

ENERGY, ENVIRONMENT AND SOCIETY

Chapter - 7

Design of Solar PV Rural Systems

Assoc. Prof. Manchan Tiwari

Kathmandu Engineering College

Nepal

LEARNING OBJECTIVES OF THE LECTURE

- Demand assessment and calculation
- Data Collection for Solar Resource assessment
- Basics of survey and investigation for solar PV system
- Aspects of system design
- Basics of array design, battery sizing and charge control sizing

STEPS OF SOLAR PV SYSTEM DESIGN

- Load Assessment and Calculation
- Solar Resource Assessment
- Survey and Investigation
- System Design

Note: *Guidelines For The Study of Solar Mini Grid Projects*: Alternative Energy Promotion Centre, The Government of Nepal, Ministry of Energy, Water Resources and Irrigation is taken as major reference for this lecture.

LOAD ASSESSMENT AND CALCULATION

- The important aspects to consider while considering system load are
 - Accurate Load Knowledge
 - Load Efficiency
 - Load Profile
 - AC or DC Load
 - Apparent and Real Power Consideration

LOAD ASSESSMENT AND CALCULATION

- It is very important to accurately determine solar PV system load to correct determination of system size and system electricity generation and losses.
- As seasonal variation causes variation in energy generation, atmospheric temperature, consumer energy consumption patterns, it is important to consider the load profile according varying seasons.
- It is essential to plot estimated daily load curve for a 24 hour period of a day in one hourly interval along with consideration for peak load (AEPC , 2022).

LOAD ASSESSMENT AND CALCULATION

SN	Electricity Uses	Quantity	Watts per Unit	Total Watts	Uses Hours per day	Coincidence Load Factor	Watt hour per day
1	Households						
1.1	Main Room Light	4	10	40	5	85%	170
1.2	TV	1	60	60	4	40%	96
1.3	Fan	2	40	80	8	95%	608
2	End Uses						
2.1	Hotels and Restaurant	1	500	500	5	100%	2500
	TOTAL			680			3374

LOAD ASSESSMENT AND CALCULATION

- Coincidence load factor is usability or availability of devices (AEPC , 2022).
- For example coincidence load factor of 85% of main room light in the table in the previous slide means only 85% of installed main room lights for 5 households shall be used on an average on any particular day.
- The TV has 40% of the coincidence factor which means that 40% of the households will be using the TV in the community at an instant.

LOAD ASSESSMENT AND CALCULATION

- Such demand analysis tools should be used for productive end uses as well.
- These daily load curve should be represented with the help of combined load curve to accurately represent the peak power sizing, storage and energy demand.
- Regarding the data required for the load table, a questionnaire can be developed which can be used to obtain the relevant data.
- It is desirable to at least survey 10% of the households to obtain the relevant data (AEPC , 2022).

LOAD ASSESSMENT AND CALCULATION

- To ensure the project is financially sustainable it is important to ensure the maximum utilization of renewable sources.
- The primary use of a solar rural system can be to meet the daily household requirement of the community in the rural region; however, the productive and community end uses should be promoted
- Due to fluctuating energy production potential of solar energy during the day, it is desirable to use diverse type of end uses to balance the intermittency to optimize the investment cost.

LOAD ASSESSMENT AND CALCULATION

- The common type of end uses can be
 - communication centers,
 - agro grinding mills,
 - small scale furniture factory,
 - poultry farms,
 - metals and grill workshops,
 - photo studios,
 - tailoring business,
 - health clinics,
 - electronic repair shops,
 - bakeries and other small enterprises.
- Generally, these end uses are operated during the day due to which no storage devices are required.

SOLAR RESOURCE ASSESSMENT

- For accurate estimate of annual energy production, solar resource assessment is essential.
- Solar resource assessment refers to the analysis of the prospective solar energy production of the site in contention.
- It is important to measure direct, diffuse and global solar radiation in a site of contention.
- As per AEPC, the solar mini grid projects which are to be implemented should have global horizontal irradiation value of more than 4 kWh per m² per day
- These data can be obtained either by ground-based measurement stations or by solar models that utilize satellite, atmospheric and meteorological data.

SOLAR RESOURCE ASSESSMENT DATABASE

Database (satellite Based)	Area	Coverage	Time Period	Time Resolution	Spatial Resolution	Values (Time series)	Parameters	Type	Website
SolarGIS	Globally	Latitude 60°N and 50°S	From 1994	15 min	0.25Km x 0.25Km	hourly	GHI, DNI	Commercial	https://solargis.com/
Meteonorm	Globally		1991-2010/ 1996-2015	1-hourly		monthly	GHI, DNI	Commercial	http://www.meteonorm.com/
Solar Energy Mining (SOLEMI)	Europe, Africa, Asia		1991-today (Europe), 1999-2006 (Asia)	1-hourly	2.5Km x 2.5Km	hourly	GHI, DNI	Commercial	https://wdc.dlr.de/data_products/SERVICES/SOLARENERGY/description.php
3Tier	Europe, Africa, Asia	48°N and 60°S	1999-present	1-hourly	3Km x 3Km	hourly	GHI, DNI	Commercial	https://www.3tier.com/
Surface meteorology and Solar Energy (SSE)-NASA	Globally		1983-2005	3-hourly	100Km x 100Km	monthly	GHI, DNI	Free	https://eosweb.larc.nasa.gov/sse/

SURVEY AND INVESTIGATION

- Following major parameters are considered for site selection (AEPC , 2022)
- Availability of Solar Resource GHI of more than 4 kWh per m² per day should be considered
- Shading due to hill, mountains, building, trees, overhead cables should be avoided.
- Availability of land area should have sufficient land area
- Topography and Orientation flat or slope surface with good southern exposure is desirable

SURVEY AND INVESTIGATION

- Following major parameters are considered for site selection (AEPC , 2022)
- Geotechnical stable ground is required
- Climatic Characteristics flooding risk, wind speed and risk of snow should be taken in considerations
- Right way of proper path of transmission and distribution lines should be considered
- Permit and Clearances should follow local land use regulations and should acquire land lease permit or construction permit where ever it is required

SYSTEM DESIGN

- Following important parameters should be considered for design of a solar power systems
 - Site location and land area requirement
 - Seasonal load profile, daily load profile
 - Surge and peak power requirements
 - Selection of PV module
 - Selection of charge controller
 - Array layout with shading analysis
 - Selection of inverter
 - Inverter and or MPPT controller configuration
 - Matching array and grid connected inverter
 - Selection of battery storage
 - Battery configurations
 - Battery selection of battery inverter
 - Inverter configurations
 - Matching battery storage and battery inverter
 - Hybrid system if any
 - Power transmission and distribution system components
 - Control and monitoring system
- (AEPC , 2022)

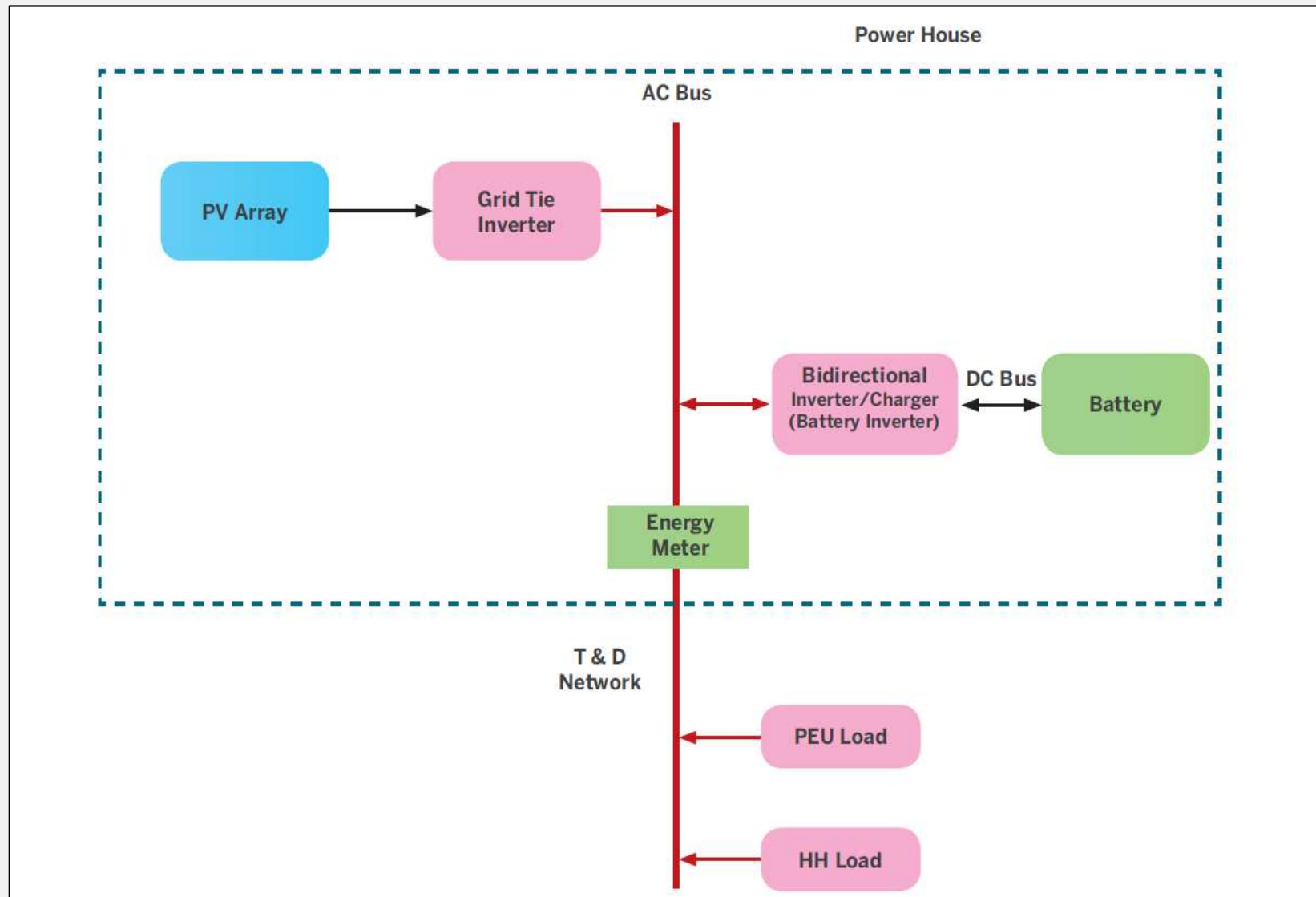
TYPES OF SYSTEM

- Types of system based on system architecture
- AC Coupled
- DC Coupled
- DC and AC Coupled
- DC AC Coupled with distributed generation

TYPES OF SYSTEM

- AC Coupled
- Separate PV and battery inverters are kept in AC coupled configuration.
- These two separate inverters connect to one another on the ac side of the system.
- PV inverter is a standard utility interactive inverter whereas the storage inverter controls battery charging and discharging (AEPC , 2022).
- This type of systems has improved conversion efficiency as the standard utility interactive inverters are often 97% to 98% efficient.

TYPES OF SYSTEM

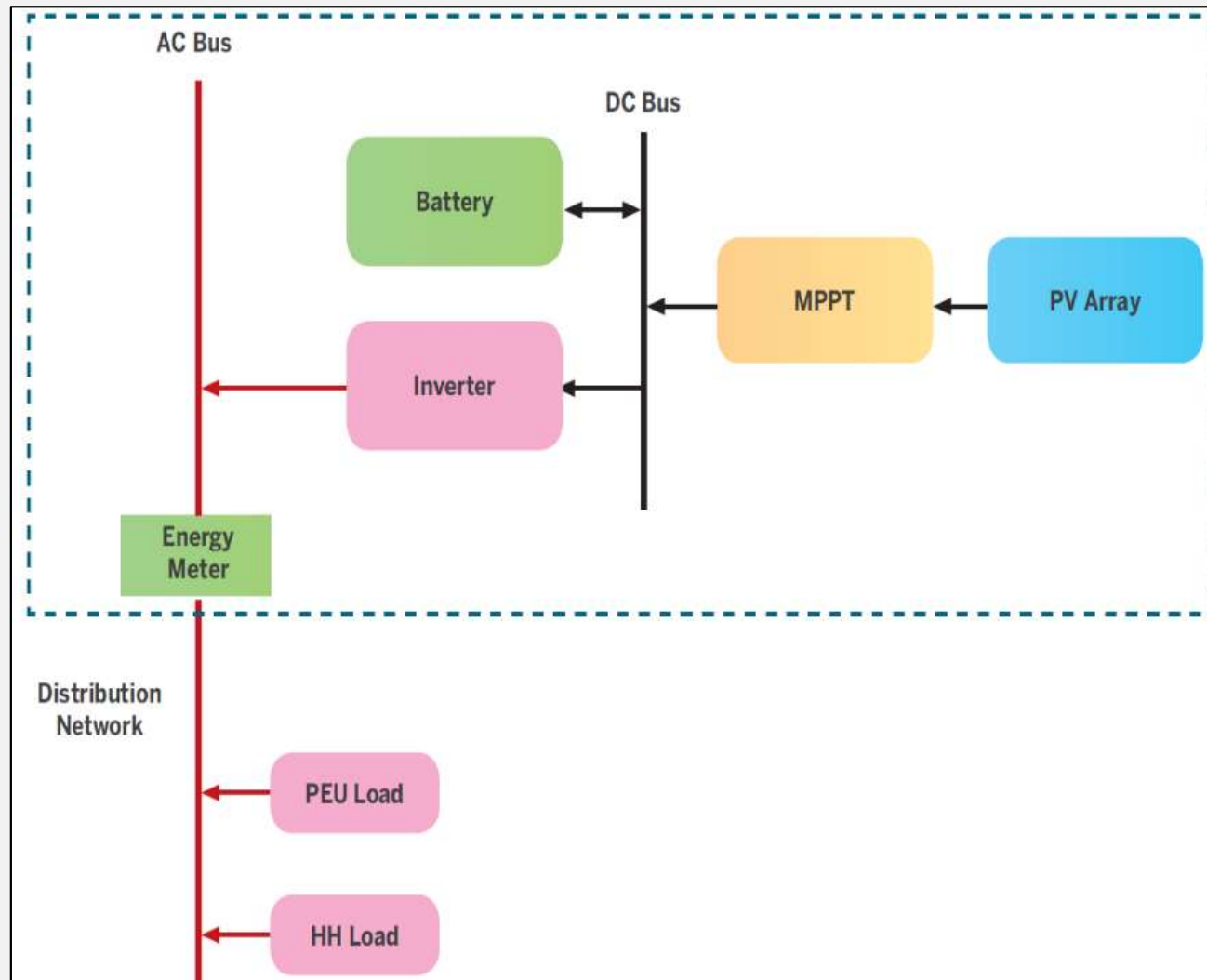


AC Coupled System (AEPC , 2022)

TYPES OF SYSTEM

- DC Coupled system
- In this kind of system, the PV and battery storage system share a common inverter using three of more interfaces.
- Two interfaces on the dc side of the converter are used for PV and battery input where as the third interface on the ac side is used as an input for the utility grid.
- The power supply from PV array is unidirectional where as the power supply from battery and utility interfaces in bidirectional (AEPC , 2022).
- This type of system results in reduced material and labor cost and are more compact in occupying space as fewer equipment are required.

TYPES OF SYSTEM

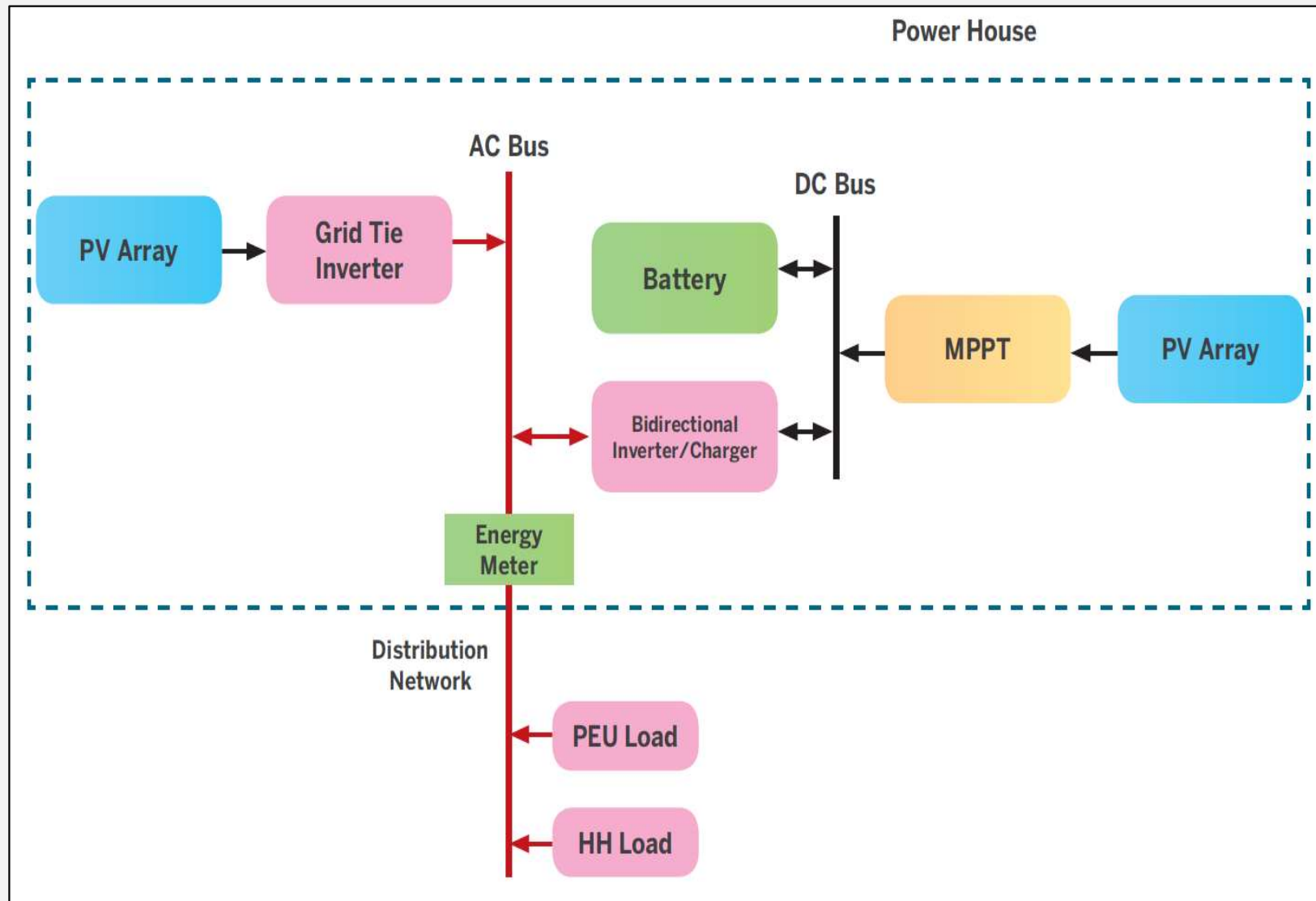


DC Coupled System (AEPC , 2022)

TYPES OF SYSTEM

- DC and AC coupled system
- This type of system uses both the concept of AC and DC coupled system.
- Here two PV array are used to power AC and DC load separately.
- This type of system reduces the risk of full drainage of battery.

TYPES OF SYSTEM

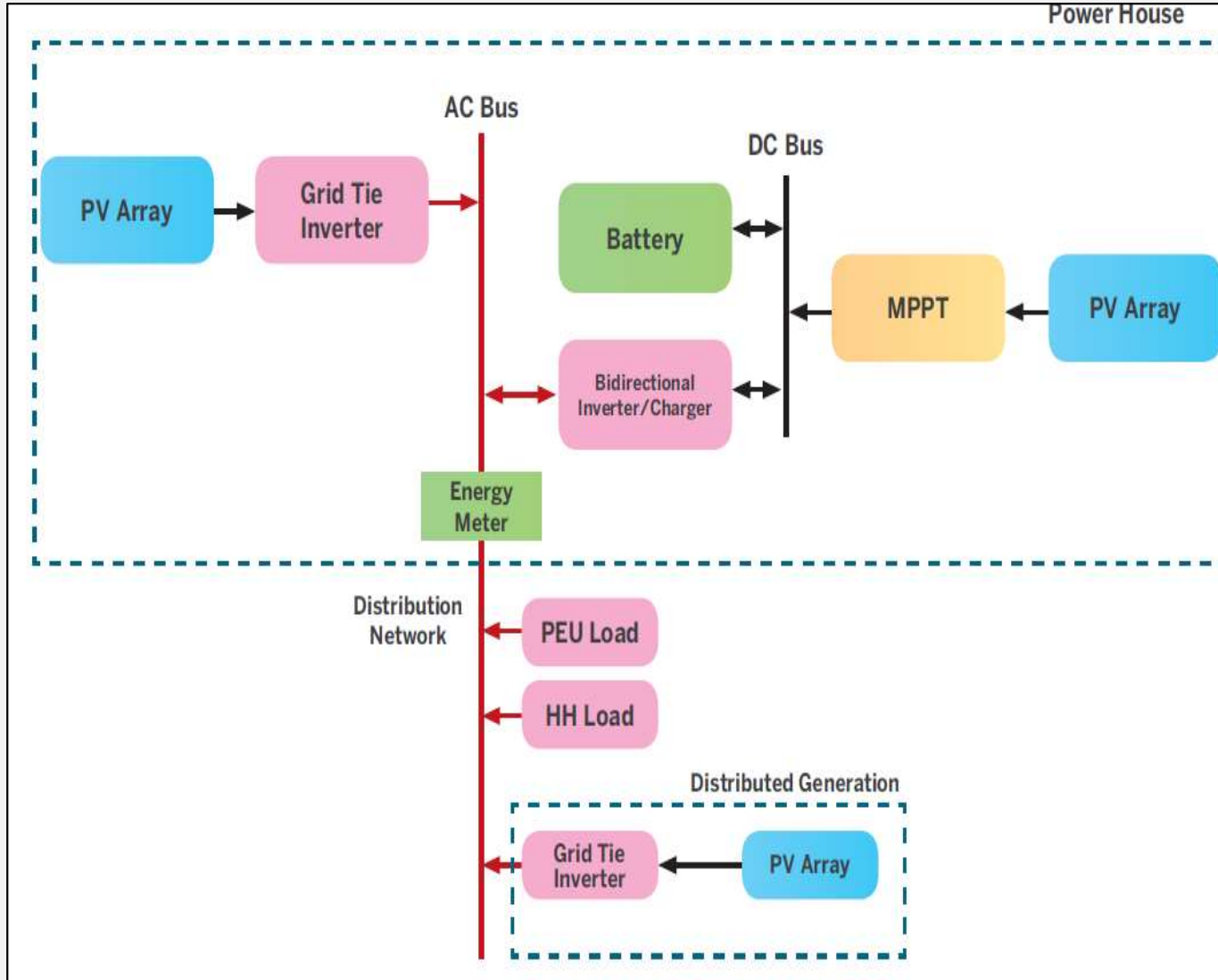


DC and AC coupled system (AEPC , 2022)

TYPES OF SYSTEM

- DC AC coupled with distributed generation
- This kind of system is used where the length of the transmission line is very high and the installation of PV system is not possible at one place.
- So, certain portion of PV array and grid tie inverter can be placed at the far end from the powerhouse and be synchronized to the grid.

TYPES OF SYSTEM



DC-AC Coupled system with distributed generation (AEPC , 2022)

GENERATION SYSTEM DESIGN: PV ARRAY

- The sizing of PV array is based on the daily energy demand and the available peak sunshine hours.
- Following equation gives the relation for PV array sizing
- $$PV \text{ Array Size (A)} = \frac{\text{Daily Energy Demand (Ampere hour)}}{\text{Total loss factor} \times \text{Peak sunshine hours (hour)}}$$
- In context of Nepal, peak sunshine hours of 4.5 to 5.5 is used. Peak sunshine hour of a particular place is equivalent to the Global Horizontal Irradiation of a particular place.
- Total loss factor of 0.6 to 0.7 is used.
- The daily energy demand in Ah is calculated by considering system and array voltage.

GENERATION SYSTEM DESIGN: PV ARRAY

- It is important to consider system voltage to convert the load demand from watt hour to ampere hour.
- For small home systems, 12 V can be selected as the system voltage, however, for large systems where, AC load is large in the range of few kVA, the DC voltage should be selected in higher range.
- It should be considered that the PV modules should be selected considering that the designed system will operate below the maximum system voltage of the module.
- Typically, modules are rated to a maximum system voltage of 600 V DC or 1000 V DC or 1500 V DC. It is also very important to match arrays based on PV inverter voltage.
- Mismatch may lead to reduction in power production. For, most of the 1500 V DC input inverter, MPPT ranges fall in between 800 to 1300 V.

GENERATION SYSTEM DESIGN: PV ARRAY

- If a single module cannot deliver the current (here we refer to I_{mp} of the module) calculated, then number of modules have to be connected in parallel to produce the required level of current. The number of modules to be connected in parallel can be found by using the following formula:

- $N_p = I_{array} / I_{mp}$
- It is to be noted that N_p may not be the whole number. The actual value of N_p should always be rounded up to the next highest integer value.

GENERATION SYSTEM DESIGN: PV ARRAY

- The number of module in series can be calculated by finding out effective open circuit voltage at the expected temperature at which the module is supposed to operate in the region.
- Following relation can be used to calculate the maximum and minimum number of module in series
 - $M1 = \frac{\text{Inverter max input voltage}}{V_{oc\ cell\ eff1}}$
 - Where
 - M1 = maximum number of module in series
- $V_{oc\ cell\ eff1} = V_{oc\ stc} + \{\gamma \times (T_{cell} - T_{stc})\}$
 - Where,
 - $V_{oc\ cell\ eff1}$ = open circuit voltage at effective cell temperature (Volts)
 - V_{stc} = open circuit voltage at standard temperature conditions (Volts)
 - γ = Voc temperature coefficient (V/°C)
 - T_{cell} = minimum expected cell temperature at specified temperature in °C

GENERATION SYSTEM DESIGN: PV ARRAY

- Similarly

- $$M2 = \frac{\text{Inverter max input voltage}}{V_{oc\ cell\ eff2}}$$

- Where

- M2 = minimum number of module in series

- $$V_{oc\ cell\ eff2} = V_{oc\ stc} + \{\gamma \times (T_{cell} - T_{stc})\}$$

- Where,

- $V_{oc\ cell\ eff2}$ = open circuit voltage at effective cell temperature (Volts)

- V_{stc} = open circuit voltage at standard temperature conditions (Volts)

- $\gamma = V_{oc}$ temperature coefficient (V/°C)

- T_{cell} = maximum expected cell temperature at specified temperature in °C

GENERATION SYSTEM DESIGN: PV ARRAY

An example below showing maximum number of modules in series

- ❑ Annual minimum temperature at project site= 10°C
- ❑ Temperature Coeff. Voc of module = -0.35%/°C
- ❑ Voc of module= 44 V
- ❑ Inverter Max input voltage = 1250V

Solution

- ✓ Temp adjustment factor = $-0.35\% \cdot (10-25) \cdot 44 = 2.31\text{V}$
- ✓ (Temp coef. is given in percentage thus have to multiply it by Voc)
- ✓ Voc cell eff = $44 + 2.31 = 46.31\text{ V}$
- ✓ Maximum no. of modules in series = inverter max input voltage/ Voc cell eff
- ✓ = $1250 / 46.31 = 26.99$
- ✓ = 26
- ✓ (always round down for maximum no. of modules)

GENERATION SYSTEM DESIGN: PV ARRAY

An example below showing minimum number of modules in series

- ❑ Annual maximum temperature of project site = 55°C
- ❑ Temperature Coeff. $V_{mp} = -0.4\%/^{\circ}\text{C}$
- ❑ $V_{mp} = 40 \text{ V}$
- ❑ MPPT mini input voltage = 700V

Solution

- ✓ Temp adjustment factor = $-0.4\% \cdot (55-25) \cdot 40 = -4.08\text{V}$
- ✓ (Temp coef. is given in percentage thus have to multiply it by V_{mp})
- ✓ $V_{mp} \text{ cell eff} = 40 + (-4.08) = 35.92 \text{ V}$
- ✓ Minimum no. of modules in series = MPPT mini input voltage / $V_{mp} \text{ cell eff}$
- ✓ $= 700 / 35.92 = 19.48$
- ✓ $= 20$
- ✓ (always round up for minimum no. of modules)

GENERATION SYSTEM DESIGN: BATTERY SIZING

- Battery system sizing and selection criteria involve many decisions and trade-offs.
- Choosing the right battery for a particular PV application depends upon many factors.
- While no specific battery is appropriate for all PV applications some common sense and a careful review of the battery literature with respect to the particular application requirements will help the system designer to greatly narrow down his choice (Sharma, 2014).

GENERATION SYSTEM DESIGN: BATTERY SIZING

- Battery size can be calculated as

- $$C = \frac{D (Ah) \times DOA}{DOD \times Eff.}$$

- Where,

- C = required capacity of battery bank in ampere hour
- D (Ah) = daily load in Ampere hour
- DOA = Days of autonomy (Generally 1.5 for hybrid and 2 for stand alone systems)
- DOD = Maximum allowable depth of discharge (0.8 for lead acid batteries)
- Eff. = Efficiency of battery system (generally 0.7 to 0.9)

GENERATION SYSTEM DESIGN: BATTERY SIZING

- Battery bank voltage selection is often dictated by the load voltage requirements, most often 12 or 24 Volts for small remote stand-alone PV systems.
- For bigger loads requiring a larger PV array it is sometimes wiser to go to the higher voltages, if possible, in order to reduce the system load current.
- Lower system currents minimize the size and cost of conductors, fuses and other current handling components of the PV system (Sharma, 2014).

GENERATION SYSTEM DESIGN: BATTERY SIZING

- Battery charge and discharge rate (C rate)
- A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity.
- In the US battery capacity is typically specified as C20 however in Asia the capacity is given as C10.
- In Nepal it is typically C10 or C/10 however it could be different depending on where the batteries came from.
- For a battery with a capacity of 100 Amp-hrs, this equates to a discharge current of 10 Amps at C10 rate.

GENERATION SYSTEM DESIGN: BATTERY SIZING

- C10- Charge and discharge@10Hr
- C20- Charge and discharge@20Hr
- Example: - 100Ah @C10 and C20
- Charging/discharging
 - @C10- 10A for 10 hrs
 - @C20- 5A for 20 hrs
 - Capacity: -
 - 100Ah@C10: - $10A \times 12V = 120W$
 - 100Ah@C20: - $5A \times 12V = 60W$

GENERATION SYSTEM DESIGN: MPPT

- An MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes energy output from solar arrays.
- MPPT keeps tracking maximum power point from the STC (Standard Test Conditions) rating under almost all situations.
- MPPT controller is usually used in AC coupled systems.
- $\text{MPPT Size (Watt)} = \text{Array Size (Watt)}$
- MPPT is mostly inbuilt in the PV inverter.
- The PV array side voltage can go up to 250V whereas the output side voltage depends upon the DC input voltage (12V or 24V or 48V) of PV inverter.

GENERATION SYSTEM DESIGN: SOLAR CHARGE CONTROLLER

- Solar charge controller is also known as MPPT charge controller which is generally in DC coupling systems.
- It has battery protection as well as MPPT function features inbuilt.
- It gathers energy from solar arrays and stores it in batteries.
- In small DC coupled system the charge controller are mostly available without MPPT function, such small scale charge controller comes with pulse width modulation (PWM) for battery protection features.
- For understanding the charge controller are divided as MPPT and PWM charge controllers

GENERATION SYSTEM DESIGN: SOLAR CHARGE CONTROLLER

- The current rating of charge controller can be calculated as
- Solar Charge Controller (A) = $I_{mp} \times N_p \times 1.25$
- Where,
- N_p = total number of modules connected in parallel in the array
- I_{mp} = nominal current of the module
- 1.25 is the safety margin (1.25 for PWM and 1.33 for MPPT)

GENERATION SYSTEM DESIGN: INVERTER SIZING

- Battery inverters are sized based on the peak load of the system. To optimize the sizing of battery inverters, only the peak load to be supplied from the battery can be considered
- $$\text{Battery Inverter Size (VA)} = \frac{\text{System Peak Load (Watt)}}{\text{Efficiency} \times \text{Power Factor}}$$
- Battery inverter efficiency can be taken as 0.85 to 0.95 where as power factor can be taken as 0.8.

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THANK YOU