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Design & Operation of Rooftop Photovoltaic System with Net-Metering Mechanism

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ABSTRACT: A rooftop photovoltaic system generates electricity by using solar panels mounted on the rooftop of a residential or building. It is typically in the range of 5 to 20 kilowatts (kW) for residential buildings. The metropolitan cities facilitate the empty rooftop spaces and can naturally avoid the feasible land use and environmental concerns. Feed-in tariff (FIT) or Net-Metering mechanism is to sell the generated electricity to the grid at a price higher than what the grid charges for the consumers. This FIT mechanism provides payback for the investment of the consumer and also localize production and reduce transmission losses through power lines. Consumer can feed solar power into the electric grid and hence receive a premium tariff per generated kWh reflecting the benefits of solar power to compensate for the extra costs of usual electricity.

KEYWORDS: Net-Metering; PV System; Solar Energy; Semiconductors; Rooftop.

I. INTRODUCTION

Globe population is projected to twice by the middle of the 21st century (Global Energy, 1998). Population growth will consequently increase 3-5 times by the year 2050, and a 10-15 times by 2100. As a result, power necessities are amplified by three folds by the year 2050 and five folds by the year 2100. The use of renewable energy is possible alternative of burning fossil fuels

Table (1.1): Ecological consequences by different energy sources

	Air Pollution	Air Pollution	Water/Sea	Fauna	Vegetation	Area	Aesthetic
Coal	Red	Red	Blue	Blue	Red	Red	Red
Oil	Red	Red	Blue	Blue	Red	Yellow	Blue
Peat	Red	Red	Blue	Red	Red	Red	Red
Household Waste	Blue	Red	Yellow	Yellow	Yellow	Yellow	Yellow
Hydro Power	Blue	Yellow	Blue	Red	Blue	Red	Red
Wind Power	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Yellow
Forest Energy	Yellow	Blue	Blue	Blue	Blue	Blue	Blue
Energy Forest arable land	Yellow	Blue	Yellow	Yellow	Blue	Blue	Yellow
Forest Energy residues	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
Straw	Yellow	Blue	Yellow	Yellow	Yellow	Blue	Yellow
Energy crops arable land	Yellow	Blue	Yellow	Yellow	Yellow	Blue	Yellow
Heat produced by solar	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Solar	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Efficiency of Energy	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

Yellow	Minimum or no ecological consequences
Blue	Some ecological consequences
Red	High ecological consequences

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Solar energy is one of the practicable options. This form of Non-Conventional energy occupies less space compared to the space occupied Conventional energy. Table 1.1 tabulates various Conventional and Non-Conventional energy sources in terms of consequences and harm to the atmosphere. The first solar cell was created in 1883. The revolution

in solar cell technology came in 1954 by Bell Laboratories stumbled across the photovoltaic (or PV) properties of silicon. Present commercial PV cells have enhanced to 11–15% efficiency.

The choice of Net-Metering, or interconnecting a customer producing electricity to the utility grid, makes solar electric systems more reasonably practicable. The metropolitan atmosphere provides a bare rooftop spaces and will provide space for production of solar electricity with the rooftop PV cells. Feed-in tariff (FIT) or Net-Metering mechanism is to trade the generated electricity to the grid and payback to the installer. It also improved capability for localized production and implanted generation reduces transmission losses in power lines.

II. PRINCIPLE OF OPERATION OF SOLAR POWER

The Sun is ultimate source for the world; the quantity of solar energy incident on the earth's is approximately 1.5 x 1018 kWh/year, which is about 10,000 times of annual energy consumption by world. The density of power radiated from the sun is 1.373 kW/m^2. Solar cell is a piece of equipment which converts photons in light to direct-current (DC) and voltage. The associated technology is called Solar Photovoltaic (SPV). A silicon PV cell is a thin wafer consisting of a very thin layer of phosphorous-doped (N-type) and a thicker layer of boron-doped (P-type) silicon.

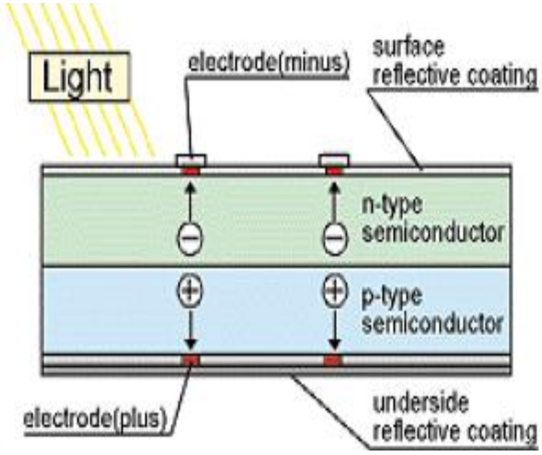

Figure 2.1: Silicon Solar Cell

When the sunlight falls on the semiconductor material; an electron energized and moves towards the N-type material. This will cause negatives charged particles in the n-type and positives charged particles in the P-type semiconductors, generating flow of electricity. This is known as **Photovoltaic effect**. Figure 2.1 shows the working method of a silicon solar cell.

III. THE COMPONENTS OF A GRID-TIED PV SYSTEM

This includes:

PV Array: PV array is installation of various PV panels together. Installing these arrays on rooftops is most common (say 200W×6 Panels)

DC Disconnect: The DC Disconnect acts like a protective switch, when this switch is opened manually; the circuit becomes open and stops power supply from the PV array to the Consumer system.

DC/AC Inverter: The Photo Voltaic module generates Direct Current (D.C) power; however, we use Alternating Current (AC) power for house hold needs and Power Grids. The Inverter is used to converts the DC power to AC power by switching devices.

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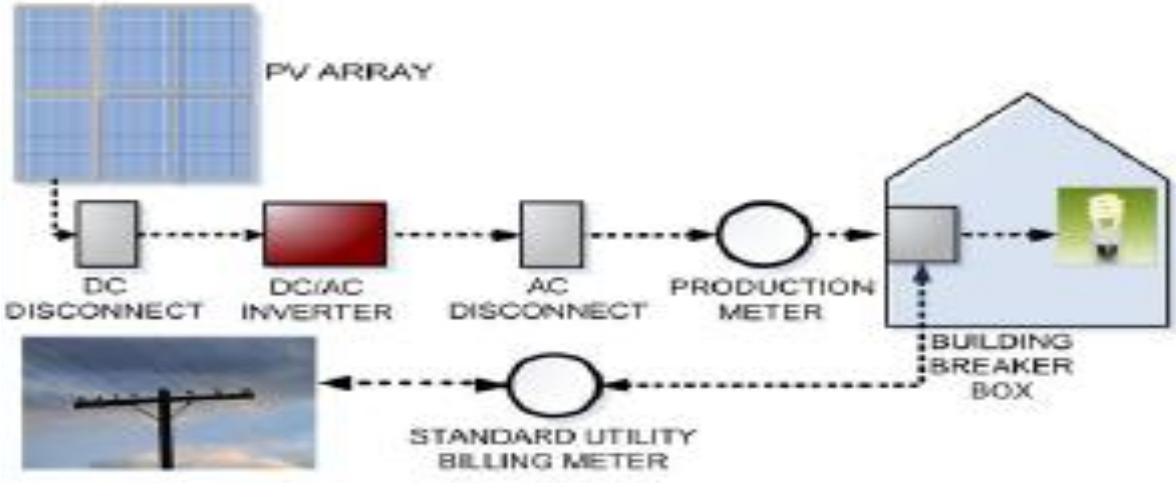

Figure 3.1: Feed-in tariff (FIT) or Net-Metering mechanism

AC Disconnect: It is another protective switch and is habitually built-in into the Inverter.
Production Meter: Output Energy (KWh) is measure by Production Meter by PV array and records the amount of electricity Produced.
Building Breaker Box and Standard Utility Meter: Other name for Utility Meter is building's circuit panel or electrical service panel. If the building is using electricity, the PV-produced electricity will be used first. If the building needs more electricity than the PV System is producing, utility grid power is automatically pulled into the building. When the PV System produces more electricity than is needed, the excess flows back out to the utility, spinning your utility billing meter backwards in the process. You earn credit for the excess power produced and can use that credit when the System is not producing energy. This process is referred to as "net metering."

IV. DESIGNING ROOFTOP PV SYSTEM (CASE STUDY)

A. Case description

A small home in a city of Hyderabad wants to supply Electricity from APSEB mains and also use to solar energy to all loads. The house is to be occupied in different time intervals, first from 6am-10am, 10am-5 pm, 5pm-10pm and 10pm-6am during the month. The home has four rooms and different electrical appliances.

B. Typical Rooftop System Design

1. *Design Assumptions*

• Latitude (Hyderabad City)	17.37°N
• Longitude (Hyderabad City)	78.48°E
• Battery	LMS400
• Depth of discharge	0.8
• Array output efficiency	85%
• Inverter η%	90%
• Battery η%	85%

2. *PV Module Design*

• Model	ELDORA	250P
• Rated Peak Power	(Pmmp)	255W
• O.C Voltage	(Voc)	89.7V
• S.C Current	(Isc)	3.51
• Vrated	(Vmpp)	82.77V
• Irated	(Impp)	3.1A
• Fill Factor	(FF)	76.78%

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• Efficiency (%) 15.84%
• Fire rating (Type) Class-C

3. *Inverter Capacity*
•Type MSW (Modified sine Wave)
•Phase Single Phase
•Power Rating 1.5 kVA
•Voltage Rating 80V/230V
•Frequency 50Hz

C. Assessment of Load profile

Assessment of load profile includes the variety of appliances, wattage and the number of hours operated a day. The associated appliances in the house are tabulated in table 4.1

Table 4.1: Assessment of Various Home Appliances

No.	Appliance	Qty	Rated wattage	Operational hours / day	Energy / day (Watt-hours)
1	Lights	4	40	4	640
2	PL Lights	2	11	4	88
3	Television	1	70	3	210
4	Fan	3	70	5	1050
5	Washing Machine	1	2000	1	2000
6	Computer	2	200	1	400
7	Microwave	1	800	0.5	400
8	Refrigerator	1	200	5	1500
9	Air Conditioner	1	1080	5	5400
10	Water Heater	1	1000	0.5	500
				Total Power Consumption /day	**12,188Wh =12.2KWh =12.2Units/day**
*Assumed that the Air Conditioner/Refrigerator functions for 24 hours in a day, whereas compressor for 5 hours per day.					

D. Assessment of Solar Generation profile

Assessment of source profile includes the Rooftop PV Modules with 6 No of panels. Each panel rating is of 200W.The number of hours the PV cell will operate a day is 6hr as tabulated below in table 4.2.

Table 4.2: Assessment of Solar Power Generation at different timing in a day

Time	**Voc**	**Isc**	**Power**	**Energy(W-h)**
11AM	80.2	2.65	212.53	212.53
12PM	79.3	2.92	231.556	231.556
01PM	80.03	2.86	228.8858	228.8858
02PM	81.5	2.52	205.38	205.38
03PM	81.51	1.98	161.3898	161.3898
04PM	80.25	1.36	109.14	109.14
Energy Generated per Panel				**1148.88W-hr**
No of panels are 06				1148.88×06
Total Energy Generated per day				6893.28W-hr
Due to shading the loss 15%(0.15*6893.28)				1033.992W-hr
Net Energy Generated per day				**5859.29W-hr**
Net Energy Generated per month(5859.29*30)				**175.78KWh=175.78 Units/Month**

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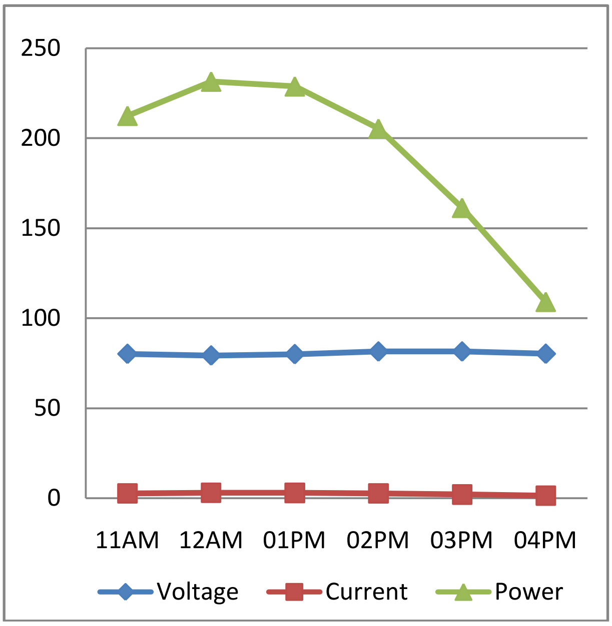
The following graphs fig 4.1(a)& fig 4.1(b) shows the variation of Voltage, current and power with different inclination angles of PV system



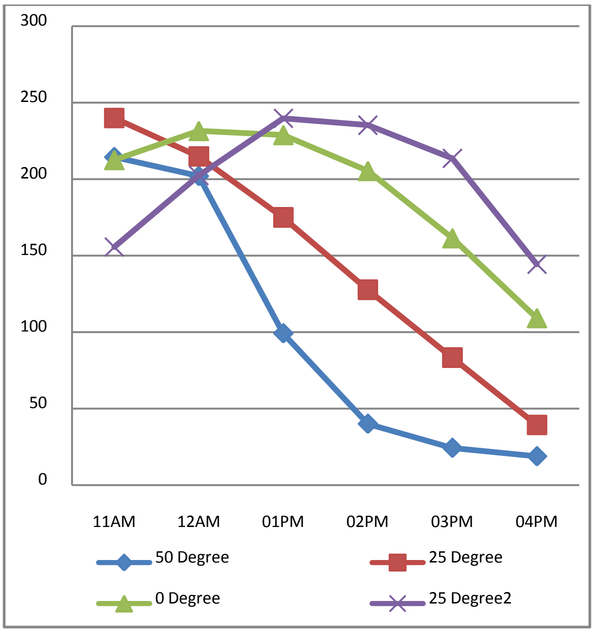


Figure 4.1(a): Variation of Voltage, Current and Power of PV System in day
Figure 4.1(b): Variation of power of PV System in day with different inclined position

E. Assessment of Tariff:

The following table (4.3) shows the Surcharge of consumers by TSPDCL

Table4.3: Retail Supply Tariff Schedule for year 2015-16
(Ref: TSPDCL)

Units Consumed	Energy Charges Rs/Unit)
LT-I (A): upto 50 units	
First 50 units	1.45
LT-I(B): Between 50 and upto 100 units/Month	
First 50 units	1.45
51-100 units	2.6
LT-I(B): Between 100 and upto 200 units/Month	
First 50 units	2.6
51-100 units	2.6
101-150 units	3.6
151-200 units	3.6
LT-I(B): more than 200 units/month	
First 50 units	2.6
51 - 100 units	3.25
101-150	4.88
151-200	5.63
201-250	6.38
251-300	6.88
301-400	7.38
401-500	7.88
Above 500	8.38

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V CONCLUSION

From the load assessment profile with 1KW load, the Energy consumed is 12.2 Units/day. Therefore per month it becomes 366 Units/Month. As per normal tariff rates without Net-Metering per month become

Table 5.1: Tariff without Net-Metering

Without Net-Metering		
Units Consumed	Energy Charges Rs/Unit)	Amount
First 50 units	2.6	130.00
51 - 100 units	3.25	162.50
101-150	4.88	244.00
151-200	5.63	281.50
201-250	6.38	319.00
251-300	6.88	344.00
301-400	7.38	487.07
For 366 Units	**Total Amount/month**	**1968/-**
	Per Year	**23,616/-**

By using the Net metering, from the solar power generation, the No.of units generated is around 175.78 Units/Months.Net Energy consumed by the consumer is (366-175.78=190Units) So the tariff paid is shown in table 4.5

Table 5.2: Tariff with Net-Metering

With Net-Metering			
Units Consumed	Energy Charges Rs/Unit)	Amount	
First 50 units	2.6	130.00	
51 - 100 units	3.25	162.50	
101-150	4.88	244.00	
151-200	5.63	281.50	
For 190 Units	**Total Amount/Month**	**818/-**	
		Per Year	**9,816/-**

The following table-4.6 shows the net saving of Energy and the cost of saving over a year is shown

Table 5.3: Retail Supply Tariff Schedule for year 2015-16
(Ref: TSPDCL)

	Units/Month	Cost/Month	Cost/Year
Without Net-Metering	366	1968	23,616/-
With Net-Metering	175.78	818	9,816/-
Net Saving	***190 Units***	***1150***	***19800/-***

It can be concluding that by using the Net-Metering, the annual saving will be around 40%.

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