CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 MATERIALS FOR SOLAR ENERGY

Fossil fuel storages are lowering now and cost is increases due to continuously increases in demand and low supply. Current Global Energy Scenario says that increasing electricity energy demand due to increasing Population. And fossil fuel is main contributor for pollution and Global warming, and then every country is doing effort to switch over the new renewable energy technology. When solar system concept first comes in market there is huge large cost than conventional energy sources. As a technology developed new material such as nano materials are introduced now they have saving in cost and production is increased. At the different location different season then sunlight is not equal to all places. Then it is placed as per geographical location and solar radiation data. Solar P.V materials and blocks is converted sunlight into electrical energy by photoelectric effect, the efficiency of solar cell is depends on the semiconductor material band gap and structure of PV cell. When the incident of photon energy is greater than band gap energy of semiconductor then the photons absorbed increases the energy of the valence band electrons and causes the jump of electron in to the conduction bond. As temperature increases of PV cells then decreases in band gap and reduced efficiency of panel. (Smith, 2019).

3.1.1. BASIC WORKING OF SOLAR PHOTOVOLTAIC CELL

When solar cell is get contact in the solar rays the P-N junction, light photon easily through very thin P type layer the light energy in the form of photons supply enough energy to the junction to create number of electron hole pairs. And energy is transfer to load through connections.

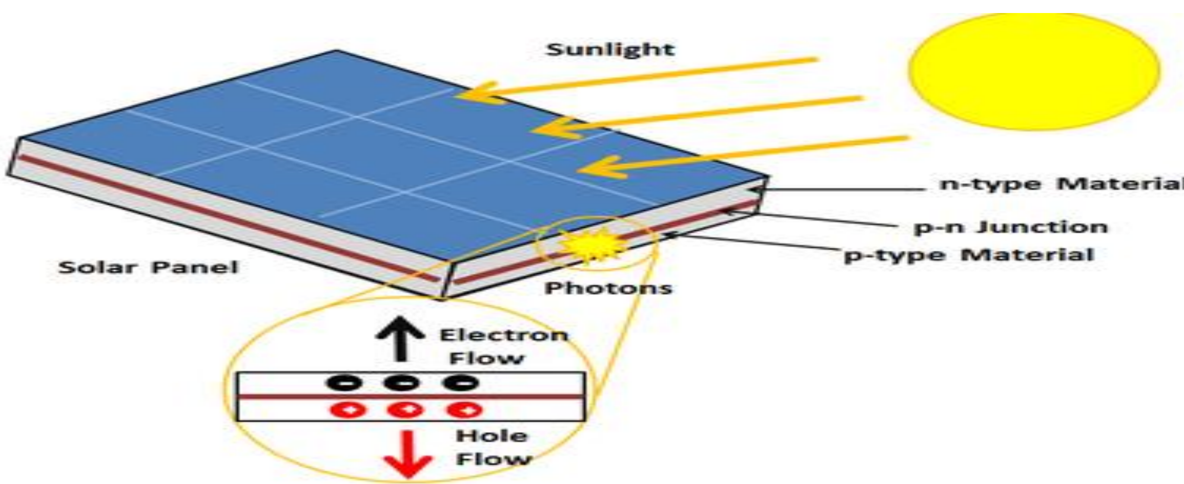

Figure 3.1 Working of solar photovoltaic cell (Source: research gate)

3.1.2. CLASSIFICATIONS OF SOLAR PV MATERIALS

The main factors impacts the choice of 90% of the world's photo voltaic solar cell are smaller variation of silicon purity, cost, space and efficiency. Detailed classification of solar materials.

1) Crystalline Silicon solar Cell: crystalline silicon solar cells are most commonly used in solar panels. Its energy conversion efficiencies are over 25%. There are also two types:

A) Mono-crystalline Silicon Solar Cells (mono-si): It is also called as single crystal silicon cell. Czocharalaski process is used to manufacture the mono crystalline solar cells.

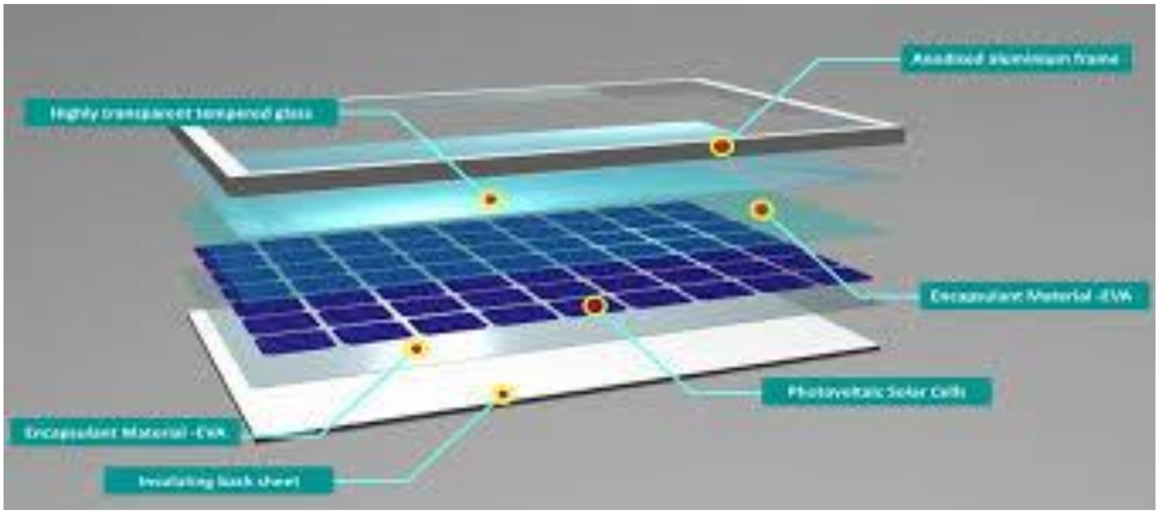

Figure A Crystalline structure (sources: engr. Shahzada Fahad 2020)

Efficiency of mono si solar cells are 21% now it's improved to 26.7% due to the development of technology. Mono si cells are more performance giving at worm weather.

B. Polycrystalline Silicon Cell: Polycrystalline silicon is simple and cheaper to manufacture and it is made from raw silicon it is melted and poured into square mound. It is less efficient than mono crystalline. These serials are composition of many crystalline of different size and shapes. It includes ceramic, rock, and ice and its efficiency is 13-16% because of low quality of silicon material used.

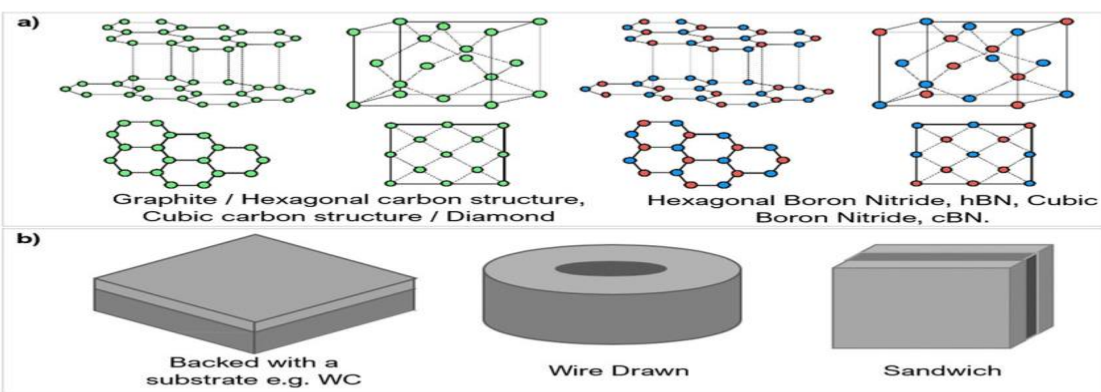

Figure A Structure of Polycrystalline material (Source: research gate)

C. Thin Film Solar Cells (TF): Thin film solar cells also called as second generation solar cell. It made by one or more layers of glass, plastic or metal. film thickness varies from nanometres to tens of micrometers it is cheaper than crystalline based solar cells but more space required and efficiency of thin film solar cell is 21.7% to 23.4%

Figure C: Thin film

Developed technology now and it is used in small scale applications especially as the power source for electronic calculators. For last 15 years it is used in electricity generation, and its efficiency is 8.8 to 10.2%.

Figure C Application of Amorphous silicon cell

D. Cadmium Telluride solar cell (CdTe): Cadmium telluride PV is the only thin film technology with low cost than conventional solar cells, and it is made up of crystalline silicon. It is used in world's largest PV stations such as TOPAZ solar farm. And its efficiency is 16.1 to 22.1%.

E. Copper Indium Gallium Selenide Solar cell (CIGS): It is made by deposing a thin layer of copper, indium, gallium and selenium on the electrodes on the front and back for the purpose of collect current. And efficiency is 10-12% now due to modern technology it is improved to 22.8%.
F. Organic Polymer Solar Cells: Recent developments in solar photovoltaic technology polymer material is developed. It is flexible and it includes organic cells also called as plastic solar cells. It is light in weight and also used for windows, walls, roofs. The problem is that is low efficiency, low lifetime compared with other types of solar cells. as it is manufactured high quantity it's cost is reduced. Its efficiency is only 10% via tandem structure, but in 2018 record breaking efficiency noted is 17.3% via tandom structure.
G. Nano Crystal Solar Cell: The nano crystal are made up of silicon, CdTe, and CIGS materials and it's efficiency possibility up to 40-60% this is now modern technology in solar cells.
C. Solar PV Material and Efficiency

Sr. No	Material	Efficiency in %
1	Crystalline	25
2	Mono-crystalline	26.7
3	Polycrystalline	13-16
4	Thin film	21.7-23.4
5	Amorphous silicon	8.8-10.2
6	Cadmium telluride	22.2
7	Copper indium gallium selenide	22.8
8	Organic polymer	10-17.3
9	Nano crystal solar cell	40-60

Comparison of material and efficiency

3.1.3. ENVIRONMENTAL IMPACTS

Fossil fuels are increase amount of carbon in to atmosphere and also increases noise, pollution and increases the global worming for this solution is use renewable energy sources, use of solar energy reduced carbon foot print and other harmful emission to environment there is no moving part then less maintenance and no noise during the operation. Use of solar energy for better sustainable green energy for future.

3.2. DESCRIPTION OF HYBRID INVERTER COMPONENTS AND LAYOUT

A hybrid solar inverter combines solar, battery, and grid systems to ensure efficient energy management. Below is a detailed description of its components and typical layout.

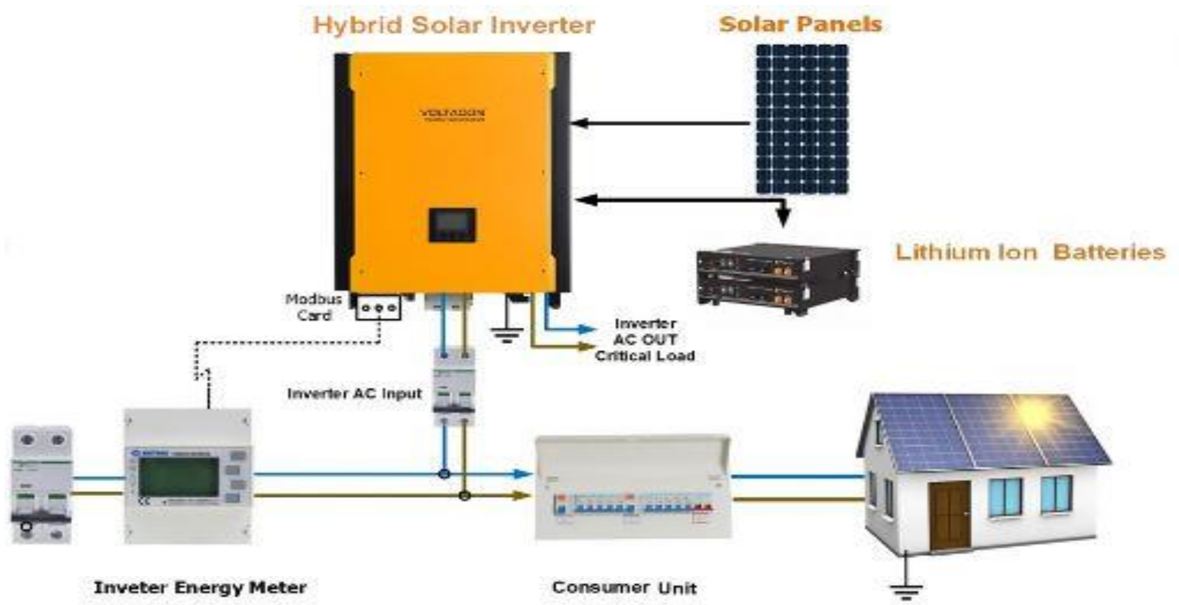

Fig. 3.2. Hybrid Inverter Components and Layout

3.2.1 COMPONENTS OF A HYBRID INVERTER

A. POWER ELECTRONICS COMPONENTS

1. MPPT Controller (Maximum Power Point Tracking):

- Optimizes the voltage and current from the solar panels to maximize power output.
- Key component for increasing system efficiency.

2. Inverter Circuit (DC to AC Converter):

- Converts DC power from solar panels or batteries to AC power for home appliances or grid connection.
- Uses IGBTs (Insulated Gate Bipolar Transistors) or MOSFETs for switching.

3. Rectifier Circuit (AC to DC Converter):

- Converts grid power to DC for charging batteries.

4. DC-DC Converter:

- Steps up or steps down the voltage as required for batteries or loads.

5. Battery Management System (BMS):

- Ensures the safe operation of batteries by monitoring charge/discharge cycles, temperature, and voltage.
- Protects against overcharging, deep discharge, and short circuits.

6. Microcontroller/Processor Unit:

- Central control system for coordinating the operation of solar input, battery charging, and grid management.
- Executes algorithms for MPPT, load priority, and energy flow.

7. Filters (LC or LCL):
- Reduces harmonic distortion in the AC output, ensuring clean and stable power supply.

8. Transformer (Optional):
- Provides galvanic isolation for safety and adjusts voltage levels if needed.

9. Cooling System:
- Includes heat sinks, temperature sensors, and fans to dissipate heat from power electronics.

Fig. 3.1.1 Power Electronics Components of Solar Power System (Source: Tycorun 2023)

B. AUXILIARY COMPONENTS

i. **Display and User Interface:**
- LCD or LED screen for monitoring system parameters (e.g., voltage, current, and load).

ii. **Connectivity Modules:**
- Wi-Fi, Bluetooth, RS485, and CAN bus modules for remote monitoring and smart home integration.

iii. **Protections:**
- Fuses: Protect against overcurrent.
- Surge Arresters: Protect against voltage spikes.
- Relay Switches: Ensure safe isolation during faults.

iv. **Relay and Contactor Units:**
- Manage automatic switching between solar, battery, and grid power.

v. **Chassis/Enclosure:**

- o Provides physical protection and ensures compliance with IP65 or IP67 standards for outdoor installations.

C. LAYOUT OF A HYBRID SOLAR INVERTER

Front Panel Layout:

- o Display Screen: Positioned centrally for real-time data display.
- o LED Indicators: Show operational status (Solar, Battery, Grid, Fault).
- o Control Buttons: Power ON/OFF and menu navigation.

Internal Layout:

a. Upper Section:

- **Heat Dissipation Area:** Heat sinks and cooling fans for temperature management.

b. Middle Section:

- o **Power Electronics Board:** Contains MPPT, inverter circuits, and control modules.
- o **Filter Modules:** Located close to the AC output section to ensure clean power delivery.

c. Lower Section:

- o **Battery Terminals:** Positioned for direct connection to the battery bank.
- o **Grid Connection Terminals:** Located for incoming AC power.

d. Side Panel:

- o **Communication Ports:** RS485, CAN, and USB ports for external connections.

e. Rear Panel:

- o **Input Terminals:**
- o DC input terminals for solar panel connection.
- o AC input/output terminals for grid and load connections.

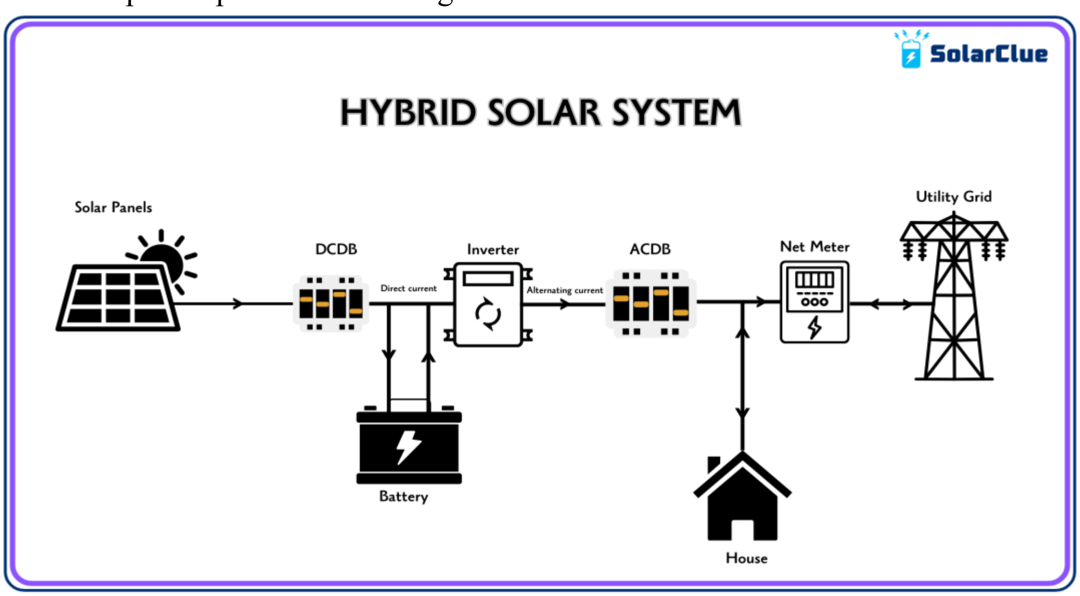

Fig. 3.1.1.3 Layout of a Hybrid Solar Inverter (Source: Sudarshan Saur's 2023)

3.2.2. DESIGN CONSIDERATION FOR CONSTRUCTING SOLAR HYBRID INVERTER

Designing a **solar hybrid inverter** in accordance with **project standards** requires a multidisciplinary approach that ensures efficiency, safety, scalability, and regulatory compliance. A solar hybrid inverter must manage multiple power sources—solar photovoltaic (PV), battery storage, and the utility grid—while delivering uninterrupted power to the load. The following considerations, based on standard engineering and project development protocols, guide the design and construction of a reliable solar hybrid inverter system. . (Jelle et al. 2018)

1. SYSTEM SIZING AND LOAD ANALYSIS

According to standard project planning procedures (e.g., IEEE 1013 and IEC 62509), the initial step involves assessing the total load demand and energy consumption profiles of the intended site. This includes:

- **Peak load estimation** for sizing the inverter's capacity.
- **Daily energy consumption** (kWh) to size the battery bank and PV array.
- **Load types** (resistive, inductive, sensitive electronics) to design for startup surges and power quality.

The inverter should be sized to handle at least 125% of the peak load to ensure resilience and operational stability under varying conditions.

2. PV ARRAY INTEGRATION

The inverter must be compatible with the solar array configuration. Project standards (IEC 61215 and IEC 61730) recommend:

- **MPPT (Maximum Power Point Tracking)** for efficient solar energy harvesting.
- **Voltage and current compatibility** between PV strings and inverter input ratings.
- **Input protection** using fuses, surge arresters, and isolation switches as per IEC 60364.

3. BATTERY STORAGE DESIGN

Battery integration is a core feature of hybrid inverters. Design must follow standards such as IEEE 1561 and IEC 62619:

- **Battery chemistry support** (Lead-acid, Lithium-ion, etc.) with Battery Management System (BMS) compatibility.
- **Voltage range and capacity** planning based on autonomy needs (e.g., 24/48V systems).
- **Charge/discharge control** via MPPT or PWM charge controllers integrated into the inverter.
- **Thermal protection and current limiting** to prevent battery degradation and safety hazards.

4. GRID SYNCHRONIZATION AND SAFETY

Hybrid inverters must safely interact with the utility grid. Standards such as IEEE 1547 and IEC 62116 dictate:

- **Anti-islanding protection** to prevent back-feeding during outages.

- **Grid voltage and frequency compliance** to synchronize correctly with local utility parameters.
- **Net metering and export limiting** configurations as required by regulatory authorities.

The inverter must allow flexible priority settings (solar > battery > grid or grid > battery > solar) through programmable logic.

5. Power Conversion Efficiency and Quality

Project efficiency standards (IEC 61683) demand high conversion efficiency (>90%) to minimize energy losses. Key considerations include:

- **Use of high-quality semiconductors** (IGBTs or MOSFETs).
- **Pure sine wave output** for sensitive loads.
- **Low Total Harmonic Distortion (THD)** to ensure compliance with power quality regulations (IEEE 519).

6. CONTROL, MONITORING, AND COMMUNICATION

According to modern project execution standards, smart control and monitoring features are essential:

- **Microcontroller/DSP-based logic** to manage source switching, battery status, and fault detection.
- **LCD/LED display panels** for user interface.
- **Remote monitoring capability** via Wi-Fi, GSM, or IoT systems.
- **Data logging** for energy performance audits.

7. SAFETY, ENCLOSURE, AND ENVIRONMENTAL PROTECTION

The system must comply with safety and environmental standards such as IEC 62109 and IP rating specifications:

- **Short-circuit, over-voltage, and over-temperature protections**.
- **Isolation between AC and DC circuits** to avoid electrical hazards.
- **IP54 or higher-rated enclosures** for dust and water protection.
- **Corrosion-resistant material** (e.g., anodized aluminum) for outdoor units.

8. STANDARDS AND COMPLIANCE

To ensure legal and operational integrity, the hybrid inverter must adhere to the following:

- **IEC 62109-1/2** – Safety of power converters.
- **IEC 62040 –** Uninterruptible power systems (for off-grid capability).

- **ISO 50001** – Energy management integration.

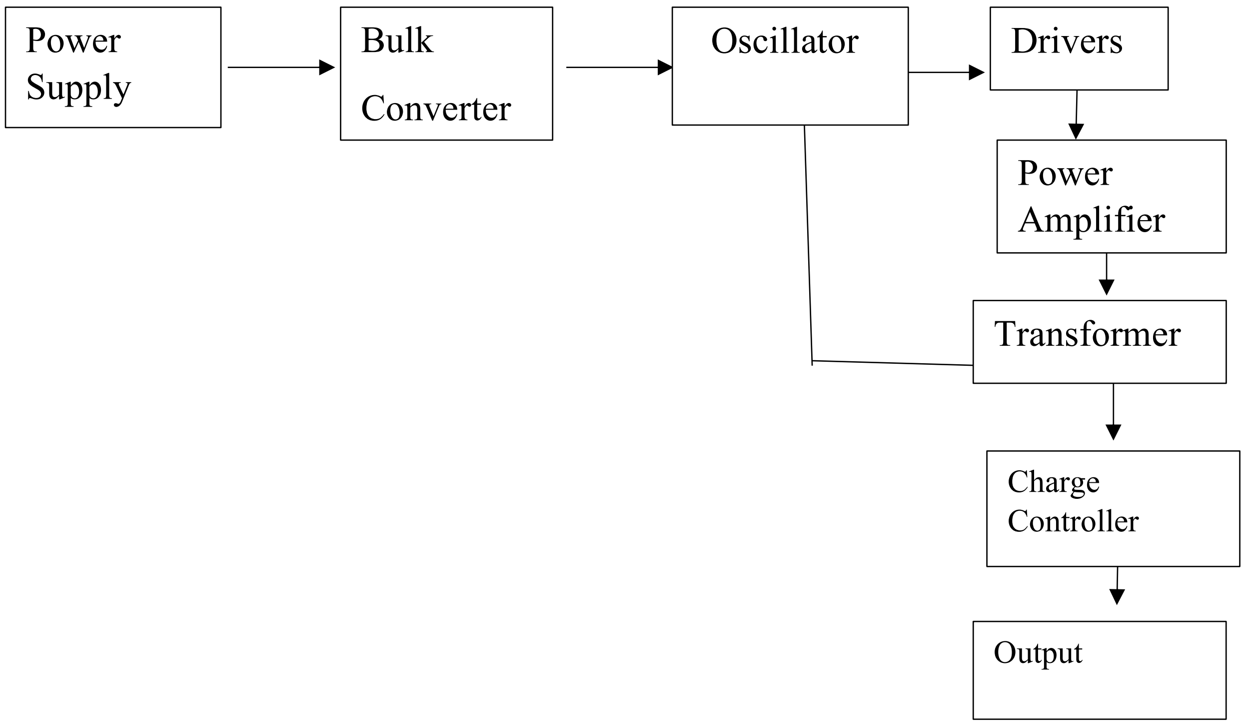

Fig 3.1.2**:** Block Diagram of 5KVA Hybrid Inverter System

3.2.3 DESIGN SPECIFICATION OF HYBRID SOLAR INVERTER

The design specification outlines the technical and operational requirements for a hybrid solar inverter. These specifications ensure compatibility, efficiency, and reliability for managing solar, grid, and battery energy sources

1. ELECTRICAL SPECIFICATIONS:

a. Input Specifications:

- **Solar Input (DC):**
  - Maximum DC Input Voltage: 550V
  - MPPT Voltage Range: 150V–500V
  - Maximum Input Current: 20A

- **Battery Input (DC):**
  - Nominal Voltage: 48V
  - Voltage Range: 40V–60V
  - Maximum Charge/Discharge Current: 50A
- **Grid Input (AC):**
  - Voltage Range: 230V ± 10%
  - Frequency: 50Hz/60Hz

b. Output Specifications:

- **AC Output:**
  - Output Voltage: 230V ± 5%
  - Output Frequency: 50Hz/60Hz ± 0.5Hz
  - Power Output: 5 kW (scalable up to 10 kW for higher models)
  - Power Factor: 0.99 (adjustable)

c. Efficiency:

- Maximum Efficiency: ≥ 98%
- European Efficiency: ≥ 97%

2. FUNCTIONAL SPECIFICATIONS:

a. System Capabilities:

1. **Grid-Tie Operation:** Supports feeding excess solar power back to the grid.

2. **Off-Grid Operation:** Provides uninterrupted power during grid outages using batteries.

3. **Hybrid Mode:** Prioritizes solar power, supports batteries, and switches to the grid only when necessary.

b. Battery Management System (BMS):

- Support for Lithium-ion, LiFePO4, and Lead-acid batteries.
- Real-time battery health monitoring.
- Overcharge, over-discharge, and short-circuit protection.

c. Maximum Power Point Tracking (MPPT):

- Dual MPPT for multiple solar panel arrays.
- Efficiency: ≥ 99.5%

d. Inverter Topology:

- Full-bridge or H-bridge with advanced Pulse Width Modulation (PWM) techniques.

e. Overload and Protection:

- Overload Protection: Up to 150% for 60 seconds.
- Surge Protection: Up to 6000V.
- Thermal Protection: Automatic shutdown at >75°C.

3. MECHANICAL SPECIFICATIONS:

a. Dimensions:

- Compact design: 450mm x 400mm x 150mm

b. Weight:

- Approx. 15-25 kg (depending on model and features)

c. Cooling System:

- Forced air cooling with temperature-controlled fans.

d. Enclosure:

- IP65-rated dustproof and waterproof casing for outdoor installation.

4. USER INTERFACE AND COMMUNICATION:

a. Display and Monitoring:

- LCD/TFT touchscreen for real-time status updates (voltage, current, battery state, etc.).
- LED indicators for system status (grid, battery, solar).

b. Connectivity:

- Wi-Fi and Bluetooth for remote monitoring via mobile app.
- RS485/Modbus and CAN bus for integration with smart home systems.

c. Control Features:

- Priority setting: Solar > Battery > Grid or customizable.
- Time-of-use settings for load optimization.

5. ENVIRONMENTAL SPECIFICATIONS:

- Operating Temperature: -10°C to 55°C
- Humidity: 0–95% non-condensing
- Altitude: Up to 2000m without derating

6. STANDARDS AND CERTIFICATIONS:

- Compliance with IEC 62109 (Safety of power converters).
- Certification: CE, UL 1741, ISO 9001.

7. EXPANDABILITY AND SCALABILITY:

- Parallel operation supported for capacity expansion.
- Compatible with solar systems ranging from 3 kW to 10 kW.

3.3 DESIGN CALCLULATION FOR SOLAR POWER SYSTEM

3.3.1 FORMULA RELATING WATTS, AMPERE, AND VOLTS

Watts = Volts x Ampere

$$Ampere = \frac{Watts}{Volts}$$

$$Power = VI$$

Taking into consideration 5KVA, the battery amperage 230Ah, and voltage 12V.

When connected in series, 12V + 12V + 12V +12V= 48V

Therefore; Power = 48V x 230Ah = 11,040 Watts

i. CALCULATING FOR INVERTER BATTERY BACK-UP TIME

$$Backup\ Time\ (in\ hours) = \frac{(Battery\ Capacity\ in\ Ah)\ x\ Input\ Voltage\ (V)}{Total\ Load\ (in\ watts)}$$

Taking the inputs for 5KVA into consideration, calculating the total load, like;

- 1 computer set = 150 Watts
- 11 Laptops = 11 x 70 = 770 Watts
- Fans = 19 x 120 = 2280 Watts
- Lighting points = 22 x 5 = 110 watts
- 1000 watts for the four classrooms

So, the total load in this case is 150 + 770 + 2280 + 110 + 1000= 4310 Watts

When six batteries are connected in series, 12V x 4 = 48V

Backup Time (in hours) = $\frac{230\ x\ 48}{4{,}310} = \frac{11{,}040}{4{,}310} = 2.56\ Hours$

ii. SOLAR PANEL CALCULATION

Given Specification for 5KVA:

Imp = 5.98A

Vmp = 54.7V

Series Connection for fourteen solar panels of 320 Watts capacity:

Vmp = 54.7V x 14 = 765.8V

Imp = 5.98A

Power = Vmp x Imp = 765.8V x 5.98A = 4,579.48 Watts

Parallel Connection for fourteen solar panels of 320 Watts capacity:

Vmp = 54.7V

Imp = 5.98A x 14 = 83.72A

Power = Vmp x Imp = 54.7V x 11.96A = 4,579.48 Watts

iii. SOLAR PANEL TO BATTERY BANK CALCULATION

$$I = \frac{P}{V}$$

For 5KVA:

$$I = \frac{\text{Total Pv array wattage}}{\text{System nominal voltage}} = \frac{4{,}579.48}{48V} = 95.41A$$

Given Specifications:

Current: 95.41A

Voltage: 48V

iv. BATTERY BANK TO INVERTER CALCULATION

For 5KVA:

$$I = \frac{\text{Inverter wattage}}{\text{System nominal voltage}} = \frac{5000W}{48V} = 104.17A$$

Given Specifications:

Current: 104.17A

Voltage: 48V

v. INVERTER TO AC LOAD CALCULATION

For 5KVA:

$$I = \frac{\text{Inverter wattage}}{\text{Distribution Utility AC Voltage}} = \frac{5000\text{W}}{230\text{VAC}} = 22.73\text{A}$$

Given Specifications:

Current: 21.73A

Voltage: 230Vac

3.3.2 THE LOAD CALCULATIONS

The power rating of all the loads in the offices were properly checked and tabulated before making a choice of the inverter. Thus, the load calculations were based solely on data comparisons from the previous work of literature, there are fifteen lecturer offices in consideration, the HOD's office which is made up of three rooms, the library, two PG classes and four classrooms. However, the four classrooms were separated with a 1000 watts circuit breaker, so there were no load calculations for it.

Table Energy Audit for the Department of Mechanical Engineering. Appliances' ratings are shown below;

Appliances'	Units	Power	Total Power
Computer Set	1	150 watts	150 watts
Laptops	11	70 watts	770 watts
Fans	19	120 watts	2280 watts
Lighting Points	22	5 watts	110 watts
			3,310 watts

3.3.3 SYSTEM PERFORMANCE PARAMETERS

This constitutes the performance parameters of the respective components of the solar panel system for the 5KVA Hybrid Inverter System.

3.3.4 SOLAR PANEL PARAMETERS

i. Nominal Maximum Power (Pmax): 320W
ii. Optimum Operating Voltage (Vmp): 54.7V
iii. Optimum Operating Current (Imp): 5.98A
iv. Open Circuit Voltage (Voc): 64.9V
v. Short Circuit Current (Isc): 6.46A
vi. Maximum Temperature: 80°C
vii. Application Class: Class A
viii. Cell Technology: Monocrystalline
ix. Standard Test Conditions:

- AM = 1.5
- IRRADIANCE = $1000 \mathrm{W/m^2}$
- Temp = 25°C

3.4. ASSEMBLING AND TESTING OF SOLAR HYBRID INVERTER

The solar hybrid inverter is a crucial component in modern solar energy systems, responsible for converting DC power from solar panels and batteries into usable AC power, while intelligently managing grid and storage integration. The assembling and testing process of this inverter must adhere strictly to project standards, ensuring optimal performance, safety, and compliance with international and national regulations.

3.4.1 ASSEMBLING OF SOLAR HYBRID INVERTER

3.4.1.1 COMPONENT VERIFICATION

All components must be verified for quality, compatibility, and certification before integration. Key components include:

- ✓ Solar charge controller (MPPT or PWM)
- ✓ DC-DC converter
- ✓ DC-AC inverter module
- ✓ Battery bank and BMS
- ✓ Microcontroller or DSP board
- ✓ Input/output terminals
- ✓ Cooling system (heat sinks or fans)
- ✓ Enclosure (IP54 or higher)

Each part must meet the relevant standards such as IEC 62109-1/2, IEC 62509, and IEEE 1013.

3.4.1.2 MECHANICAL ASSEMBLY

- ✓ Mount components securely within the enclosure using non-conductive mounting brackets.
- ✓ Route internal wiring through protective conduits and use cable ties to organize circuits.
- ✓ Ensure ventilation pathways are clear and fans or heat sinks are properly aligned for thermal regulation.

3.4.1.3 ELECTRICAL INTEGRATION

- ✓ Connect solar input to MPPT input terminals with proper overcurrent protection (fuses or breakers).
- ✓ Interface battery bank with inverter terminals through a Battery Management System (BMS).
- ✓ Connect AC output to load and grid via isolators and relays

- ✓ Ensure wiring complies with IEC 60364, with correct cable sizing, insulation, and color coding.
- ✓ Install surge protection, grounding systems, and safety interlocks per NEC and IEC guidelines.

3.5 TESTING OF SOLAR HYBRID INVERTER

Testing must validate the inverter's functionality, safety, and reliability before commissioning.

3.5.1 PRE-OPERATIONAL CHECKS

- ✓ Visual Inspection: Confirm correct component placement, polarity, and cable connections.
- ✓ Continuity Test: Use a multimeter to check for open or short circuits in DC and AC paths.
- ✓ Insulation Resistance Test: Conduct with a megohmmeter to ensure safety insulation is intact between live and grounded parts.

3.5.2 FUNCTIONAL TESTING

- ✓ Testing should follow IEC 61683, IEC 62116, and IEEE 1547 standards:
- ✓ Solar Input Test: Apply simulated or real solar input and observe MPPT function under varying irradiance.
- ✓ Battery Operation Test: Verify charge/discharge cycles, current limits, and BMS communication.
- ✓ Inverter Output Test: Connect AC loads and verify output waveform, voltage regulation, and frequency accuracy.
- ✓ Grid Synchronization Test: Ensure the inverter synchronizes with the utility grid and supports export/import functions.

3.5.3 SAFETY AND PROTECTION TESTS

- ✓ Overload and Short Circuit Test: Simulate fault conditions to confirm automatic protection response.
- ✓ Anti-Islanding Test: Ensure disconnection from the grid during outage to avoid back-feed, as per IEC 62116.
- ✓ Thermal Performance Test: Monitor temperature rise under full load operation and evaluate cooling system efficiency.

3.5.4 PERFORMANCE EVALUATION

- ✓ Efficiency Test: Measure inverter DC-to-AC conversion efficiency; target >90%.
- ✓ Power Quality Test: Check total harmonic distortion (THD), aiming for <5% to protect sensitive loads.
- ✓ Data Logging: Monitor real-time values including input/output voltages, currents, battery state, and fault logs.

3.5.5 DOCUMENTATION AND COMMISSIONING

- ✓ Compile test results into a commissioning report.

- ✓ Issue compliance certificates for standards met (e.g., IEC, IEEE, NEC).
- ✓ Affix warning labels, wiring diagrams, and operational instructions on the inverter casing.
- ✓ Provide the user manual including maintenance procedures, safety instructions, and warranty terms.

3.6 ASSEMBLING OF COMPONET PART

The assembly of component parts in a solar hybrid inverter is a critical phase in the system development process. This stage involves integrating all functional units in accordance with engineering design specifications, safety standards, and quality control requirements. Each component must be assembled in a manner that ensures mechanical stability, electrical reliability, and compliance with international standards such as IEC 62109 (Safety of Power Converters), IEC 60364 (Electrical Installations), and ISO 9001 (Quality Management).

3.6.1 MAJOR COMPONENTS AND ASSEMBLY PROCEDURES

3.6.1.1 ENCLOSURE AND MOUNTING FRAME

1. Use a metallic or polycarbonate enclosure with a minimum rating of IP54 to protect against dust and moisture.
2. Drill and mount component holders, standoffs, or DIN rails securely for stable positioning of PCBs, relays, and fuses.
3. Ensure adequate space for ventilation and future maintenance.

A. SOLAR CHARGE CONTROLLER (MPPT MODULE)

1. Mount the MPPT controller on a dedicated section of the enclosure using screw terminals or panel mount brackets.
2. Connect the solar input terminals using appropriately rated cables, ensuring polarity is correct.\
3. Ensure thermal pathways or heat sinks are unobstructed to allow passive or active cooling.

B. BATTERY BANK INTERFACE

1. Use a fuse-protected cable connection from the battery to the inverter’s DC input.
2. Incorporate a Battery Management System (BMS) to manage charging parameters, monitor battery health, and provide overcharge and deep-discharge protection.
3. Mount the battery connector with lockable terminals to prevent accidental disconnection.

C. INVERTER MODULE (DC TO AC CONVERTER)

1. Position the inverter PCB or power board securely with insulated spacers to prevent short circuits.
2. Connect the inverter module to the MPPT output and the AC output terminal block.
3. Ensure all semiconductor switches (MOSFETs or IGBTs) are mounted with heat sinks and thermal paste for effective dissipation.

D. DC-DC CONVERTER (IF SEPARATE FROM MPPT)

1. Install a step-up or buck-boost converter module where voltage level shifting is necessary.

2. Maintain isolation between low-voltage and high-voltage sections using insulating sheets or acrylic barriers.

E. MICROCONTROLLER / CONTROL UNIT

1. Mount the control board on a separate tray or within an EMI-shielded section of the enclosure.
2. Interface it with sensors (voltage, current, and temperature), the BMS, and relay control lines.
3. Include a provision for firmware updates through USB or UART programming ports.

F. PROTECTION AND SAFETY DEVICES

1. Install circuit breakers, SPDs (Surge Protection Devices), fuses, and relays as per the single-line diagram.
2. Use color-coded wiring (e.g., red for positive DC, black for negative, green/yellow for ground) in accordance with IEC 60446.
3. Connect the earth terminal to all metal parts and the inverter ground point.

G. COOLING SYSTEM

- ✓ Mount fans (if active cooling is used) on ventilation grills and connect them to temperature-controlled relays.
- ✓ Heat sinks must be installed with tight mechanical fastening and thermal interface materials.
- ✓ 2.9 AC Output Terminal Block
- ✓ Securely install a terminal block rated for the system's maximum current and voltage (typically 230V AC, 50/60 Hz).
- ✓ Connect the output to load breakers and grid interface circuits if grid-tied.

H. GENERAL ASSEMBLY GUIDELINES

- ✓ Tightening Torque: Use appropriate torque for electrical terminals to prevent overheating.
- ✓ Clearance and Cree page: Maintain minimum spacing between high-voltage components (as per IEC 60664).
- ✓ Labeling: Label all inputs/outputs, terminals, and fuses using heat-resistant tags.
- ✓ Documentation: Update the assembly drawing and wiring layout after each modification.

I. QUALITY AND SAFETY CHECKS

- ✓ Perform a continuity check on all connections before power-on.
- ✓ Verify insulation resistance using a meohmmeter.
- ✓ Confirm that all moving parts (fans, relays) are properly mounted and unimpeded.
- ✓ Ensure that all fasteners are tightened and no loose wires or solder joints exist

Fig. 3.6: Pictorial View of the 5KVA Hybrid Inverter System (Source Frank 2024)

3.7 SYSTEM FLOWCHART

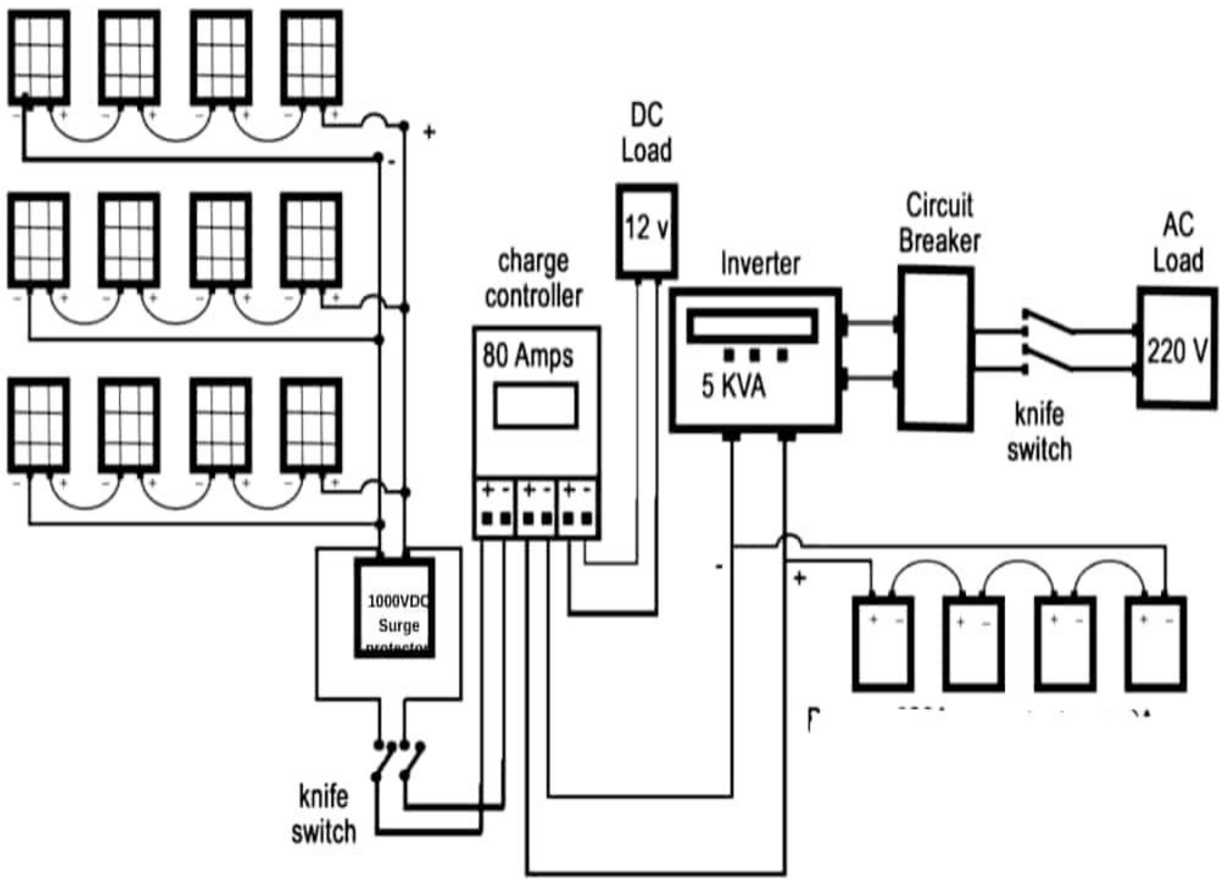

Fig 3.5: Flow chart for 5KVA Inverter System (Source: Pinterest)