Solar Energy Generation Potential on National Highways

Anurag Swain

Sr. Deputy General Manager (Electrical & Instrumentation), My Home Power Consultancy Services Pvt. Ltd
My Home Hub, 3rd Block, 5th Floor, Madhapur, Hyderabad,-500081, Telangana, India

---***---

Abstract – The Solar PV Power Generation System is a cheaper way of Renewable Energy Generation, requires large area. As cost of the land is growing day by day, there is a strong requirement to use the available land as efficiently as possible. Here, I explored the potential of PV Solar energy generation on Highway Road divider (middle portion), which is 4.5 to 5 meter wide, mostly planted by small flower plant. This space can contribute for renewable energy generation without extra cost for the land. The Solar PV panels can be installed 1 meter above the planted area to generate the electricity. Within 2.9 KM length of the Highway, we can able to install 1.2MWp capacity of Solar PV Plant, the annual energy generation shall be 1.824GWh.

Ahmedabad-Rajkot Highway distance is 202 KM, which has installation capacity of 67MWp, the annual generation shall be 101 GWh. Ahmedabad-Vadodara via NH is 114KM , which has installation capacity of 39 MW, the annual generation shall be 58.5GWh.

If my concept will be implemented throughout India, it will increase the power generation to more than a few GWh.

Key Words: Solar PV Power Generation, Renewable Energy. ON Grid System, PV Panel

1.0 INTRODUCTION:

Our National Highways spread from north to south and east to west, are exposed to sun. The 4 lane National Highway is a typical 3+7+5+7+3=25 meters wide road, whereas the road divider is 4.5 to 5 meters wide. This portion is mostly planted by small plants. If we fix Solar PV panels within this portion, we can able to generate large quantity of Electricity.

The Solar PV modules shall be mounted 1 meter above the road divider. During daytime with availability of sunlight, within 2.9 KM length of highway, we can able to install 1.2 MWp of PV Solar Plant. The Solar central inverter shall convert the generated DC Power to 1 MW of AC Power at 400V level. The 1250 KVA step-up Trans former shall step up the voltage to 33 KV level & synchronize with 33KV Grid. The 1.2 MWp systems will generate 4500 to 5000 KWH daily. The annual generation shall be 1825 MWH.

This is an ON-Grid system. It can be converted to Off Grid System by adding suitable battery backup & design modification.

2.0 SYSTEM DESCRIPTION:

Now considering standard Solar PV panel of 315 Wp (Make: Canadian Solar, Dimension: 2m x 1m) is available in market require 2 sq. meter of space. If we will arrange 4 numbers of modules in rows, it requires 4 m x 2 m=8 sq. meter of space. 20 numbers of modules will be arranged in 5 rows & 4 columns matrix. The space in between each row shall be 0.75 meter. The module arrangement system was shown in the DRG NO: 1 &2

Space required for this matrix=4m (Wide) x 13 m (Length)
=4 m (Wide) x {(2m x 5) + (0.75m x 4)}
=4 m (Wide) x {10 m +3 m}
=4 m x 13 m

Area required=52 sq. meter
20 Number of Modules connected in series to form string.
String output Power = 315 Wp x 20=6.3 kWp.
String Voltage =36.6 V x 20=732 V DC
String Current=8.61 A
Arranging of 95 numbers of such matrixes shall be connected in parallel to form 598.5 kWp power output.

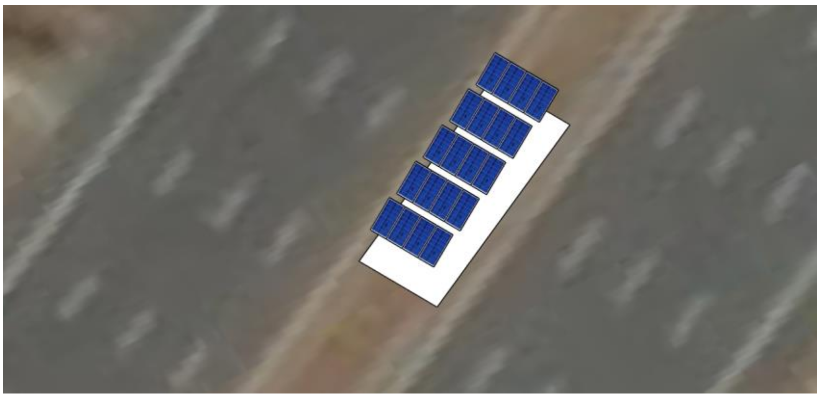
Total numbers of Modules= 20 x 95 = 1900 numbers
Total Output Power= 6.8 kWp x 95 = 598.5 kWp
Length required = 13 M x 95= 1235 M=1.235 KM

Now arranging 2 set 598.5 kWp + additional 1 string extra
Total nos of Modules (2x1900)+20=3800+20=3820
Power output= (2 x 598.5) + 6.3= 1203 kWp
Total numbers matrix =95+95+1=191 numbers
Total length required=1235+1235+2=2472 meter
Space required for fixing of inverter & other Items =7 m
Total length= 2472+7=2478 m= 2.478 km, Say=3 km

FIG-1

The DC generated power will be 1.203 MWp. The Solar Central Inverter of 1200 KW (Here we have taken the design based on the ABB-Make Model NO: PVS 800-57-1000 KW-C) will convert the DC to AC output,
Input Voltage to Inverter= 758 VDC,
Output of the Inverter=400 VAC
The Solar panels arrange are shown in **DRG-1 & 2.** Total 20 modules are arranged in 4 Rows X 5 Column.

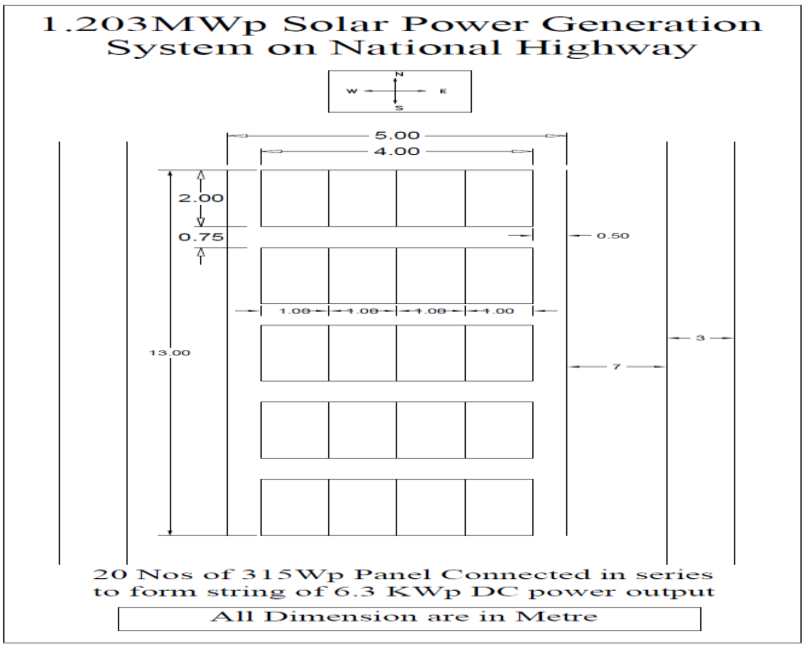
DRG-1



The Inverter shall be fixed in-between the two set of 95 Matrix space. The AC power shall be Stepped-up from 400 V to 33 KV by 1250 KVA Transformer & shall synchronize with 33 KV Grid.

The Transformer shall be fixed in a two pole structure at the side of the High way. The 400 V AC cable shall be laid underground to the Transformer. The 33 KV transmission line shall be run parallel to the High way, which will be connected to nearby 33 /132 KV Sub-station.
A revenue metering system (main, check & stand-by) with PT & CT and protection breaker/isolator along with Transformer shall be installed in the two pole structure.
A suitable SCADA system shall be installed with GPRS modem for remote monitoring of data as shown in **DRG-3**

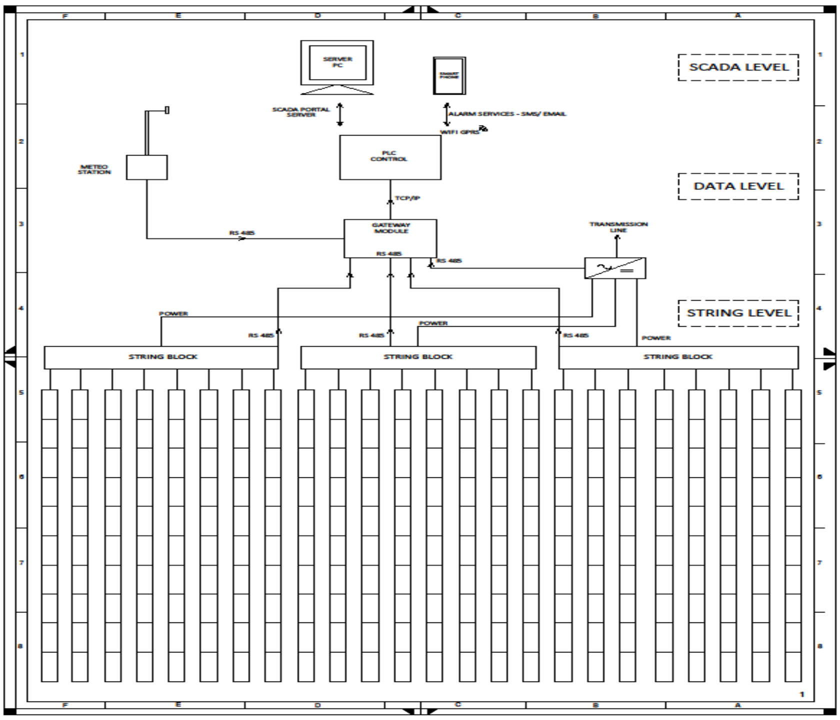
3.0 SOLAR PANEL ARRANGEMENT DRAWING: DRG-2



4.0 DATA AQUASIATION & REMOTE MONITORING

The Remote monitoring & SCADA system is shown in **DRG-2.** The 485 Communication ports are available Within the inverter, UPS, Electrical Panels, String Combiner Boxes, weather monitoring (if applicable). All the data ports shall be connected by STP (sealed twisted pair) cable & shall be connected to micro logic PLC/ SCADA system. The GPRS Cellular modem shall be connected to the SCADA network. All the important parameter like Generation units ,KVA, Voltage, Current along with weather data shall be remotely monitored & controlled (If required) from the control room from any part of the Country.

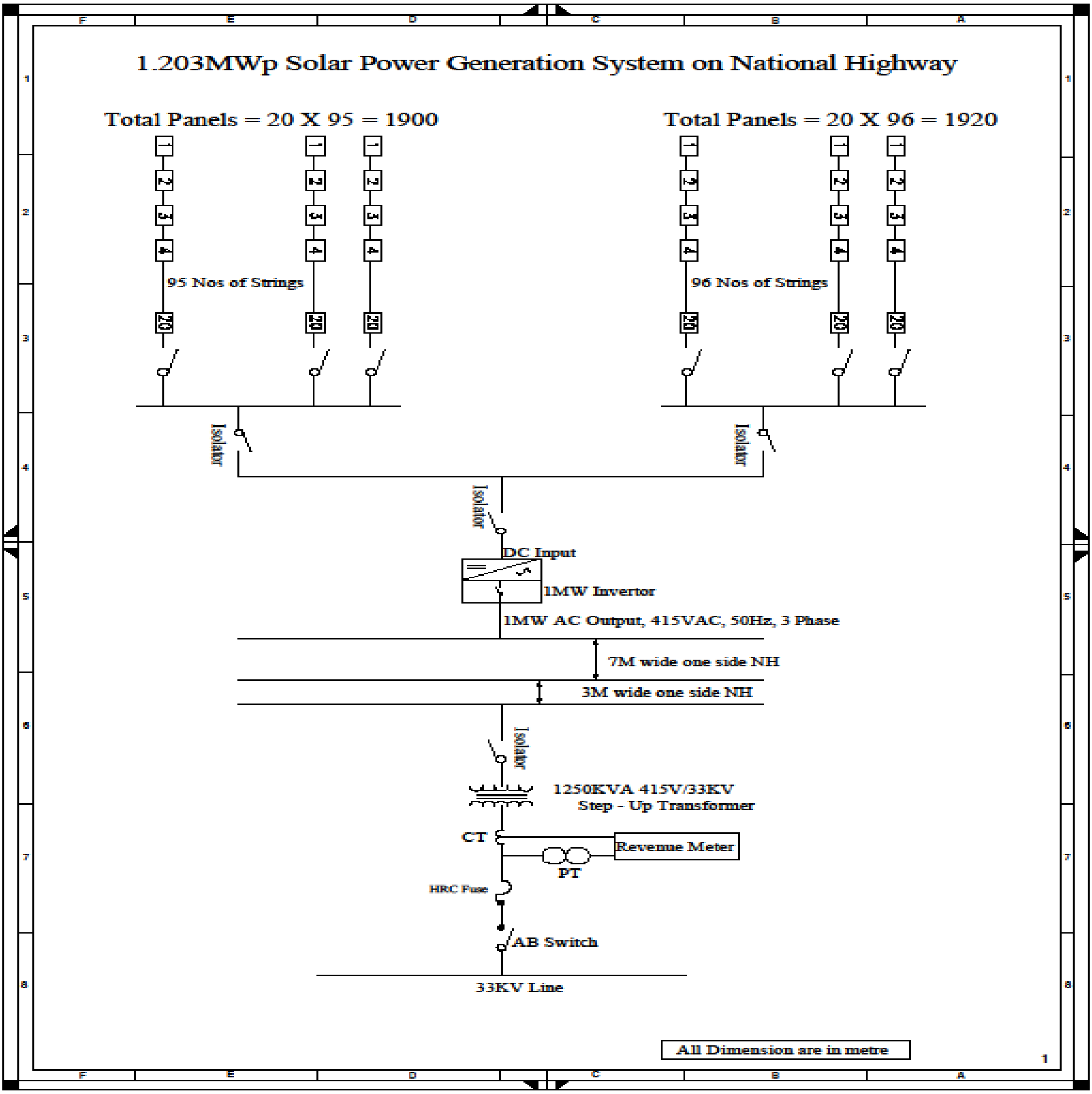
DRG-3



5.0 COST & PAYBACK:

The cost of 1.2 MWp systems shall be INR 5.7 Cr.
Yearly Generation:1825 MWH, Cost of Unit:Rs 6.50,
The system wills generate 1.2 MWp of DC or 1 MW of AC.
Yearly Revenue Generation=1825 x 1000 x 6.50=1.18625 Cr. Investment Cost Rs 5.7 Crore without Taxes & duties
Payback with respect to Investment cost with taxes & duties & Bank Interest will be 6 Years.

6.0 ELECTRICAL SINGLE LINE DIAGRAM: (DRG-4)



7.1 GRID –CONNECTED SYSTEM: SIMULATION PARAMETERS.

Geographical Site: **Grid-Connected Site at South-India**

Situation	Latitude	15.4°N	Longitude	78.2°E
Time defined as	Legal Time	Time zone UT+5	Altitude	245 m
	Albedo	0.20		

Meteo data : Synthetic Hourly data

Simulation variant : **Fixed optimum**

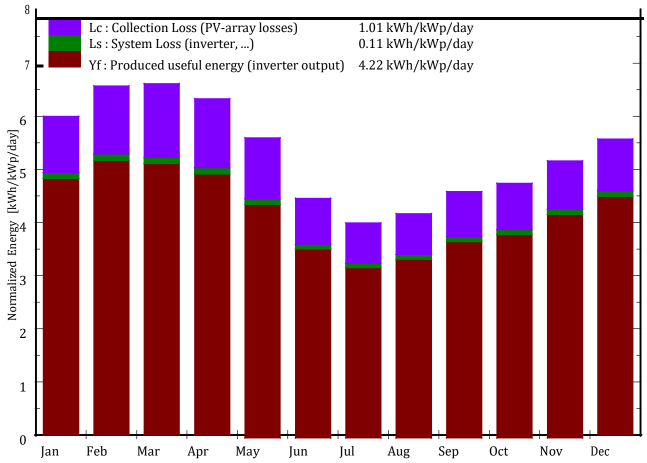
Simulation parameters					
Collector Plane Orientation		Tilt	18°	Azimuth	0°
Horizon	Free Horizon				
Near Shadings	No Shadings				
PV Array Characteristics					
PV module	Si-poly	Model	**CS6X - 315P**		
	Manufacturer		Canadian Solar Inc.		
Number of PV modules	In series		20 modules	In parallel	191 strings
Total number of PV modules	Nb. modules		3820	Unit Nom. Power	315 Wp
Array global power	Nominal (STC)		**1203 kWp**	At operating cond.	1080 kWp (50°C)
Array operating characteristics (50°C)		U mpp	651 V	I mpp	1660 A
Total area	Module area		**7330 m²**	Cell area	6694 m²
Inverter		Model	**PVS800-57-1000kW-C**		
	Manufacturer		ABB		
Characteristics	Operating Voltage		600-850 V	Unit Nom. Power	1000 kW AC
PV Array loss factors					
Thermal Loss factor	Uc (const.)		29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp.	(G=800 W/m², Temp=20°C, Wind=1 m/s.)			NOCT	45 °C
Wiring Ohmic Loss	Global array res.		6.6 mOhm	Loss Fraction	1.5 % at STC
Array Soiling Losses				Loss Fraction	5.0 %
Module Quality Loss				Loss Fraction	0.1 %
Module Mismatch Losses				Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parameterization		IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05
System loss factors					
AC loss, transformer to injection	Grid Voltage		33 kV		
		Wires	300 m 3x35 mm²	Loss Fraction	0.5 % at STC
External transformer	Iron loss (24H connection)		1180 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive	losses	0.0 m Ohm	Loss Fraction	0.0 % at STC

User's needs : Unlimited load (grid)

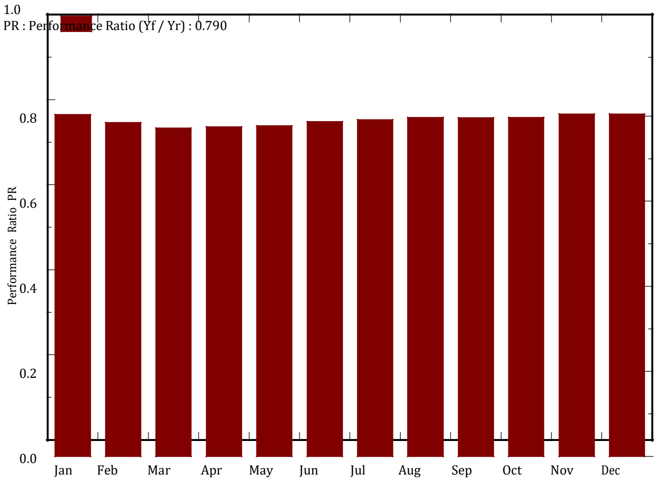
7.2 GRID-CONNECTED SYSTEM:MAIN RESULTS

Simulation variant :	**Fixed optimum**			
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	CS6X - 315P	Pnom	315 Wp
PV Array	Nb. of modules	3820	Pnom total	**1203 kWp**
Inverter	Model	PVS800-57-1000kW-C	Pnom	1000 kW ac
User's needs	Unlimited load (grid)			
Main simulation results				
System Production	**Produced Energy**	**1854 MWh/year**	Specific prod.	1541 kWh/kWp/year
	Performance Ratio PR	79.0 %		

Normalized productions (per installed kWp): Nominal power 1203 kWp



Performance Ratio PR



Fixed optimum

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	158.1	24.30	186.0	180.9	184.4	179.9	13.52	13.20
February	163.8	26.90	184.1	179.2	178.2	174.0	13.20	12.89
March	196.8	30.00	205.2	199.3	195.2	190.6	12.98	12.67
April	196.5	30.10	190.1	184.4	181.5	177.3	13.03	12.73
May	190.7	31.00	175.2	169.3	167.9	163.9	13.08	12.77
June	148.8	28.70	135.4	130.5	131.7	128.2	13.27	12.92
July	134.9	27.80	125.5	120.8	122.8	119.5	13.35	13.00
August	136.7	27.80	130.9	126.3	128.9	125.5	13.43	13.08
September	139.2	27.70	139.1	134.7	136.8	133.3	13.41	13.07
October	139.8	26.10	148.7	144.3	146.3	142.6	13.42	13.08
November	138.0	24.80	156.6	152.0	155.6	151.8	13.55	13.22
December	144.8	24.00	172.7	167.8	171.6	167.4	13.55	13.22
Year	1888.0	27.43	1949.5	1889.5	1900.8	1854.1	13.30	12.98

Legends:			
GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

7.3 GRID –CONNECTED SYSTEM: LOSS DIAGRAM

	Value	%	Unit	Description
	1888.00		KWH/m2	Horizontal Global Irradiation Global Incident in Collection plane
Add	62.30	3.30%	%	
	1950.30		KWH/m2	
Less	60.46	3.10%	%	IAM factor on Global
	1889.84		KWH/m2	
	13853700.00		KWH	Effective Irradiance on Collector
	2274777.54		KWH	PV Conversion (nominal energy at STC efficiency (16.42%)
Less	2274.78	0.10%	%	PV loss due to irradiance Level
	2272502.76		KWH	
Less	209070.25	9.20%	%	PV loss due to Temperature
	2063432.51		KWH	
Less	103171.63	5.00%	%	Array Soiling Loss
	1960260.88		KWH	
Less	1960.26	0.10%	%	Module Quality Loss
	1958300.62		KWH	
Less	39166.01	2.00%	%	Module array mismatch loss

	1919134.61		KWH	
Less	19191.35	1.00%	%	Ohmic wiring loss
	1899943.26		KWH	**Array virtual energy at MPP**
Less	30399.09	1.60%	%	Inverter loss during operation(efficiency)
	1869544.17		KWH	
Less	0.00	0.00%	%	Inverter loss over nominal Inv. Power
	1869544.17		KWH	
Less	0.00	0.00%	%	Inverter loss due to power threshold
	1869544.17		KWH	
Less	0.00	0.00%	%	Inverter loss over nominal Inv. Voltage
	1869544.17			
Less	0.00	0.00%	%	Inverter loss due to voltage threshold
	1869544.17		KWH	Available Energy at Inverter Output
Less	5608.63	0.30%	%	AC Ohmic Loss
	1863935.54		KWH	
Less	11183.61	0.60%	%	External Transformer Loss
	1852751.93		KWH	Energy to be Injected to Grid
	1825000		**KWH**	**Guaranteed Annual Generation**

8.1 PERFORMANCE RATIO CALCULATION:

Performance Ratio is the ratio of Electrical energy generated by the Solar Modules to Solar Energy received as irradiance by the Solar Modules.

PR= (Total Electrical Energy generated by the Solar Modules)/ (Total Solar Energy received as irradiance by the Modules)
PR =E/ (A x R x H)
E = A x R x H x PR
E = Energy generated by the Solar Modules in kWh
A = Total solar modules area in m^2
R = Solar Module yield (%)
H = Annual average solar radiation on panels
PR = Performance Ratio, coefficient for losses (range between 0.5 and 0.9)

Multiply with 100 will indicate Performance Ratio in %.
Be aware that this nominal ratio is given for Standard Test Conditions (STC):
Radiation=1000 W/m^2,
Cell Temperature=25 °C,
Wind Speed=1 M/S,
AM (Incidence Factor) =1.5
The unit of the nominal power of the photovoltaic panel in these conditions is called "Watt-Peak"(Wp or kWp=1000 Wp or MWp=1000000 Wp).

H: Annual average solar radiation on panels: Typical values lie between 200 kWh/m^2 and 2600 kWh/m^2.
For the typical site, with available Latitude and Longitude Data, the annual average solar radiation is 1888 kWh/m^2.
PR: PR (Performance Ratio) is a very important value to evaluate the quality of a photovoltaic installation because it gives the performance of the installation independently of the orientation, inclination of the panel. It includes all losses.

8.2 PROCEDURE FOR PR CALCULATION:

- The measurement of Energy and Solar irradiance will be done for 72 Hours of clear sunny days.
- The energy is measured on ABT meter at Generation Switch Yard/Transformer Yard.
- Solar Irradiance recorded at site on installed weather station.

8.3 PERFORMANCE RATIO FOR1.2 MWp:

PR= (E)/ (A*R*H)
E=5079.45KWH
A=7330 m2
R=0.1642 (Yield is 16.42 %) of Panel
H=1888 kWh/m^2
PR=0.81534 or (81.53 %) for 1852 MWH
PR=0.80313 or (80.31 %) for 1825 MWH (Guaranteed Generation)

9.0 CONCLUSIONS:

The Golden Quadrilateral is a highway network connecting Delhi, Mumbai, Chennai, and Kolkata of length **5,846 KM** that can have installation capacity of **1948 MW.** Similarly, for the four-lane north-south to east-west (NS-EW) Corridor highway of **7,300 KM**. the NS-EW Corridor highway has **2433 MW** capacity of installation. This will open up large potential of power generation in a very short period of time which is very much needed in India to have aggressive industrial growth which is presently in strong need for power. This way, huge potential of solar energy generation exists on the National Highways with capacities based on the length. This leads not only meeting the energy demand but also reduction in CO2 emissions. For all the above ideas, to see the light of day, there is an urgent need for an attractive policy by the government of India to increase the solar potential generation along the Highway.

ACKNOWLEDGEMENT

The authors are grateful for the help and support from Mr. G Krishna Balaji & Mr. Phanidra Aravapalli from Hyderabad.

REFERENCES

1. Solar Module Data Sheet (310 Wp/340 Wp
Make: Canadian Solar)
2. ABB Invertor 1KW PVS800-57 Central Inverters
3. Solar energy generation potential along national highways published in International Journal of Energy and Environmental Engineering; December 2013,

BIOGRAPHIES

ANURAG SWAIN:
M.Tech.(I.T.) Punjabi University PGDEM (Energy Conservation & Management) -Sri Krishana devaraya University, Anatapur. Graduate Engg. (ECE) from IE(I) B.Sc(PCME) from Utkal University.
Fellow of IE (I), IETE (I) & CET (I),
Professional Engineer from Engineering Council of India
Chartered Engineer (C.Eng.)from IE(I) & IETE(I)
Life member of MISOI & MISTE.

Presently working as Sr.Dy.G.M. (E&I) at My Home Power Consultancy Services Pvt. Ltd, a flag ship company of My Home Group, Hyderabad, India.
His interests are New & Renewable Energy, integration of alternative energy, Distributed Control System, Distributed Generation, SMART GRID, SMART Home, Intelligent Building & SMART CITY