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# Performance Analysis of Solar Rooftop Power Plants in Smart Cities of India under changing Climatic Conditions

Madhuchandrika Chattopadhyay[1]
[1] Research Scholar
Dept. of Mechanical Engineering
AMET University, Chennai.
*Email ID: madhuchandrika.c19@gmail.com*

R Rajavel[2]
[2] Professor & HOD
Dept. of Mechanical Engineering
AMET University, Chennai.

**Abstract: The Ministry of Urban Development, Govt. of India has announced "Smart Cities Mission" on 28th February 2016. The government of India under present Prime Minister has the vision to develop 100 smart cities with emphasis on smart energy, smart waste management, smart building and sustainable environment. The Smart City guidelines under smart energy objective insist 10% of the Smart City's energy requirement come from solar energy by generating electricity through solar PV rooftop installation, street lightings etc. Since the solar power plants are exposed to various climatic conditions for more than 20 years, ambient temperature and humidity have the direct effect on their energy generation. The solar modules are sensitive to ambient temperature and humidity variations affecting primarily the output voltage and output current linearly. It has already been observed by many climate scientists that temperature and humidity are rising in the cities all over the world due to heat Island effect. This paper covers the study of change in climatic parameters like temperature and humidity of major smart cities of India from 1997-2016 and their effect on the performance of rooftop solar PV installations.**

***Keywords: smart cities mission, climate change, temperature, humidity, heat island effect***

## 1. Introduction

The Ministry of Urban Development, Govt. Of India has launched "Smart Cities Mission" on 25th June 2015.[1] The government of India under Prime Minister Shri Narendra Modi has the vision to develop 100 smart cities with emphasis on smart energy, smart waste management, smart building and sustainable environment. The Smart City guidelines under smart energy objective insist 10% of the Smart City's energy requirement come from solar by generating electricity through PV rooftop installation, street lightings etc.[2] The first 20 smart cities were announced on 28th January 2016. The second list of 13 smart cities was announced on 25th May 2016. Next 27 cities were announced in the third list on 20th September 2016. Another set of 30 cities were announced on 23rd June 2017.[1] The total 90 cities out of 100 are qualified as smart cities till now. This ambitious mission set by the Govt. of India may face some challenges due to radical climate change that is occurring in India over a period of two decades.

A PV module performance is usually rated under Standard Test Conditions (STC = 1000 $W/m^2$, AM1.5, 25°C), but the real operating temperature is significantly higher and is a vital parameter in determining the module energy output. Since the solar power plants are exposed to ambient weather conditions for about 25 years, the temperature has a direct effect on their energy generation.

The increase in temperature shrinks bandgap of the semiconductor and the open circuit voltage $V_{oc}$ decreases.[3] PV cells, therefore, have a negative temperature coefficient of $V_{oc}$.[4,5] Humidity is another ambient parameter which refracts, reflects and diffracts the direct visible solar radiation. This dispersion effect results in deterring the reception of the direct component of solar radiation by water vapour particles present in the atmosphere. The variation of humidity alters the irradiance non-linearly and irradiance causes little variations in $V_{oc}$ in a non-linear manner and large variations in $I_{sc}$ linearly.[6] Hence the low relative humidity enhances the performance of the PV systems.[7]

This paper has analysed the climatic parameters like maximum temperature and relative humidity variations of some major smart cities of India for the period of 20years. The data on temperature and humidity from 1997-2016 collected online from Tutiempo Network, S.L.

## 2. Climatic Changes:

### a. Summer (1997-2016)

In India, April and May months in the year are considered as hottest months. The maximum temperatures recorded in these months are very high in contrast to the temperature of the other months of the whole year. Figures (a) to (f) show the increase in temperatures from 1997 to 2016 of various major smart cities in different zones of India. It has been observed that there is a steady increase in temperature of every smart city for the last 20 years with the difference in temperatures ranging between 1°C to 5.3°C by considering the year 1997 and 2016 as a yardstick.

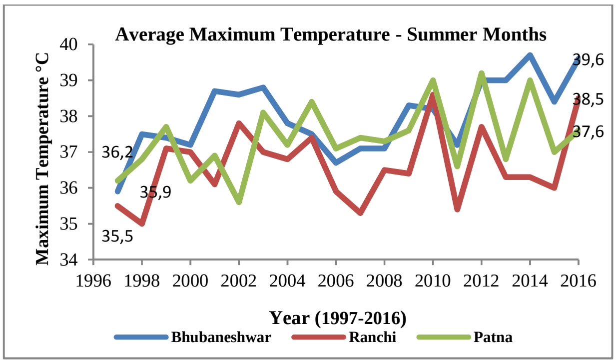



Fig (a): East Zone

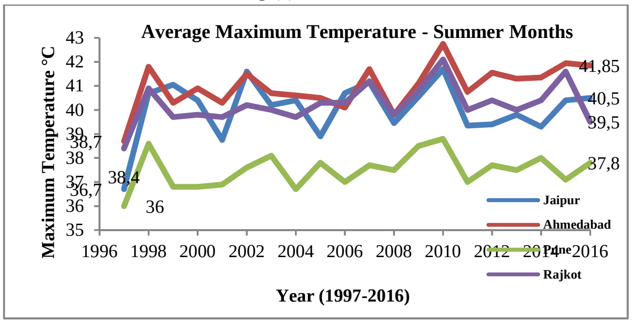



Fig (b): West Zone

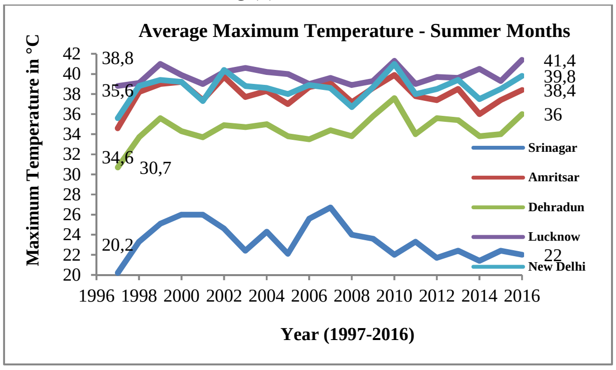



Fig (c): North Zone

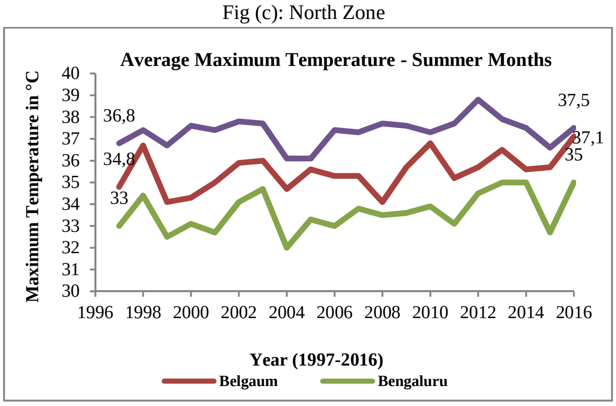



Fig (d): South Zone

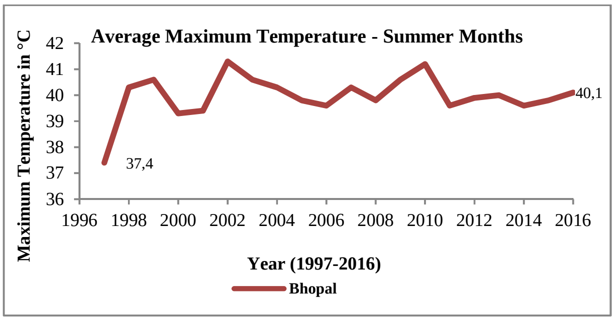



Fig (e): Central Zone

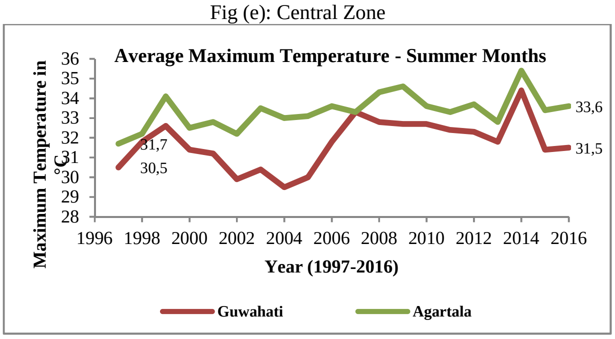



Fig (f): North East Zone

### b. Monsoon (1997-2016)

During monsoon season, the humidity is on the higher side. As per Indian Meteorological Department (IMD, Govt. of India), June, July, August, and September are considered as monsoon months. Fig. (g) and Fig. (h) shows that the average maximum relative humidity which had been consistently more than 80% from 1997-2016 in these four months. In coastal regions, humidity plays an important role in determining the energy generation of solar power plants and rain only adds more humidity.

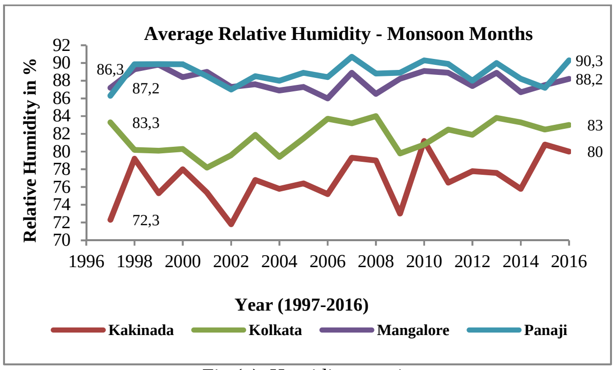



Fig (g). Humidity area 1

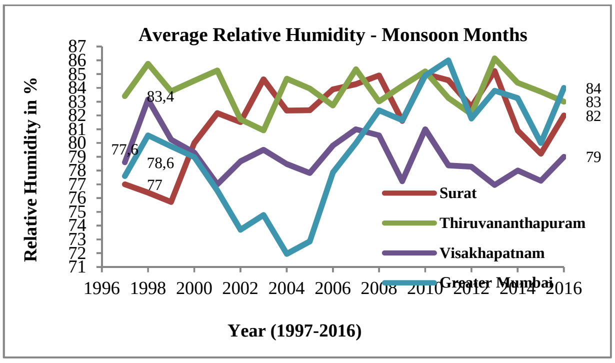



Fig (h). Humidity area 2

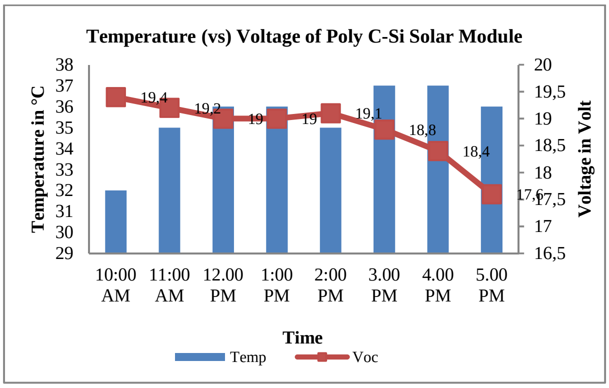
## 3. Outdoor Characterization

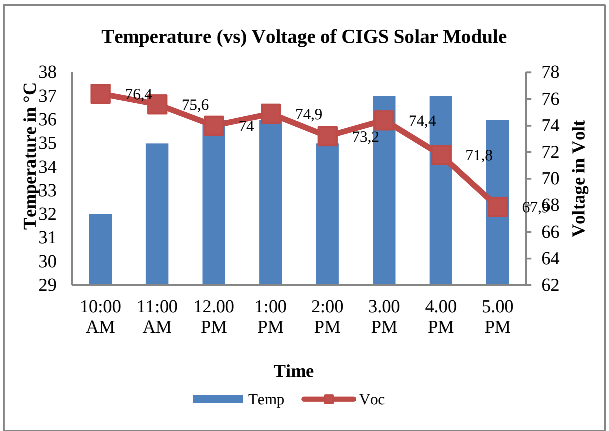
A 40Wp Poly crystalline silicon solar module, a 20Wp Amorphous silicon solar module, and a 160Wp CIGS module are chosen to ascertain the above-mentioned theory. The modules are installed on the roof of a building which is near to Jadavpur University, Kolkata. The modules are tilted at 23$^{o}$ angle facing south. Temperature sensor, thermocouples, and a clamp meter are used to measure the ambient temperature, module temperature, voltage and current output from all three solar modules. May 2016 as summer month and September 2016 as monsoon month are chosen for analysis of maximum temperatures and relative humidity. The readings of ambient temperature, humidity, current, and voltage are taken simultaneously in every one hour from 10 am to 5 pm for two weeks in each month. The module temperatures are also taken in every one hour during May from 10 am to 5 pm.

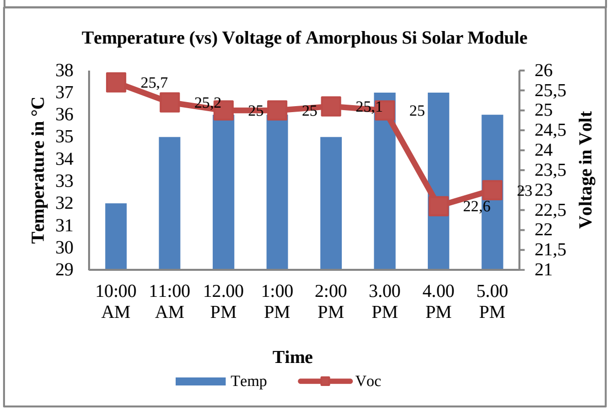
### Observations:

The daily voltage output of three solar modules as a function of ambient temperature in the selected period of time is plotted in the graph (i), (ii) and (iii). The ambient temperature normally varied between 30$^{o}$C to 45$^{o}$C from 10 am to 5 pm during the month of May in

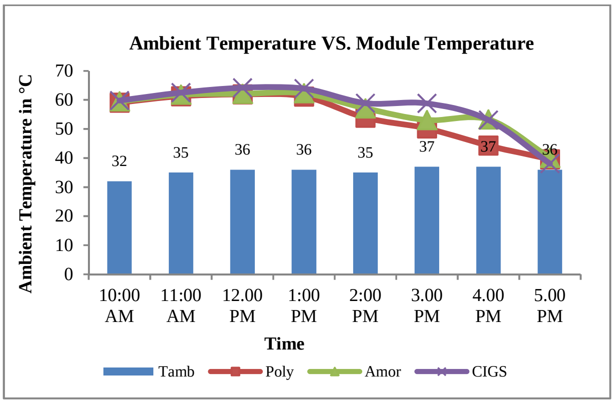
Kolkata. The graph (iv) shows that the module temperature which is always 20°C (+/- 5°C) higher than the ambient temperature from 10 am to 3 pm during the summer months. The negative effect of temperature on output voltage is observed in all solar modules and is valid to all high-temperature cities.



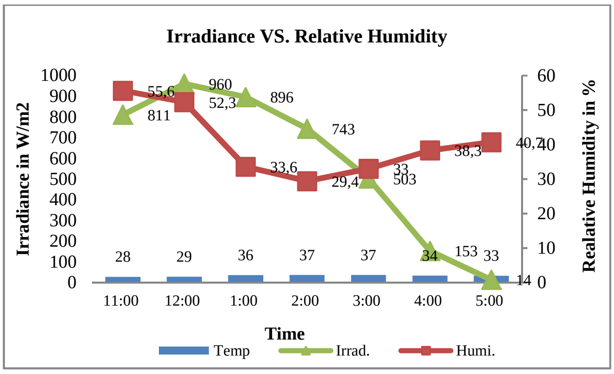




graph (i), (ii) and (iii)

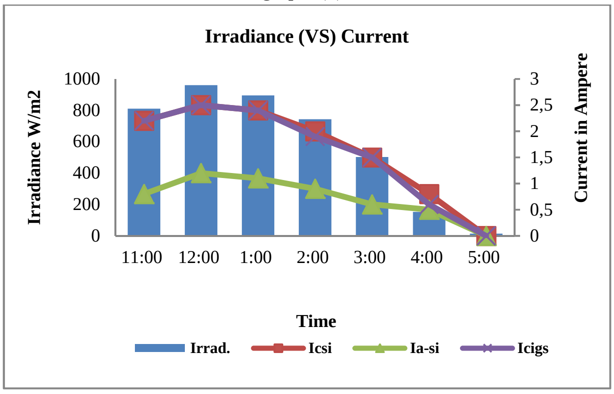



graph (iv)

The daily current output of three solar modules as a function of irradiance and humidity in the selected period of time is plotted in the graph (v) to (vi). The humidity is normally high during the morning and late afternoon in September in Kolkata. The graphs show that with an increase in humidity, the irradiance reduces which in turn has a negative effect on short circuit current and power output of solar modules.




graph (v)



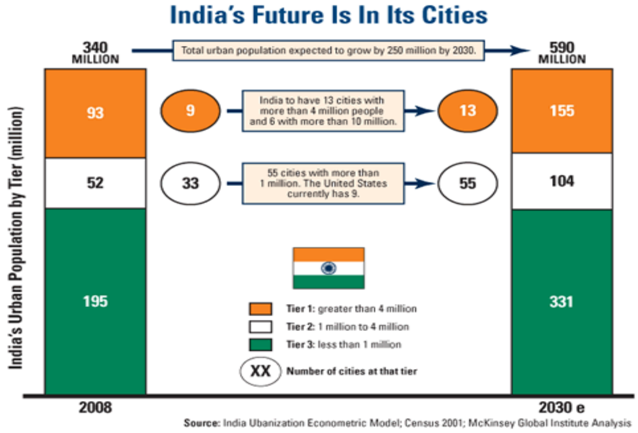

graph (vi)

## 4. Causes of Climate change in cities:

The natural greenhouse gases trap the infrared radiation emitted back by the earth and act as a blanket surrounding the earth which keeps the average global temperature above the freezing point. Water vapour is the principal greenhouse gas and carbon dioxide ($CO_2$) is the second-most important one. Methane, nitrous oxide, ozone and several other gases present in the atmosphere in small amounts also contribute to the greenhouse effect. The concentration of $CO_2$ in the atmosphere is increasing due to the burning of fossil fuels at a faster rate than the rate at which they were created, as a result warming the earth's climate. The rise in temperature increases water vapour concentration, traps solar radiation further intensifying the greenhouse effect.[8] The measure of moisture in the atmosphere defines humidity. The water vapour will invariably affect the amount of received irradiance at the location where humidity percentage is higher.[6]

According to European Commission 2015 report, India with 6.5% is the fourth largest $CO_2$ emitter in the world. The $CO_2$ emissions in India increased from 652486.70 K tons in 1990 to 2341896.77 K tons in 2014.[9]

Migration into cities for better opportunities and living will increase the consumption of more energy-intensive goods and transportation services, which will in turn increase emissions. As per McKinsey Global Institute report, India's urban population is expected to increase to 590 million by 2030. Population density is also a major factor in determining the anthropogenic heat production within a city.




Author Stanley E. Manahan explained in his book that - Human activities generate significant amounts of heat and produce large quantities of $CO_2$ and other greenhouse gases that retain heat. The net result of these effects is that a city is capped by a heat dome in which the temperature is as much as 5°C warmer than in the surrounding rural areas, such that the large cities have been described as "heat islands." The Urban surface reflects less radiation back to the atmosphere and they instead absorb and store more of it, which raises the area's temperature.[10]

## 5. Result and Conclusion

Similar to National Solar Mission, Smart cities mission is also a very ambitious initiative of Govt. of India to provide uninterrupted electricity and clean environment for its citizens. The main clause of the smart city is to generate 10% of the total power from solar energy. The government may reach the target of 40GW rooftop solar PV installation, but the challenge remains whether the plants will generate adequate energy in high temperature and high humid cities.

The study has shown that there is a huge rise in ambient temperature and humidity in the major cities which are declared as smart cities. This rise has been recorded and continuous for last two decades due to global warming. As observed, the generation decreases with the rise of temperature and humidity in any city. According to IPCC 2014 report, the surface temperature is projected to rise over the 21st century under all assess emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. An appropriate solar PV technology that is less sensitive to increase of temperature and humidity to be chosen in Rooftop Solar PV installation for generation of adequate energy in high temperature and humid smart cities.

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