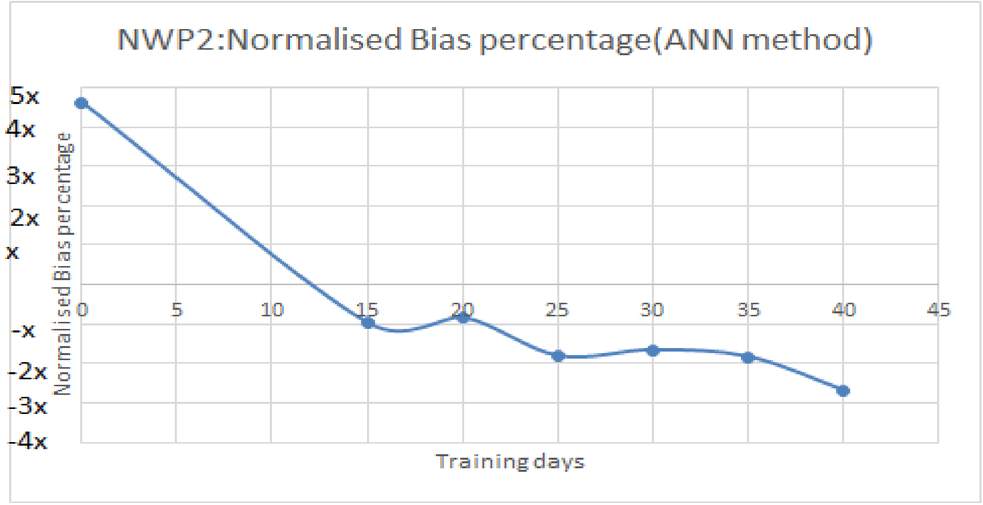
FINDINGS…

Bias correction results





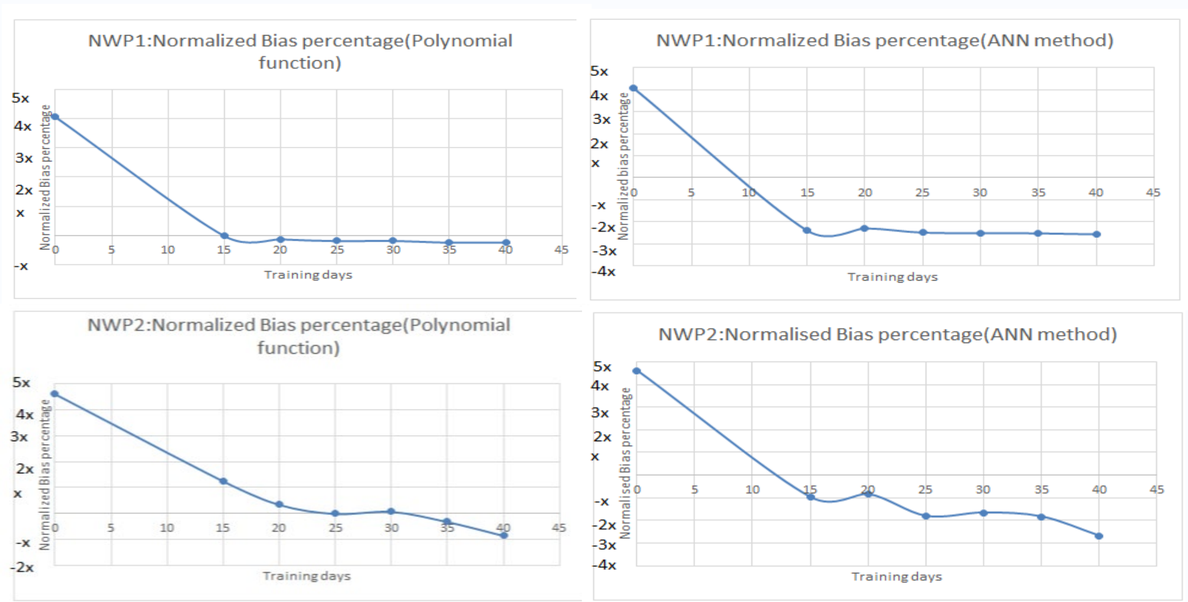




FINDINGS…

Bias correction results

- Data from 17th December 2018 till 16th June 2019 was used for the analysis.
- “Polynomial Method” and “ANN method” were cross compared for its effectiveness.
- Sliding window approach was adopted to test the methods for different set of training days.
- Ground measured GHI data from the plant was used for training the model.
- It can be seen “Polynomial method” is showing better results than ANN based approach.
- Training period of 25 and 30 days are showing the best results



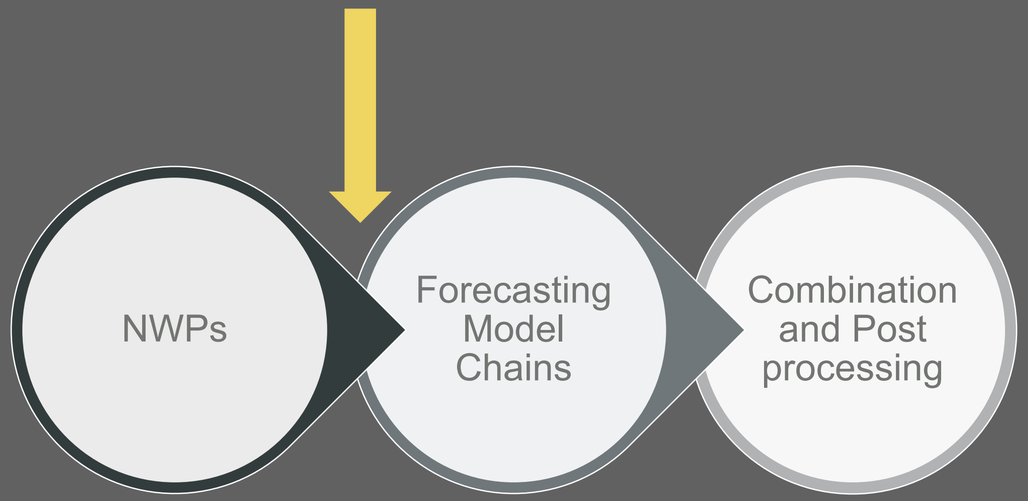
BEFORE FEEDING DATA TO MODEL CLEAN THE DATA…

DATA QUALITY ASSESSMENT & FLAGGING

Parameters from Individual Power Plant	Availability of Data from the Power Plant
Static Data	√
GHI	√
GTI	√
Ambient Temperature	√
Module Temperature	√
DC Power	× (most cases)
AC Power	√

Power Plant Data

Static and dynamic data (AC Power data) received from the power plants were utilized for the forecasting model development.

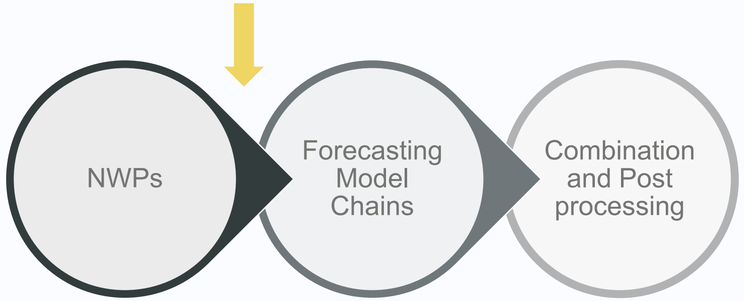


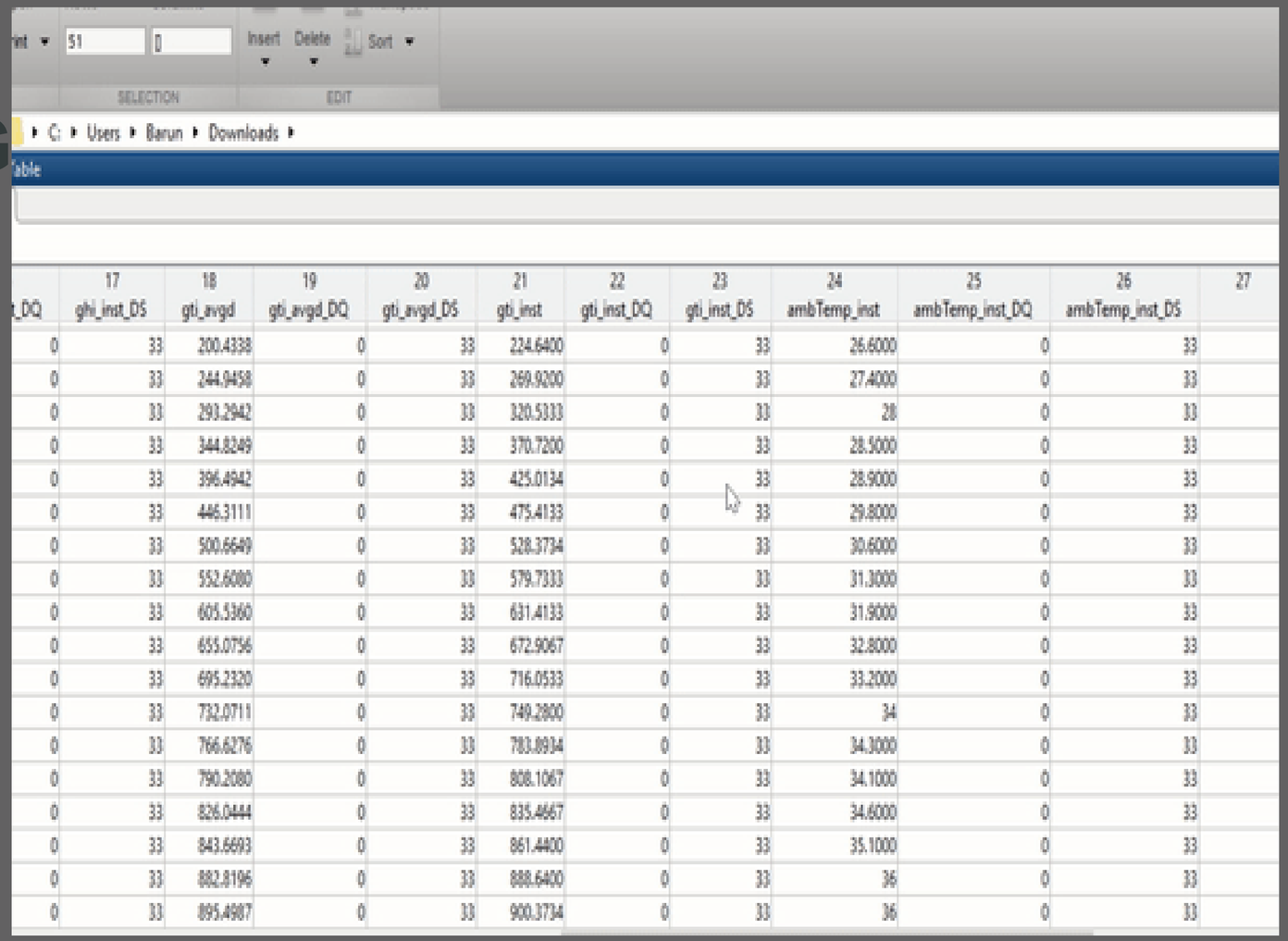
BEFORE FEEDING DATA TO MODEL CLEAN THE DATA…

DATA QUALITY ASSESSMENT & FLAGGING

DATA QUALITY, DQ

DATA STATUS, DS

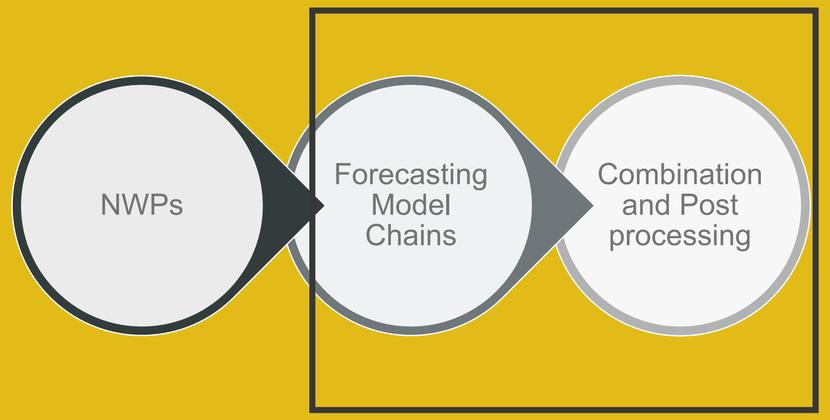




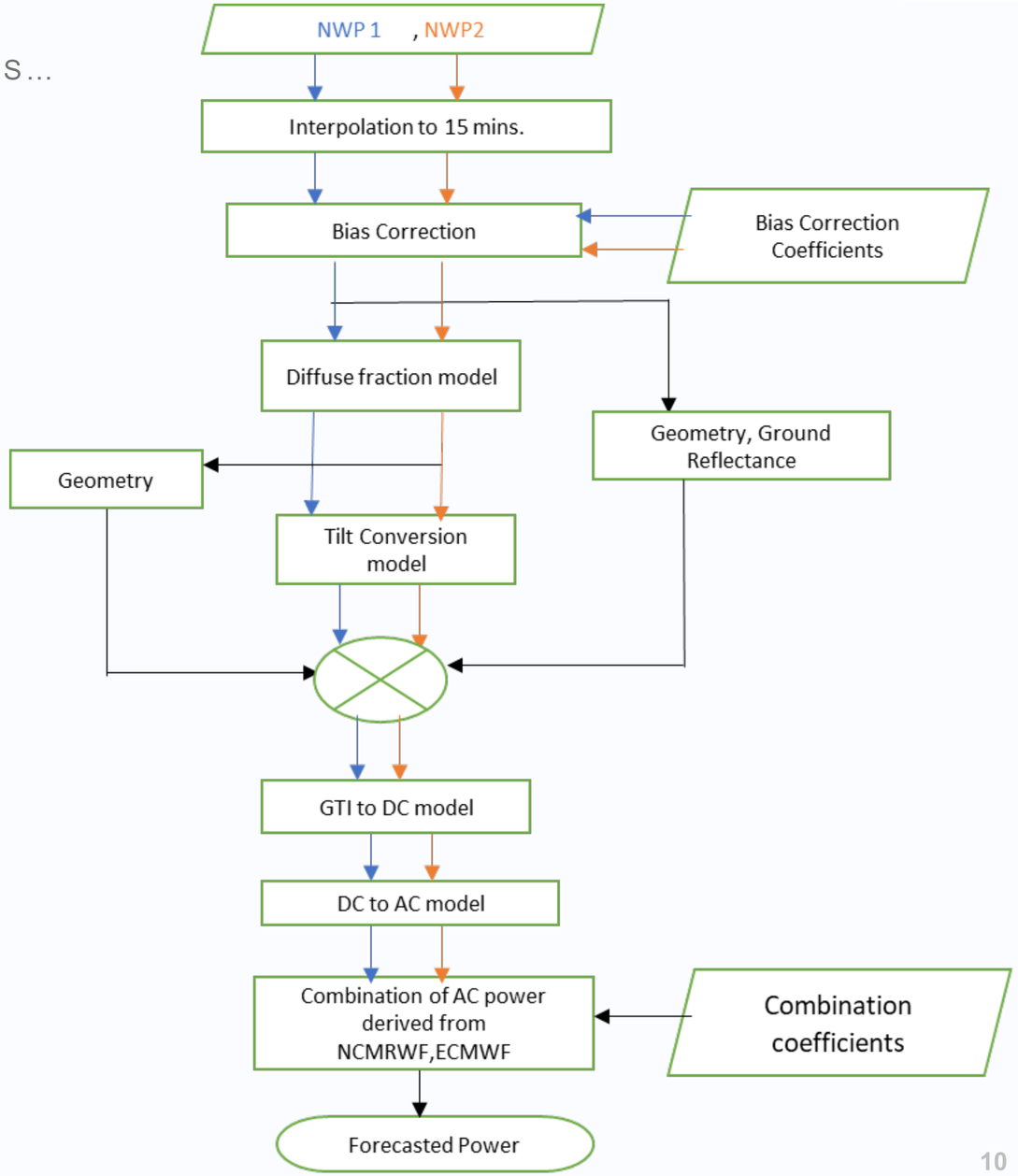
_DQ	17 ghi_inst_DS	18 gti_avgd	19 gti_avgd_DQ	20 gti_avgd_DS	21 gti_inst	22 gti_inst_DQ	23 gti_inst_DS	24 ambTemp_inst	25 ambTemp_inst_DQ	26 ambTemp_inst_DS	27
0	33	200.4338	0	33	224.6400	0	33	26.6000	0	33	
0	33	244.9458	0	33	269.9200	0	33	27.4000	0	33	
0	33	293.2942	0	33	320.5333	0	33	28	0	33	
0	33	344.8249	0	33	370.7200	0	33	28.5000	0	33	
0	33	396.4942	0	33	425.0134	0	33	28.9000	0	33	
0	33	446.3111	0	33	475.4133	0	33	29.8000	0	33	
0	33	500.6649	0	33	528.3734	0	33	30.6000	0	33	
0	33	552.6080	0	33	579.7333	0	33	31.3000	0	33	
0	33	605.5360	0	33	631.4133	0	33	31.9000	0	33	
0	33	655.0756	0	33	672.9067	0	33	32.8000	0	33	
0	33	695.2320	0	33	716.0533	0	33	33.2000	0	33	
0	33	732.0711	0	33	749.2800	0	33	34	0	33	
0	33	766.6276	0	33	783.8934	0	33	34.3000	0	33	
0	33	790.2080	0	33	808.1067	0	33	34.1000	0	33	
0	33	826.0444	0	33	835.4667	0	33	34.6000	0	33	
0	33	843.6693	0	33	861.4400	0	33	35.1000	0	33	
0	33	882.8196	0	33	888.6400	0	33	36	0	33	
0	33	895.4987	0	33	900.3734	0	33	36	0	33	

PHYSICAL EQUATIONS OF SOLAR POWERPLANTS AND STATISTICS…

FORECAST MODEL CHAIN & COMBINATION



- The coefficients/weights are calculated by fitting the polynomial equation, Neural network system with ground measured GHI data.
- Optimum number of training days are obtained from historic data. Bias correction coefficient are obtained fitting data on optimum selected days.



FORECAST MODEL CHAIN & COMBINATION continued…

- *Diffuse Fraction model by Chandrasekar and Kumar:*
  - $k_d = 1.0086 - 0.178k \; for \; k \leq 0.24$
  - $k_d = 0.9686 + 0.1325k + 1.4183k^2 - 10.1860k^3 + 8.3733k^4 \; for \; 0.24 < k \leq 0.8$
  - $k_d = 0.197 \; for \; k > 0.8$

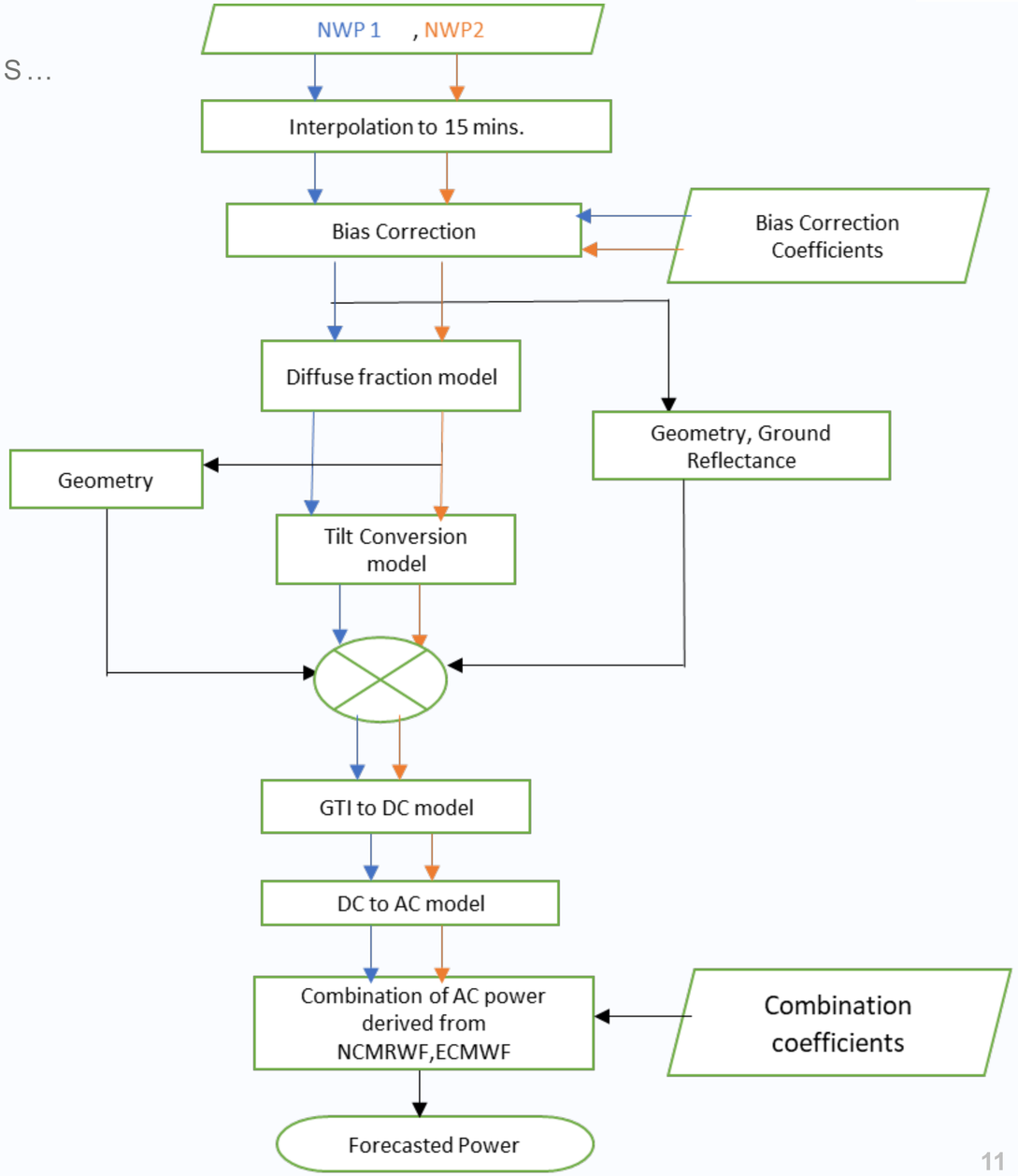
  Where k_d= diffuse fraction, k= clearness index

- Klucher Model Equations

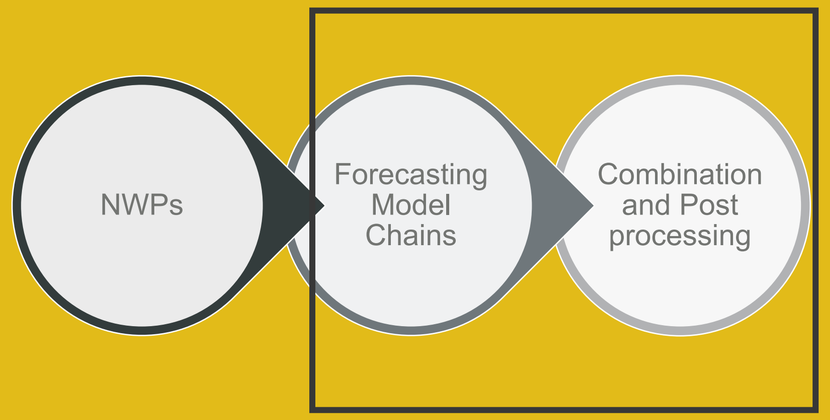
$$I_T = \frac{(I_H - I_D) * \cos(\psi)}{\sin(\alpha)} + I_D \left(\frac{1+\cos\varepsilon}{2}\right)\left(1 + F sin^3\left(\frac{\varepsilon}{2}\right)\right)\left(1 + F cos^2(\psi) sin^3(90 - \alpha)\right)$$

$$F = 1 - \left(\frac{I_D}{I_H}\right)^2$$

I_T =insolation on surface tilted toward the equator at angle ε
I_H=total insolation received on horizontal surface
I_D=diffuse insolation received on horizontal surface
(α) = solar elevation angle
(ψ)= angle between sun direction and normal direction of tilted surface



FORECAST MODEL CHAIN & COMBINATION continued…



- Modelled GTI is fed as input to DC model, DC model is function of GTI, Temperature. Huld and Beyer models are used as module efficiency models.

- Parameters of the Schmidt and Sauer model (Pself, Vloss, rloss) will be found out by fitting the equation with input of DC and AC power measurements.

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

$$ACPowerFcst_{Combi} = a1 * ACPower\ Fcst_{NCMRWF} + a2.* ACPowerFcst_{ECMWF}$$

MODELS	NCMRWF AC FORECAST			ECMWF AC FORECAST			COMBINATION OF NCMRWF & ECMWF AT POWER END		
	nRMSE (%)	nMAE (%)	nMBE (%)	nRMSE (%)	nMAE (%)	nMBE (%)	nRMSE (%)	nMAE (%)	nMBE (%)
CHAIN-1	X1	Y1	Z1	0.908X1	1.088Y1	-0.314Z1	0.861X1	0.955Y1	1.04Z1
CHAIN-2	1.014X1	1.13Y1	-1.064Z1	0.895X1	1.025Y1	0.232Z1	0.866X1	0.955Y1	1.17Z1

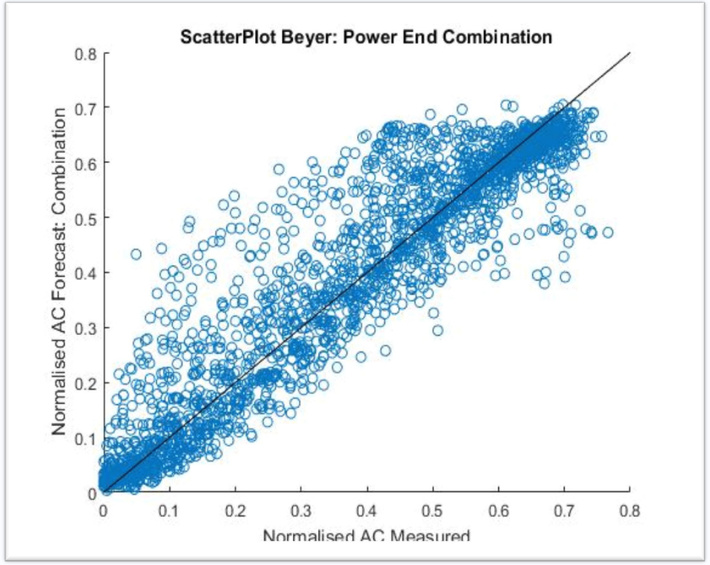
The coefficient of the combination equation was trained on 15 days sliding window approach.

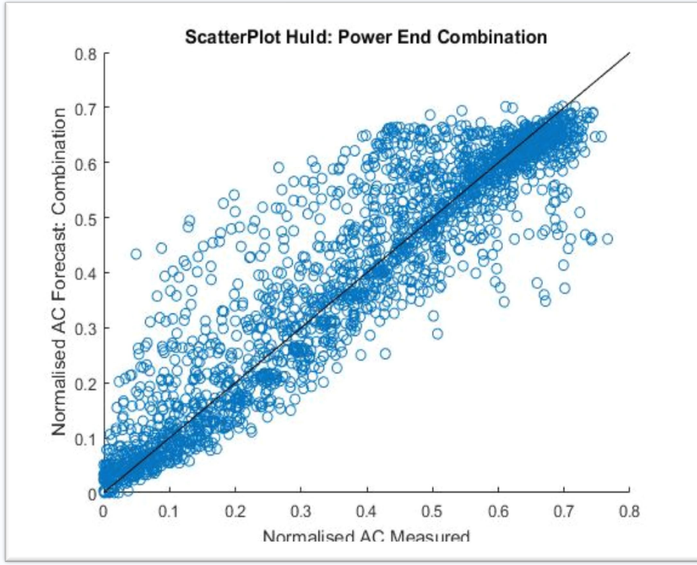
FINDINGS…

AC power forecast Validation Results

- The validation period is between 1st May 2019 till 16th June 2019. (Cloudy months)
- The effectiveness of two GTI to DC models (Huld and Beyer) were cross compared.
- Combination of AC power were also performed, 15 days worked better.

MODELS	NCMRWF AC FORECAST			ECMWF AC FORECAST			COMBINATION OF NCMRWF & ECMWF AT POWER END		
	nRMSE (%)	nMAE (%)	nMBE (%)	nRMSE (%)	nMAE (%)	nMBE (%)	nRMSE (%)	nMAE (%)	nMBE (%)
CHAIN-1	X1	Y1	Z1	0.908X1	1.088Y1	-0.314Z1	0.861X1	0.955Y1	1.04Z1
CHAIN-2	1.014X1	1.13Y1	-1.064Z1	0.895X1	1.025Y1	0.232Z1	0.866X1	0.955Y1	1.17Z1





Lets conclude...

Discussions and conclusion

- In this work, **development of indigenous day ahead forecasting** for point forecast of solar power plants was attempted.
- **Combination of physical and statistical** methodologies was adopted.
- It was seen that combination of NWP models is **improving the forecasting accuracy** of individual plants.
- The **weightage of different NWP's are different** for the validation days.
- Some of the steps taken to finetune the forecasting system that are being undertaken are as follows:
  - If **aerosol information** in NWP model is incorporated by the meteorological agencies, updated NWP results will be included.
  - Bias correction coefficients calculated on **seasonal basis**.
  - Testing with **advanced diffuse fraction models**.
  - Analyzing the NWP model performance based on **weather classes** defined by meteorological agencies and development of corresponding combination coefficients.

Lets conclude...

Discussions and conclusion

The following are some of the **issues/bottlenecks**. If they are improved, model performance could be enhanced:

- In the current work**, DC power data** (dynamic), the exact period in which **tilt angle is changing** (manual seasonal tilt), were **not received from the plant operator.**
- The data from Availability Based Tariff meters is more accurate. However, this data is being received only in the interval **of 15 days**. The data from SCADA requires a lot of cleaning.
- Sometimes, It was also observed that **pyranometers and other sensors are not being maintain**ed well. Even the highest quality instruments not properly maintained, will result in poor data which will affect the model performance.

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Thank you,
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