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An Archive of Solar Panel Management

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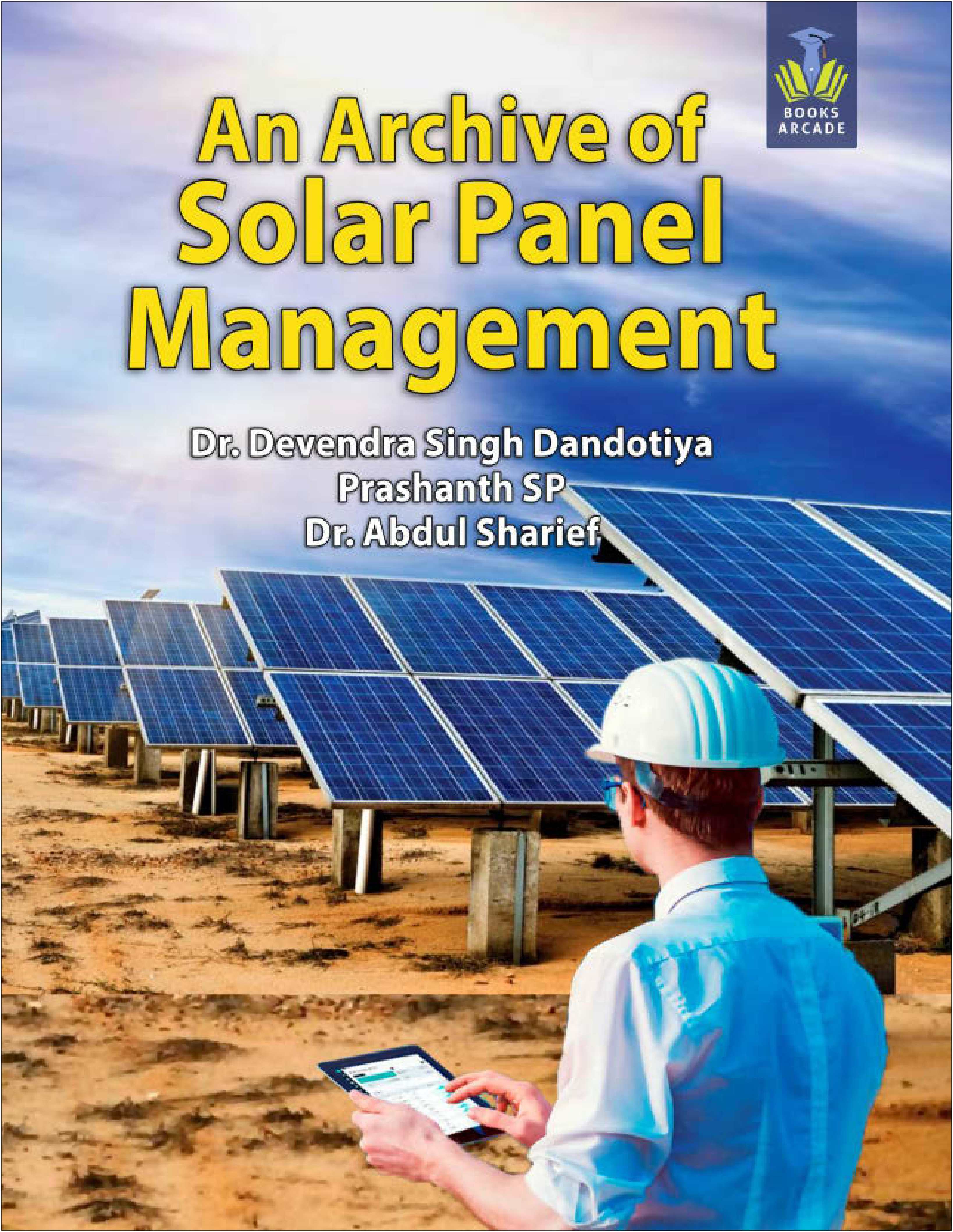

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CHAPTER 1

SOLAR PANEL

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Use a variety of energy types, including thermal, chemical, mechanical, electrical, and others. Electrical energy is the most widely used type of energy because it can be transferred easily and efficiently. Electrical energy is in greater demand every day. The majority of it is produced by traditional fuels like fossil fuels, nuclear fuels, etc. However, conventional sources have their limitations and eventually produce pollution and exhaust. As a result, are relying more on non-conventional energy sources including wind, solar, tidal, and geothermal [1]. The largest source of energy is solar energy, and all other forms of energy are solely dependent on it. For example, wind is caused by air currents, which are only due to the expansion of air caused by solar energy, and fossil fuels are dependent on solar energy due to their life cycles. So, utilizing a photovoltaic cell or solar cell, we may directly turn it into electrical energy rather of taking it in an indirect manner. However, are unable to capture so much energy. Solar panels may transform solar energy into electrical energy. Because currently use fixed solar panels, which prevent them from producing at their greatest capacity when sunlight strikes at a 90-degree angle, efficiency has decreased, leading to the creation of this. Looking at the current situation, it is obvious that traditional energy sources like coal, natural gas, oil, etc. are on the verge of extinction. The environment is being damaged by traditional energy use because fossil fuels like coal, oil, and natural gas are used. The current project is made up of parts like an LDR module, a servo motor, a solar panel, and others that, when working, would not pollute the environment like other traditional energy sources do and instead serve as a storage facility for solar energy [2]. No other energy is more abundant than solar energy in terms of availability and freedom, usage, along with the rest of the fact that it is converted into electrical energy.

If history is to be believed, the first solar panel was created in the year 1881. The concept of the solar cell was later developed by Russell Ohl in the year 1941, and as a result, a solar panel's usability has improved in comparison to earlier times. As far as monitoring the mother energy is concerned, it is unlikely but not impossible; therefore, efforts have been made through this initiative to prevent any energy from being missed. The solar panel will rotate in proportion to the movement of the Sun itself with the assistance of a servo motor nearby that uses an LDR module to measure the intensity of the sun's rays that are fixed on its upper edge. This will allow the solar panel to capture and store the most energy possible. This endeavor is born out of the desire for such objectivity. The Sun generates the most energy ever in this solar system to produce and transfer life from one organism to another when heat is the source of all creation. In this case, the project known as "Automatic Solar Tracking System" aims to make the most of the energy obtained from the Sun and to transform it into other forms of production. The fundamental goal of this project is to make this system an economically advantageous topic that is simple to access and that, in the end, functions at its best. This system is a time-worthy production that was made to create the greatest of its kind in the wake of technological growth, when time is moving at its best.

In a stretch, it could be said that this project, which is a solar energy extension, is a renewable energy source and an endless phenomenon [3]. The best potential of the solar cells is reflected from the 10 to 20 percent of solar cells that are employed commercially, thus there is room for improvement in the way solar cells are used. This technology is an environmentally friendly solution, making it a valuable asset in the world of pollution. When every aspect of existence is engulfed by an ocean of pollution. This system's viability depends on its capacity to function. It might set a new standard in contrast to other perplexing systems [4].

PV Solar Panels:

An assembly of photovoltaic solar cells installed on a frame (often rectangular) is known as a solar cell panel, solar electric panel, photo-voltaic (PV) module, PV panel, or solar panel. A well-organized collection of PV panels is known as a photovoltaic system or solar array. Sunlight is used by solar panels to collect radiant energy, which is then transformed into direct current (DC) power. A photovoltaic system's arrays can be used to produce solar power that either directly powers electrical equipment or, through the use of an inverter system, is sent back into the alternating current (AC) grid [5].

Work of PV Panels: PV stands for "photovoltaic" in solar panels since they are made up of tiny, interconnected photovoltaic cells. Silicone is the most often utilised semiconducting material in the construction of PV cells. Although PV cells are typically relatively tiny, they may be very effective when used in solar panels and solar arrays. An electric field is produced when the cells are exposed to the sun. Electric energy is generated to a greater extent with stronger suns. But even on overcast days, the cells may still generate power because they don't require direct sunlight to function. PV panels come in a variety of sizes and forms, and they are simple to instal on top of an existing roof.

Advantages of PV Panels

- It may be quite advantageous to use PV panels as a source of power. You may start saving money as soon as the solar panels are acquired and the installation fees are paid off because the price of power will be lower.
- Solar panels can also be used to generate some income in addition to these savings. You may break even faster thanks to the existing Smart Export Guarantee, which lets you make money by selling extra solar energy back to the grid.
- The fact that solar energy is ecologically benign is one of its numerous benefits. Utilizing those helps reduce our carbon footprint.

Various PV module arrays: Only a certain amount of electricity can be generated by a single solar module; thus, most systems use many modules that combine their voltages or currents. An array of photovoltaic modules, an inverter, a battery pack for energy storage, a charge controller, connecting cable, circuit breakers, fuses, disconnect switches, voltage metres, and optionally a solar tracking device are the usual components of a photovoltaic system. Equipment is chosen with care to maximise output, store energy, minimise power loss during transmission, and switch from direct current to alternating current.

An electric power system that uses photovoltaics to provide useable solar electricity is known as a photovoltaic system, often known as a PV system or solar power system. It is made up of a combination of several parts, such as solar panels that take in and convert sunlight into power, solar inverters that change the output from direct to alternating current, mounting hardware, wiring, and other electrical components needed to make up a functional system. It could also have an integrated battery and a solar tracking system to enhance the device's overall performance. PV systems, which convert light directly into electricity, should not be confused with other solar technologies used for heating and cooling, such as concentrated solar power or solar thermal. The PV system's visible component, the collection of solar panels, is the only component of a solar array; the remaining hardware, which is sometimes referred to as the rest of the system, is not included (BOS). Small rooftop-mounted or building-integrated PV systems can have a few to several tens of kilowatts of electricity, while huge utility-scale power plants can have hundreds of megawatts of power. The majority of PV systems today are linked to the grid, with off-grid or standalone systems making up a minor percentage of the market [6].

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CHAPTER 2

COMPONENTS OF SOLAR CELL

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Solar energy is created by photovoltaic cells, which transform solar light energy into electrical energy. The "solar" in their name refers to the high-intensity energy that they capture from the sun. The solar panel is used in household, commercial, and street lighting applications. In photovoltaics, light is directly transformed into electricity at the atomic level. A characteristic of some materials known as the photoelectric effect leads them to absorb light photons and release electrons. An electric current that may be utilised as electricity results from the collection of these free electrons. A solid-state electrical device known as a solar cell, also known as a photovoltaic cell or a photoelectric cell, uses the photovoltaic effect to convert light energy directly into electricity. The most popular photovoltaic cells in use right now are those made of crystalline silicon. A photovoltaic module is a group of solar cells that are electrically coupled to one another and fixed in a frame or support structure. Modules are made to provide power at a certain voltage, like a standard 12 volt system. The amount of light that strikes the Module directly affects the current that is generated. An array can be created by wiring many modules together. A module or array will typically produce more power the greater its surface area. Electricity is generated using direct current (DC) using photovoltaic modules and arrays. To generate any desired voltage and current combination, they may be linked electrically in both series and parallel configurations [1].

Solar Tracker: A Solar Tracker is a device that continuously tracks the sun's motion as it moves from east to west. All tracking systems' primary job is to grant one or two degrees of mobility freedom. Solar collectors and solar panels are kept pointed squarely at the sun throughout the day by the use of trackers. Sun trackers enhance the solar energy that the solar energy collector receives and boost the energy output of the heat/electricity that is produced. The production of solar panels may be increased by 20–30% with solar trackers, which boosts the project's profitability [2].

Importance of Solar Tracker:

The sun moves around 360 degrees of east-west space in a single day, yet from the perspective of any given position, only 180 of those degrees are visible during the course of a half-day. This is slightly mitigated by local horizon effects, resulting in an effective motion of around 150 degrees. According to the chart above, a solar panel that is fixedly oriented between the extremes of dawn and sunset will experience mobility of 75 degrees on either side and hence lose 75% of its energy in the morning and evening. The losses can be recovered by turning the panels to the east and west. A single-axis tracker is one that rotates in an east-west orientation. Over the course of a day, the sun also traverses a 46-degree north-south angle. Thus, the sun will travel 23 degrees on each side of the identical set of panels placed in the middle of the two local extremes, resulting in losses of 8.3%. A tracker that takes into consideration both. A dual-axis tracker is used to measure daily and seasonal movements [3].

Solar Tracker Design:

A photovoltaic array's orientation toward the sun is achieved via a solar tracker. Trackers are used in flat-panel photovoltaic (PV) applications to reduce the angle at which incoming light strikes a photovoltaic panel. The solar array now produces more electricity as a result. Azimuth-altitude dual axis trackers can be used here (AADAT). Due to its capacity to monitor the sun both vertically and horizontally, dual axis trackers are able to harvest the most solar energy. Dual axis trackers can position themselves such that they are facing the sun regardless of where it is in the sky [4].

Figure 1: Represented the A square solar panel with two degrees of freedom is set up.

The configuration of a square solar panel with two degrees of freedom is shown above Figure 1. Here, the two degrees of freedom for rotation are driven by two DC motors. To cut down on losses from linkages and joints and to avoid utilising additional mechanisms and linkages, the motors can be installed directly on the rotation pins of the rotational joints [5].

Servo motors:

When using servo motors in closed loop applications, the motor control circuit is supplied information about the position of the output motor shaft. Resolvers, Encoders, and Potentiometers are common positional "Feedback" devices used in radio-controlled models of boats and aeroplanes, among other things (Figure 2). A servo motor can provide large torques directly and typically has a built-in gearbox for speed reduction. Due to the associated gearbox and feedback systems, the output shaft of a servo motor does not revolve as freely as the shafts of DC motors [6].

Figure 2: Represented the Servo Motor.

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CHAPTER 3

SOLAR TRACKERS

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The efficiency of solar cells was less than 1% when Charles Frit invented them in 1883. Different technologies have emerged over time to increase the effectiveness of solar panels. The use of solar trackers is one such invention. A solar tracker is a tool that enables PV modules to move in the direction of the sun to get more exposure to it. As a result, the solar panel system's effectiveness also rises. Even if the gadgets are expensive, there are some situations where they are the ideal choice. Depending on the movement, there are two main categories of solar trackers:

A. Dual-axis B. Single-axis

Solar tracking, as opposed to fixed solar panels, improves efficiency and extends the daily sun peak hours. The gadgets don't, however, make financial sense for many houses. Therefore, before choosing a course of action, it is advisable to weigh the costs of installing solar panels and purchasing tracking devices [1]. When Consider Solar Trackers

Limited Space: In order to increase the effectiveness of the solar panels if your installation space is constrained, should think about solar trackers. The tools make sure get the most out of the sun's rays all day long. Solar tracking will significantly extend the hours when the sun is at its strongest, whether the solar panels are on the ground or the roof. The amount of solar peak hours, for instance, might increase from 5.5 to 7 hours a day, depending on the sort of tracker use [2].

Business sense: If the cost of purchasing tracking devices is more than the cost of purchasing additional solar panels to increase the current capacity, should choose the latter. For a single photovoltaic module in a 5 kW solar panel system, a solar tracker may cost $500 or more. As a result, the cost of the total solar panel installation may exceed $5,000. The cost of solar panels, on the other hand, is around $3 per watt. Consider how many units each choice increases the output of your solar panel system.

Climate: When the direction of the roof does not favour the installation of solar panels, and can use solar trackers to increase the sun's exposure. For maximum exposure, the devices will tilt the modules in the direction of the sun. If there are a lot of foggy days in your location, might also want to think about solar tracking.

Obstructions or Shading: Solar trackers can be used to boost efficiency if don't want to prune nearby trees or eliminate obstructions. To prevent any shadowing, the gadgets make sure the solar panels are facing away from the shadow of the item. In cases when the available area is even more shaded, increasing the quantity of solar panels might not be an option.

Solar tracking device types

According to how they operate, solar trackers may be divided into three types:

Hand-operated solar trackers: The PV modules must be tilted in the tracks so they face the sun, as suggested by their name. Unfortunately, because can't continuously shifting the solar panels, trackers are less effective. It is even feasible on occasion to neglect to tilt the system.

Devices for passive solar tracking: Another unpopular variety of solar tracker is this one. The tilting mechanisms rely on solar radiation. A low-boiling-point liquid found in passive solar trackers evaporates when exposed to sunlight. The solar panels tilt to the side to face the sun after the evaporation [3].

Trackers for Active Solar Energy: This is a more developed variation of the first two. In order to monitor the direction with the maximum levels of solar radiation and increase efficiency, the trackers feature motor components that can be adjusted based on the direction of the sun. Even though active solar trackers require more maintenance, they are easy to maintain and have a high level of efficiency. In addition to the way they operate, solar trackers can be categorized based on versatility in direction. There are two types of solar trackers that fall under this category:

A. Single-axis
B. Dual-axis solar trackers.

Single-Axis Solar Tracking devices: Depending on where the sun is, the gadgets can only be adjusted from north to south or from east to west. Efficiency may be increased by the solar trackers by over 25%. Large-scale initiatives like community solar power plants frequently use them. Single-axis trackers can also be divided into centralized and decentralized groups. While centralized solar trackers may modify a row or many rows of solar panels, decentralized solar trackers service a single PV module [4].

Dual-Axis Solar Trackers: These gadgets follow the sun's location and can travel in either east or west or south or north. The trackers contribute to a 45% boost in solar panel efficiency. Dual-axis solar trackers are expensive, but they are perfect for commercial solar installations with lots of users and restricted space. The tracking devices are adjusted according to the sun's rising and setting times, but they also tilt with the sun's location throughout the year. The sun is in a different position during each season due to the earth's rotation.

Solar trackers have advantages:

- Enhanced solar panel efficiency: Dual-axis solar trackers may enhance production by up to 45% while single-axis solar trackers can increase efficiency by up to 25%.
- Make solar viable in locations with limited eligibility: certain regions have an unfavorable climate for sun energy. To make solar energy dependable, might increase the overall output instead of using as many solar panels.
- Solar tracking can lessen your reliance on the grid if your solar system is grid-tied and ensures maximum utilisation of the sun's peak hours.

- Make the most use of the available land. Tracking devices take up less room than more solar panels, which would improve the system's capacity.

Solar trackers have disadvantages:

- The cost of the devices might quadruple the overall cost of a solar energy installation, which is one of solar trackers' drawbacks.
- **Raises maintenance costs:** Since solar trackers include moving parts, they raise the maintenance costs of solar panel systems.
- **Complex to install:** Solar tracking is difficult to install since it requires a special design to work with the system. They need more site preparation, excavating, and planning. It is simple to install and maintain fixed solar panels [5].

Need to Think about Solar Tracking: For certain solar panel installations, solar trackers are not the best option. Therefore, when picking solar tracking, should take into account aspects like climate, space, and shading. The gadgets are appropriate for locations with constrained space and high energy needs. The best sites to put the devices are in commercial structures should examine the projects' cost since solar tracking requires a substantial financial expenditure. Some solar finance companies may reject your loan application because they view solar as a high-risk investment. As a result, should consider each of these elements. However, a solar energy tracking device might be useful if live in a place where solar energy is not economically viable. For the best tracking, should also select a qualified solar panel installer. Contact us right away, and we'll determine whether solar tracking devices are the best option for your property. To get the most for your money, can rely on Dynamic for a thorough review of your project. Dual axis solar tracking system was chosen. Due to the fact that the dual axis tracking system is more advantageous and efficient than the single axis tracking system [6].

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CHAPTER 4

MONO-CRYSTALLINE SOLAR PANELS

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A solar panel made up of monocrystalline solar cells is referred to as a monocrystalline solar panel. Similar to a semiconductor, these cells are constructed from a cylindrical silicon ingot that was produced from a single, highly pure silicon crystal. Wafers are cut from the cylindrical ingot to create cells. The circular wafers are wires cut into an octagonal shape to maximize the use of the cells. The octagonal shape of these chambers gives them a distinctive appearance. The color of these cells is also consistent [1] . The monocrystalline solar panel receives sunlight, which is absorbed by the cells, which then use a complex process to produce an electric field. The power produced by this electric field, which consists of voltage and current, is determined by the equation P = V x I. (current). Direct-current devices can be powered directly by this energy (DC). An inverter can also be used to convert this electricity to alternating current (AC) [2].

Characteristics of monocrystalline solar panels: One of the three categories of materials that display photovoltaic qualities is monocrystalline solar cells. The other two are thin-film solar panels and polycrystalline solar cells. The advantages of monocrystalline solar panels over the other two types of panels are well acknowledged. These are what they are:

1. The pyramidal shape of these solar panel cells provides a bigger surface area for absorbing more solar energy.
2. To limit reflection and thus improve absorption, the cells are covered with silicon nitride.
3. The top surface is diffused with phosphorous, which contributes to the creation of an orientation that is electrically negative as opposed to the bottom, which has a positive electrical orientation. Metal conductors printed on the cells allow the generated electricity to be collected.
4. Due to the aforementioned characteristics, monocrystalline solar cells have a major advantage over its two other equivalents in that solar energy is converted into electricity more effectively.
5. The lifespan of these panels is up to 30 years.
6. These panels are more resistant to heat [3] .

Applications: Monocrystalline solar panels are used in the following situations due to their many benefits:

1. Because solar panels are more effective, they can generate more power from the same amount of space than panels made of other materials. Both urban and rural solar rooftops use these panels pretty frequently.

2. Large-scale solar applications on expanses of unusable land are strongly encouraged using these panels.
3. In addition to being beneficial for industrial and commercial uses, these panels.
4. Smaller solar panels that produce between 5 and 25 W of electricity can be used to power computers, cameras, and cell phones.
5. For powering higher wattage items like refrigerators and microwaves, panels providing between 40 and 130 W are helpful.
6. These panels are fantastic for illuminating gardens.
7. These panels can be utilized to power rural dwellings in an array.
8. These panels work well for street illumination when used alone [4].

Comparison of the Pros and Cons of Monocrystalline Solar Panels: Despite being the most effective solar cell on the market, monocrystalline solar panels have a number of benefits and drawbacks, each of which is outlined below. The following are a few benefits of monocrystalline solar panels:

1. Due of their great efficiency, they take less space than other varieties and have the highest level of efficiency (17–22%).
2. According to the manufacturers, this type of solar cell has the longest lifespan, and the most of them have a 25-year warranty.
3. These panels operate better in low-light conditions, making them perfect for overcast places, and they have superior heat resistance [5].

The following are some drawbacks of monocrystalline solar panels:

1. The performance levels typically decline as temperature rises, making them the priciest solar cells on the market and therefore out of everyone's price range.
2. Comparatively speaking to other solar cell types, it is a slight loss.
3. When silicon is chopped while being manufactured, a lot of waste material is produced.

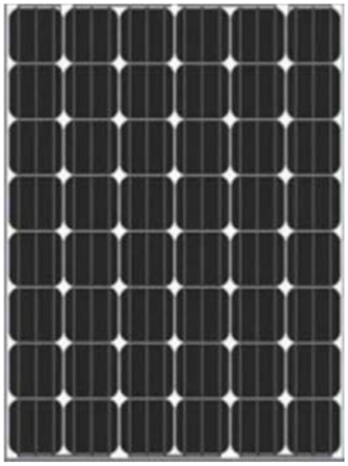

Figure 1: Representation of the Monocrystalline Solar Panels.

Cost of monocrystalline solar panels: Due to the method these panels are made, monocrystalline solar panels are more expensive than other types of solar panels. Their high power and efficiency ratings also raise the cost.

The majority of high-end solar panels, including those from Sun Power and LG, are monocrystalline. Monocrystalline solar panels are more expensive than polycrystalline modules by around $0.05 per watt, according to the Lawrence Berkeley National Laboratory (Figure 1). The cost difference among polycrystalline and monocrystalline solar panels has decreased as solar technology and manufacturing have advanced [6].

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CHAPTER 5

POLYCRYSTALLINE SOLAR PANELS

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One PV cell in polycrystalline or multicrystalline solar panels contains several silicon crystals. A number of silicon shards are melted together to form the wafers of polycrystalline solar panels. The molten silicon vat used to make the solar cells for polycrystalline panels is allowed to cool directly on the panel [1]. These solar panels have a mosaic-like pattern on their surface. These square solar panels are made of silicon crystals, which give them their vivid blue color and square shape. Polycrystalline solar panels have constrained internal electron mobility because of the multiple silicon crystals found in each cell (Figure 1). These solar panels absorb solar energy from the sun and convert it to electricity [2].

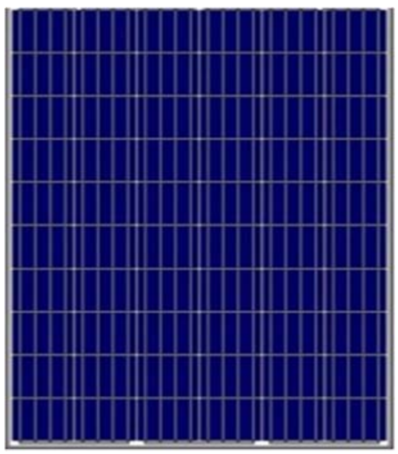

Figure 1: Represented the Polycrystalline Solar Panels

Work of polycrystalline solar panels: These solar panels are made of a lot of photovoltaic cells. Each cell contains silicon crystals, allowing it to function as a semiconductor device. At the PN junction (the intersection of N-type and P-type materials), photons from sunlight provide electrons energy that allows them to circulate as an electric current. In this situation, P-type materials are electron-deficient while N-type materials have an abundance of electrons. Two electrodes are connected to the PV cells. The electrodes on the upper surface is made up of small wires, whereas the electrodes on the bottom is a conductors that resembles foil [3].

Polycrystalline Solar Panel Features:

1. Since polycrystalline solar panels employ a larger proportion of silicon during production than monocrystalline solar panels do, they are more environmentally friendly than their monocrystalline counterparts. As a result, relatively little waste is produced

2. The lowest and highest temperatures that polycrystalline solar panels can resist are -40 °C and 85 °C, respectively.
3. Polycrystalline solar panels have a poorer heat tolerance than monocrystalline panels.
4. As a result, at higher temperatures, these solar panels perform less effectively than others.
5. Polycrystalline solar panels have a higher temperature coefficient than monocrystalline panels.
6. The power density of these panels is great.
7. A built-in structural framework that reduces the cost and complexity of mounting [4] .

Applications:

Applications for polycrystalline solar panels include:

1. Roof-mounted arrays are a good fit for polycrystalline panels.
2. To harness the power of the sun and provide electricity to adjacent areas, they are utilised in enormous solar farms.
3. They are utilized in independent or self-powered equipment like off-grid homes, remote traffic signals, etc.

The following is a list of the benefits and drawbacks of polycrystalline solar panels.

The following are some benefits of polycrystalline panels.

1. Polycrystalline solar panels are less expensive than monocrystalline ones because of their simplicity in manufacturing and utilization of multiple silicon cells.
2. The polycrystalline panel has less waste due to the way the silicon wafers are attached to it.
3. They work with battery and inverter technologies.
4. The amount of fossil fuels used for manufacturing is minimal.

The following are some drawbacks of polycrystalline solar panels:

1. Polycrystalline solar panels are less efficient than monocrystalline solar panels because of the lower silicon purity.
2. Despite the fact that the difference is closing, polycrystalline solar panels normally need a bit more surface area than the best monocrystalline solar panels to produce the same quantity of power.
3. They may not last as long.
4. High temperatures quickly cause them to become damaged [5].

Solar panels with monocrystalline versus polycrystalline crystals:

The following is a comparison between monocrystalline and polycrystalline solar cells.

1. Because a monocrystalline solar panel is made of a single crystal, it gives the electrons greater room to move, improving the flow of power. This explains why monocrystalline solar panels are more effectual than polycrystalline ones.
2. This explains why monocrystalline solar panels are more efficient than polycrystalline ones. Polycrystalline solar panels have a little lower efficiency, however this has the advantage of being a more inexpensive choice for clients.

3. When you search for polycrystalline solar panels for sale, the vendors could point out the blue color of these panels as opposed to the black color of the monocrystalline panels.
4. The area available for the electrons in each cell will be reduced as the silicon pieces used to make the wafers for polycrystalline solar panels are melted together. Because of this, polycrystalline solar panels' efficiency ratings are lower.
5. The cost of monocrystalline solar panels will be somewhat higher than that of polycrystalline solar panels.
6. Some industry experts claim that systems using monocrystalline solar panels have been known to malfunction if they are even slightly coated in snow, dust, or if a portion of the panel is shadowed. On the other hand, polycrystalline solar panels are a little more durable under these circumstances [6].

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CHAPTER 6

THIN FILM SOLAR PANELS

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A collection of thin-film solar cells makes up a thin-film solar panel. Using the photovoltaic effect, these solar panels transform solar energy into electrical energy. There are numerous layers of photon-absorbing materials inside each thin-film solar cell. These layers may be 300–350 times thinner than those of conventional silicon panels. Those solar panels are divided into groups based on the substance that serves as their substrate. Substrates can be made from materials such amorphous silicon (a-Si), copper indium gallium selenide (CIGS), cadmium telluride (CdTe), and gallium arsenide (GaAs) [1]. Thin-film solar cells with a GaAs substrate are the most effective of them, outperforming rivals by roughly 28.8%. A solar panel is essentially a semiconductor device made up of a variety of photovoltaic and solar cells (PV). P-type and n-type materials combine to make each PV cell. When it comes to materials, n-type materials have free electrons while p-type materials are electron-poor. When sunlight hits the panel, it excites the electrons, which then flow through the p-n junction and produce a lot of current. This current can then be utilised to power different equipment inside a building immediately, or it can be stored in the batteries for later use. Typically, silicon is employed as the semiconducting material in conventional solar panels. However, materials such as Copper Indium Gallium Selenide, Cadmium Telluride, Amorphous Silicon, or Gallium Arsenide are utilized in place of silicon in the case of thin-film solar panels [2].

Characteristics of Thin-Film Solar Panels

1. Lightweight and bendable thin-film solar panels are available.
2. Compared to conventional silicon panels, these panels' installation is significantly simpler and requires less labour.
3. Because they produce a lot less pollutants during manufacture than conventional solar panels do, this is because they contain a very little amount of silicon.
4. Since they are lightweight, installation is simple.
5. Applications with big roofs or open areas are best suited for these solar panels [3].

Applications of Thin-Film Solar Panels: In order to be put in institutional and commercial buildings with vast rooftops/open areas, thin-film solar panels need a greater area.

1. Forested regions can also utilize them.
2. Solar farms can make use of thin-film solar panels.

3. These panels may be mounted on the roof of buses and recreational vehicles to power fan motors, Wi-Fi modems, and other small gadgets. They may also assist in keeping a bus's temperature stable.
4. Large steel water tanks can be equipped with thin-film solar panels to provide power for water pumping.

Benefits and Drawbacks of Thin-Film Solar Cell:

Thin-film solar panels have the most potential for mass manufacture of all other varieties. It's because the creation of these solar cells does not just rely on molten silicon, but rather a variety of photovoltaic materials, including amorphous silicon, copper indium gallium selenide, and cadmium telluride.

1. Simple to use.
2. Flexible compared to conventional solar cells.
3. Thin wafer sheets are readily available.
4. Thin-film solar panels offer a wide range of uses, such as a non-conventional power source, a portable heater for shavers, and a heater for hot water in showers.
5. Environmental factors like shade and extreme heat have no impact on thin-film panels.
6. Less expensive than conventional solar panels [4].

Disadvantages:

1. Only 20 to 30 percent of light is converted into power, making it less effective. Complex structure
2. Given the degree of efficiency currently, more room is required. Thin-film solar cells need around 50% more room to be installed before they can produce the same amount of power as conventional solar panels.
3. A lot of heat is retained. Because thin-film solar cells are often put directly to a surface, they tend to retain more heat, making it difficult to quickly cool panels.
4. Large-scale manufacture of thin-film cells is challenging due to the high cost of fabrication.
5. Handling requires additional caution.

Cost of Thin-Film Solar Cell: Compared to conventional solar cells composed of crystalline silicon, thin-film solar cells are less expensive. Contrarily, thin-film cells, such CdTe-based solar cells, require a lot less energy. Cheaper expensive to produce than silicon cells in terms of raw materials (up to 100 times less). Additionally, thin-film cells absorb sunlight at almost the perfect wavelength. As a result, the power [5]. The cost of electricity produced by thin-film solar cells is the lowest currently accessible. Most solar panel producers are aware that price is a barrier to most solar panels being more affordable for the general population. Manufacturers are working to cut prices while keeping this problem in mind. Currently, thin-film solar cells cost between $0.50 and $1.00 per watt. The goal of several producers is to lower the price to under $0.70 per peak watt of electricity. In particular, when compared to the conventional solar panel, where the average price per watt for solar panels is between $2.58 and $3.38 silicone cell, installing solar panels at home will be cost-effective for domestic users (in the US).

Types of Thin-film Solar cells

1. There are four types of thin-film solar cells:
2. Cadmium Telluride (Cd Te)
3. Amorphous Silicon (a-Si)
4. Copper Indium Di selenide (CIS)
5. Gallium Arsenide (GaAs)[6]

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CHAPTER 7

LDR'S AND ARDUINO

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Since the LDR is a passive transducer, we will use a potential divider circuit to calculate the appropriate voltage from the LDR's resistance. The resistance of LDRs is inversely correlated to the brightness or intensity of light striking them, meaning that the higher the brightness or intensity of light, the lower the resistance, and vice versa. LDRs are sometimes referred to as photo resistors or photo conductors. It operates using the photo conductivity principle. LDR resistance falls off when light intensity rises and vice versa. LDRs are primarily utilised for sensing in solar energy harvesting applications to supply analogue input to Arduino [1].

Working of LRD:

By detecting the amount of light present in its surroundings, this system operates. An LDR is a type of sensor that may be used to detect light. You may get it from any nearby electronics store or online at a reasonable price. When connected to VCC (5V), the LDR emits an analogue voltage whose magnitude fluctuates in direct proportion to the amount of input light it receives. In other words, the voltage coming from the LDR will increase in proportion to the brightness of the light. The analogue input pin on the Arduino is linked to the LDR since it emits an analogue voltage. The Arduino then transforms the analogue voltage (between 0 and 5 volts) into a digital value within the range of (0-1023) [2]. The translated digital values read from the LDR through the Arduino will be in the range of 800-1023, depending on how much light is present in its surroundings or on its surface. The Arduino is then programmed to activate a relay. Turn on an appliance (a light bulb), in accordance, when the light intensity is low, that is, when the digital values read are greater than normal [3], [4]. You may accomplish this by covering the LDR's surface with any item [5].

Advantages of LRD:

1. The great sensitivity of the LDR (light dependent resistor) is mostly dependent on the resistance property, and any minute changes in resistance will be visible on the device.
2. The LDR typically has two terminals and is the same size as a resistor, making it simple to connect them to the circuit.
3. The LDR requires a low voltage for power since it is a component with a low supply voltage.

4. The LDR resistance value serves as the baseline for determining the amount of power that must be supplied to it.

Disadvantages of LRD:

Small range of spectral response: The light spectrum response of an LDR (Light-dependent resistor) has a very narrow range, therefore at the light spectral extremely low frequency, a response with an LDR component is produced.

Poor-temperature stability: Because LDRs are meant to be highly sensitive, their temperature stability is quite low. This is to be expected given their great sensitivity.

Inaccurate value at the change in temperature: The LDR is extremely sensitive, thus any little changes in temperature will have a direct impact on it. This results in an inaccurate value when the temperature changes (Light Dependent Resistor) [6].

Arduino: The type of microcontroller is Arduino. The position of the motor is managed by the microcontroller. It uses an at mega 328p microcontroller. Six of the fourteen digital I/O ports on an Arduino board are used to generate PWM signals. Additionally, it has a USB connector that is used to dump programmes and a 16 MHZ crystal oscillator. The power jack powers Arduino as well. Arduino has several benefits, including affordability, sturdiness, and platform independence.

Due to its open source nature and simplicity, Arduino is a great prototyping tool for both professionals and enthusiasts.

The Arduino Uno contains a 16 MHz crystal oscillator, 6 analogue inputs, 14 digital input/output pins (of which 6 may be used as PWM outputs), a USB port, a power connector, an ICSP header, and a reset button. It comes with everything required to support the microcontroller; to get started, just use a USB cable to connect it to a computer, or an AC-to-DC converter or battery to power it. The FTDI USB-to-serial driver chip is not used by the Arduino Uno, which is how it differs from all previous boards.

Instead, it has an Atmega8U2 microcontroller chip that has been configured to function as a USB to serial converter. The Italian word "Uno," which means "one," was chosen to symbolize the imminent release of Arduino 1.0. Moving forward, the standard versions of Arduino will be the Arduino Uno and version 1.0. The Uno, the most recent in a line of USB Arduino boards, serves as the platform's benchmark [7].

Benefits and Drawbacks of Arduino: If you can find the correct shield, it is excellent for carrying out a specific project you may have in mind, but it won't teach you anything about microcontrollers in general or the AVR in particular. It is excellent for getting results quickly, but it won't help you understand programming or microelectronics.

Advantages

1. Starting out doesn't take a lot of knowledge.
2. Depending on the shields you want, reasonably affordable
3. Many illustrations and shields are available.

4. No need for a power source or external programmers

Disadvantages

1. Lack of knowledge of the AVR microcontroller
2. Modifying sketches and shields might be challenging.
3. No debugger is provided to test scripts.
4. Don't learn how to use C or other professional programming tools.

Controller for Solar Charge: The simplest solar-focused charge controller merely:

When the battery voltage reaches a specific level, the device:

1. Monitors the battery voltage.
2. Opens the circuit.
3. Stops the charging.
4. Avoid allowing DC power to flow backward from the batteries to the solar-powered board during the nighttime hours when those boards are not producing electricity via the boards that depend on sunlight, draining the batteries.
5. Older solar-powered charge controllers used a mechanical hand-off to open or shut the circuit, stopping or starting power from leaving the generator and going to the batteries.
6. It controls the voltage that the solar panel sends back.
7. The solar cells create greater electricity the brighter the sunlight is.
8. The batteries might be harmed by the increased voltage.
9. The charge controller manages the charge to the batteries to prevent overcharging when the input voltage from the solar panel grows.

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CHAPTER 8

INTRODUCTION TO THERMAL RUNAWAY

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General Review

The rate of global warming is rising daily. The pollution produced by burning motor gasoline is one of the primary culprits. People from all across the globe have developed a fresh, creative idea using an electric vehicle to reduce the usage of fossil fuels. Because the engine of an electric car is powered by a battery, the battery serves as the engine's primary power source. Every new revolutionary concept that is put to use in the outer world has both advantages and disadvantages. While there are numerous benefits in this situation, like a decrease in pollution and advancements in the automotive sector, there are also drawbacks. The heating of the battery is one of these battery-powered cars' significant drawbacks. In order to avoid thermal runaway, which occurs when a battery becomes too hot and may need replacing the whole battery system, which is expensive and might even harm the driver, scientists from all over the globe have developed a technique called as Battery Thermal Management System [1].

Electric Vehicle

An electric motor powers an electric vehicle (EV), as opposed to an internal combustion engine that produces power by burning a mixture of fuel and gases. In order to solve the issues of increasing pollution, global warming, the depletion of natural resources, etc., such a vehicle is viewed as a potential substitute for current-generation vehicles. Even though the idea of electric cars has been around for a while, it has attracted a lot of attention in the last ten years due to the growing environmental implications of fuel-based vehicles and their growing carbon footprint.

Battery

A battery is a chemical apparatus that stores electricity as chemical energy and then transforms that chemical energy towards direct current (DC) electric energy via an electrochemical process. The first battery was created in 1800 by an Italian physicist named Alessandro Volta. Figure 1 shows how the electrochemical process in a battery includes the movement of electrons from one substance to another (referred to as electrodes) [2].

Figure 1: Illustrates the electrochemical reaction in a battery.

Four steps of the thermal runaway mechanism in lithium batteries. Everyone must be acquainted with the avalanche phenomena in semiconductor diodes if you've studied fundamental electronics. A heat avalanche is a thermal runaway. The most frequent cause of thermal runaway with lithium-ion batteries is overuse, either thermal or electrical. Excessive Joule (I2R) heat will result from extreme overcharging. When a particular location reaches a temperature where another battery materials may begin to react, in addition. Self-heating causes a thermal runaway or unregulated heat generating process to begin. There are three separate phases to the thermal runaway process within lithium-ion, as well as the fourth and final step results in destruction [3].

The Onset

The Joule heat remains relatively constant under thermal and electrical abuse, such as overcharging, till the battery temperature exceeds what is known as the onset temperature T-onset [4].

Acceleration

The reactive part of the anode is first made susceptible to exothermic interactions with the electrolyte as a result of solid-electrolyte interface decomposition. Due to the declining SEI, the electrolytes were simultaneously oxidized and reduced at the anode. At this point, self-heating starts to become noticeable (more than, say, 0.2C/minute) but climbs virtually linearly as the temperature rises. The battery construction must disperse this heat if it is to prevent exothermic reactions from becoming more and more severe as the temperature rises. The rate of self-heating rises linearly with temperature as a function. This area, also known as the ramps or acceleration zone, appears as a Ramp on a graph of the self-heating rates versus temperature. The biochemistry of the battery's components and the charge state both affect the process that accelerates heat production. Smoke and venting may also be seen at this time. Early intervention may stop the responses, and Stage 3 Thermal Runaway may be avoided. The emergence of thermal runaway can take several minutes, hours, and even days based on the battery design, components, and operating environment. Once it has begun, thermal runaway cannot be reversed [5].

Runaway

As they continue to heat up, the cells reach Stage 3, also known as Thermal Runaway. The increased rates of anode and cathode interactions, which are fed by the growing temperature inside a self-propagating process, cause the cell temperature to start rising quickly. There might be internal arcing, flame, or a quick decomposition of the components. Thermal runaway, by a broad definition, happens whenever the rate of self-heating is 10°C/min or above. No preventative action is expected to be effective at this rapid rate of self-heating. In lithium batteries, the temperature that causes the thermal runaway is known as the Runaway Temperature, T (runaway), may range from roughly 130°C to over 200°C and is highly dependent on the cell size, cell materials, as well as the cell architecture. Figure 2 shows that cathode materials often leak oxygen at high temperatures as well as at even faster reaction rates [6].

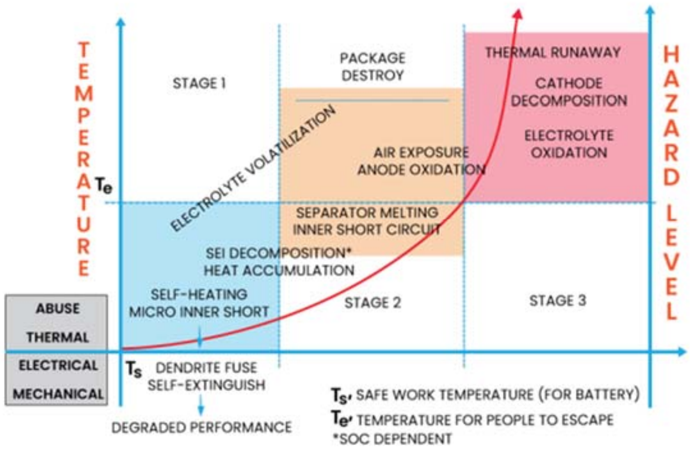

Figure 2: Illustrates the Thermal runaway will invariably destroy the battery.

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CHAPTER 9

BATTERY THERMAL MANAGEMENT SYSTEM (BTMS)

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The Thermal Management System (BTMS) of the battery regulates and discharges heat generated by electrochemical processes occurring in the cells, allowing the battery to function safely and effectively. The battery thermal management system, or BTMS, tries to maintain the battery working continuously at the appropriate temperature by managing the heat generated by the battery's components. Despite the fact that presently available commercially accessible cells may operate safely between -40 and 60 ºC, manufacturers prefer their products to operate in the 15 to 35 ºC temperature range for maximum performance. It is also indicated that there should not be a temperature difference between the battery pack's cells of more than 5 ºC in this respect. It should be noted that exposing the batteries to dangerous conditions might cause fatality. For instance, running it over 80 ºC may cause the well-known thermal runaway, which itself is known to result in fire and, in the worst scenario, an explosion of the battery with consequences for human safety. The BTMS of the battery pack is in charge of making sure that the cells operate at the optimum temperatures advised by the manufacturer.

When the expertise throughout materials and technologies for thermal energy management, trying to convert, and storage of the Thermal Energy Solutions (TES) area of CIC energy GUNE has been combined with that from the Electrochemical Energy Storage (EES) area, radical technologies in thermoelectric management with a focus on batteries emerge. While the operating range preferred by manufacturers to optimize their own performance is really between 15 and 35 ºC, commercially available organisms may run safely between -40 and 60 ºC. In addition to controlling the heat produced by its components to keep the battery operating constantly at the ideal temperature, the BTMS's (Battery Thermal Management System) main objective is to avoid rapid battery degradation. Additionally, it is indicated that there should not be a temperature difference of more than 5 ºC between the battery pack's cell components. It should be noted that exposing the batteries to dangerous conditions might cause fatality. For example, using a battery at excessively high temperatures (> 80 ºC) might result in the well-known thermal runaway, which can ignite fire and, in the worst case scenario, explode, raising concerns for human safety. The battery box's BTMS was responsible for making sure that the cells operate at the optimum temperatures advised by the manufacturer [1].

Thermal management technologies

There isn't just one choice available when selecting a BTMS for a battery-pack. The following graphic displays the top thermal management techniques that are either already commercially available or are the subject of active scientific study. This is the first primary classification of the BTMS for the systems with and without fluid moving through them. The first is known as "active BTMS," while the second is known as passive BTMS [2].

Active BTMS

Modern electric vehicles most often use forced air or coolant-based active BTMS. For instance, fans are used by both Toyota and Lexus to force cold air into to the battery cells. With Tesla or Audi automobiles, the cooling liquid, which is often a freshwater and ethylene glycol mix, goes through tubes in close contact with both of the cells. Whenever liquid coolants are used, they may either go via pipes or operate in an indirect or direct manner on both the cells (immersed throughout the fluid). The examples of liquid cooling used above all use indirect methods. One of its main flaws is the reduction in heat transfer efficiency between indirect and direct systems. This is mostly due to the heat transfer impedance there at intersection of the cell and the pipe conveying the refrigerant. Nevertheless, since there is no direct interface between the fluid as well as the electrical components of the battery, indirect methods allow to utilize common coolants now used in combustion-powered vehicles. This is why companies who use liquid cooling today choose it over alternatives, to just not mention how affordable it is. The interest in immersing cells in cooling fluids has significantly increased during the last several years within both the scientific and industrial worlds. The main advantage of this design is a more effective heat transfer since the cooling fluid and the cells are in close contact. Studies show that direct procedures might increase the transmission by as much as four times [3].

However, there are now significant barriers that preclude this method from being used in electric vehicles. The first is the need for further research into dielectric fluids that enable appropriate cell functioning, were compatible with all battery-pack components, including cells, current collectors, and electronics, are reasonably priced, and guarantee the safety of the car in the event of an accident. A more extreme example of this option is the use of fluids that have a boiling point well within required temperature range once again for cells in order to benefit from the liquid-vapor phase transition. According to scientific studies on these fluids, heat transfer may increase by up to 10 times as comparing to the use of fluids without phase change. However, because according to their low TRL (Technology Readiness Level), it is unlikely that these fluids will be employed in vehicles very soon [4].

Passive BTMS

The disadvantages of active BTMS are overcome by passive systems. These sorts of technologies have recently increased in prominence due to their useful advantages, while not yet being employed in electric automobiles. Heat pipes and phase change materials (PCMs) are two notable families which stand out among the various passive substitutes (HPs). PCMs, in particular those displaying a solid-liquid phase shift, have been extensively studied for application in BTMS. These materials are intriguing due to the possibility for studying the high energy associated with phase transitions that occur at almost constant temperatures (often >150 J/g). These two characteristics make them appealing for maintaining a constant temperature throughout the battery pack that really is close to the phase change temperature of the applied PCM [5]. The compounds that have been the focus of the greatest study for these applications include paraffins, fatty acids, or hydrated salts. These materials/combinations are ideal for battery heat regulation since their melting points are often between 30 and 50 oC. However, the relatively low thermal conductivity of the abovementioned PCM families limits the heat transfer from the batteries towards the PCM and also from the PCM to the battery pack outside. To get over this restriction, several papers in the literature recommend doping polymeric PCM with nanoparticles, fibers, or extended graphite, among many other options. The PCM might also be included into porous constructions (often metallic ones). PCMs have a number of shortcomings that keep them from being the preferred option at this time, despite their effectiveness in creating excellent temperature uniformity inside the battery pack. These are what they include: thermal conductivity is insufficient. Doping PCM increases rechargeable battery weight, decreases thermal storage capacity, and lowers energy density [6].

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CHAPTER 10

BATTERIES THERMAL MANAGEMENT SYSTEM

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Below is a list of the fundamental BTMS kinds.

A cooling air is used as the thermal medium in air systems. Air conditioning after passing through a heater or an air conditioner's evaporator may also be used as the intake air, which might come directly from the cabin or the environment. A passive air system is the former, while an active air system is the latter. Increased cooling or heating capacity may be provided via active systems. The cooling or heating power of the passive system may reach hundreds of watts, but the power of an active system is capped at 1 kW. They are also known as forced air systems for Figure 1 since a blower is used to provide air in both situations [1].

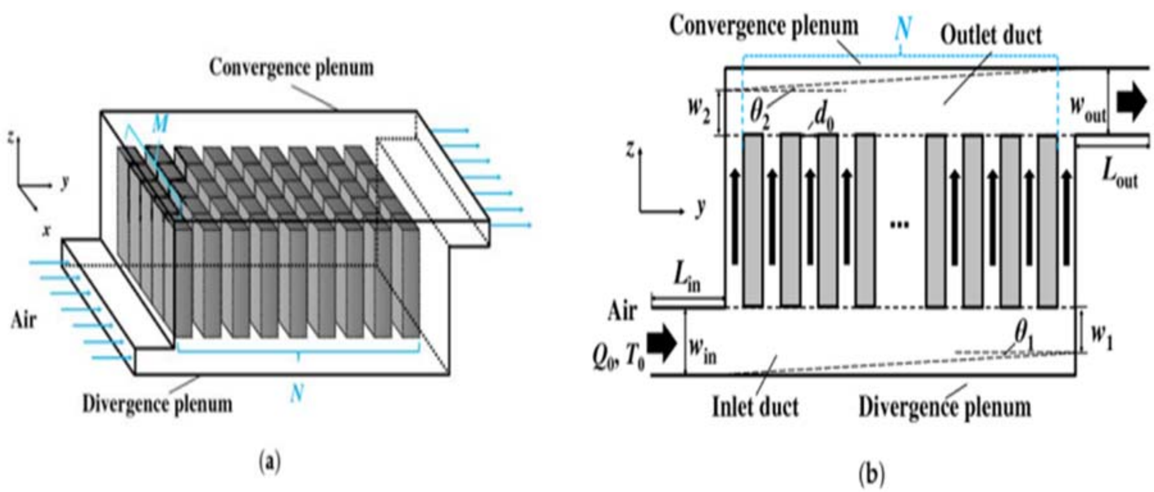

Figure 1: Illustrates the Air cooling system [2]**.**

Keep in mind that the air system provides complete ventilation, heating, and cooling functions. The exhaust air can indeed be brought back into the cabin, thus it is not necessary to construct an extra ventilator. In order to recover heat from exhaust air, a heat recovery device (air-air heat exchanger) may sometimes be installed after the battery pack. It may limit the blending of intake and exhaust air while also increasing the possibility of savings.

Liquid cooling

It is a cooling system that uses water as the coolant to keep the battery at a comfortable temperature. Due to its practical design and effective cooling capabilities, liquid cooling is by far the most widely utilized cooling technology. Mineral oil is a good example of a direct-contact or dielectric liquid cooling liquid that may come into direct contact with battery cells. The second kind is conducting liquid called indirect-contact liquid, which can only make indirect contact with the battery cells. An example of this type of liquid is an ethylene diethyl ether and water solution. Different layouts are created for the various liquids. The typical configuration for direct-contact liquid is to dunk modules in mineral oil [3]. Layout options for indirect-contact fluids include enclosing the battery module in a jacket, encircling each module individually with tubing, mounting the battery modules on the cooling or heating plate, or integrating the battery module with cooling and heating fins and plates. In order to create greater isolation between both the battery module and surroundings and subsequently better safety performance, indirect contact solutions are chosen between these two groups. The creation of the physical design of the cooling plate as well as its channels has always been the focus of research on liquid cooling systems. By focusing on characteristics such coolant drop in pressure across the passages of the cooling plates and cell core temperature, various designs are created. The channeled cooling approach demonstrated the lowest power usage when compared to other techniques, and it also demonstrated the maximum cooling performance, per earlier research just on geometric evolution of the cooling plate. But because of the relatively lengthy course of flow in Figure 2, channeled cooling is not the best option for maintaining temperature uniformity [4].

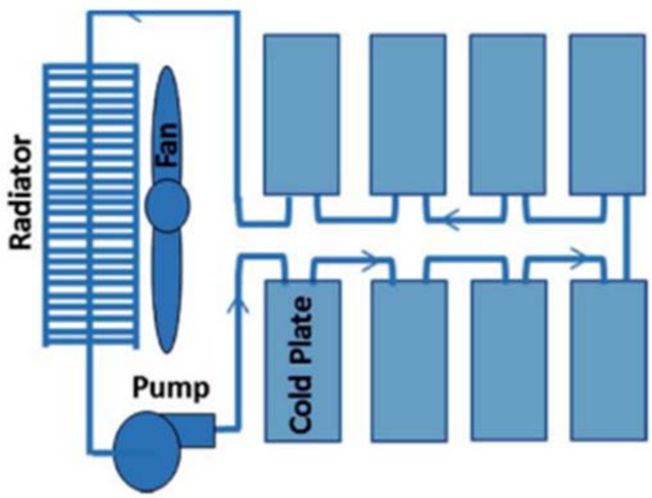

Figure 2: Illustrates the Liquid cooling system.

A number of modified pack designs have been developed to improve cooling performance, including thickened cooling fin designs, sandwich cooling plate designs, and interspersed cooling plate designs. The route of heat transfer from the bottom of a battery towards the cooling plate significantly contributes to the thermal resistance of a battery pack structure. To enhance the building elements of a large-scale, practical battery temperature management system. A thermal model for the type D-2, an alternate design for the BTMS, indirect fin-cooling battery pack was produced. It raised the total drop in pressure by 19%, increased the equivalent heat conductance to system volume by 64%, and decreased the maximum temperature differential by 5.4°C [5].

Direct Refrigerant cooling

Laser cooling systems are typically large, independent chillers with a coolant loop that circulates. These units' coolant loops are prone to failure, their coolant lines are susceptible to leaks, and their coolant has to be changed often. Due to their size, weight, and possibility for coolant freezing, particularly when using water without the need for an antifreeze component, these systems may be difficult to transport. These systems' coolant pumps have a history of failing at a rate that is 4-5 times higher than that of a refrigeration compressor, leading to expensive downtime and laser warranty costs. A small cooling system that could be combined with the laser electronics within the client's chassis was requested by our customer in order to create a cooling system that does not necessitate a pump, secondary coolant loop, or reservoirs. Their goal was to create a small, high-efficiency cooling system which would be marketed together with a laser system and be completely maintenance-free [6].

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CHAPTER 11

PHASE CHANGE MATERIAL

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Phase transition material absorbs heat when it is melted and retains it until it reaches its maximum quantity as latent heat. After a period of time during which the temperature is kept at its melting point, any temperature increase is delayed. Thus, PCM is employed in the BTMS as a conductor and buffer alone [1]. The PCM is always coupled with some other BTMS system, such as a water cooling and airflow cooling system, which regulate the battery core body temperature (Figure 1).

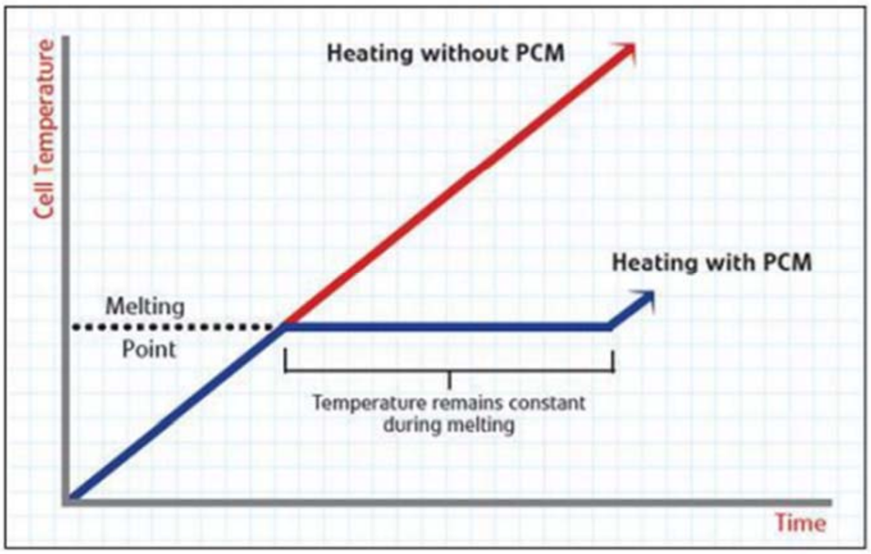

Figure 1: Illustrates the working mechanism of PCM on battery cells [2]**.**

<u>Thermoelectric cooling</u>

The capability of passive air systems to cool or heat may be increased in two different ways. One method is using thermoelectric modules. The thermoelectric cooling system changes the electric voltage from the temperature difference and vice versa. This article discusses how altering electric voltage affects temperature. It dissipates heat from the parts without using any power at all. Fans may increase heat transfer by using forced convection. In order to integrate a passive air system together with both the thermoelectric system and the connected system, which decreases the battery temperature even further than the input air temperature, the power is limited to less than one kW. All that is necessary to switch between cooling and heating operations is to change the polarity of the electrodes [3].

Heat pipe cooling

It is a passive cooling system that primarily consists of a sealed tube with refrigerant inside of it. In order to remove heat from the surrounding environment, the refrigerant is only condensed back to liquid at the cold end after being vaporized on the hot side to absorb heat. The heat pipes use a capillary structure to speed up heat transmission, which boosts the surface temperature. The covering of the heat pipe maintains a partial vacuum. The heat pipe may utilize water or another refrigerant as the coolant, and this cycle continues going round and round. The battery acts as a heat source below the heat pipe (on the side that evaporates), while the heat pipe's cooling fins act as its heat sinks (on the condensing side). According to measurements, thermal resistance is reduced by 30% in a heat pipe cooling system with natural convection compared to something like a system without a heat pipe. A 20% reduction in heat resistance is possible when air velocity is lowered during convection. The safety of the system is the largest difficulty with the cooling, which might be troublesome in an emergency. Coolant pouring onto the lithium batteries might cause a short circuit, which could cause the automobile to malfunction and perhaps be fatal. Additionally, a minimum diameter is required for the capillary tubes shown Figure 2 to guarantee a proper pressure drop and avoid clogging [4].

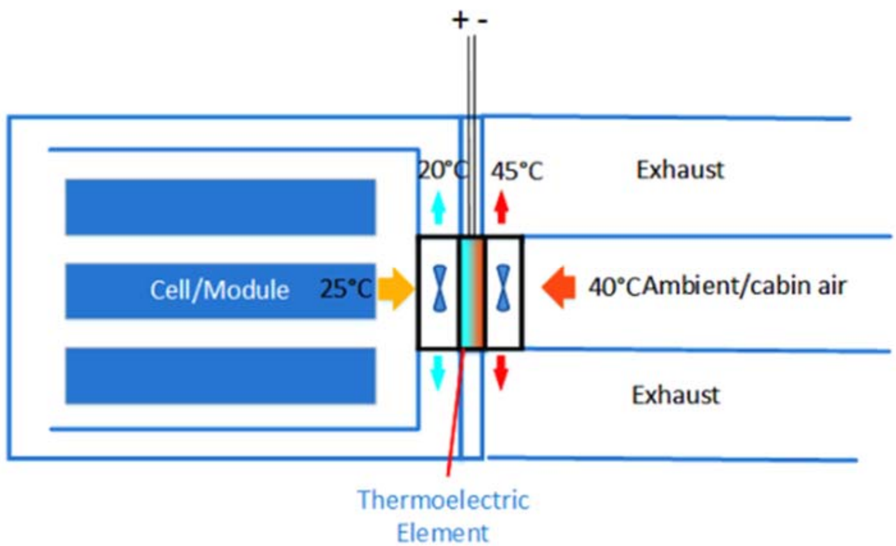

Figure 2: Illustrates the thermoelectric cooling/heating system.

Phase Change Material (PCM)

If a material undergoes a phase transition and releases or absorbs sufficient energy to provide useable heat or cooling, it is said to be a phase change substance. The first two fundamental states of matter, solid and liquid, are often where the transformation takes place. There are several types of phase transition materials [5]. Paraffin waxes are one of the most used PCM for electronics temperature control because they have a high fusion heat per unit weight, a wide melting point range, dependable cycling, a non-corrosive feature, and are chemically inert. Due of the volume transition from solid to liquid, designing with paraffin PCM demands careful void management. Due of the low heat conductivity of paraffin PCMs, sufficient conduction channels are another critical design consideration. There are other types of paraffin wax, including RUBITHERM (RT), which would be made entirely of PCM and leverages the melting and congealing processes to store and release enormous quantities of thermal energy at a relatively constant temperature. The RUBITHERM phase change materials (PCMs) offer such a highly effective approach to store heat and cold even in the presence of tiny volumes and slight temperature variations. Despite the fact that paraffin RT42 were shown to be better in all operating conditions [6].

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CHAPTER 12

EXISTING BATTERY THERMAL MANAGEMENT SYSTEM

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The liquid cooling system, which offers a small design and good cooling performance, is indeed the most often used BTMS. Water is the most often utilized coolant for liquid cooling systems because it is readily available and inexpensive, however the potential for an electric short in this system is a major issue. In order to get around this, several major producers of electric cars employ indirect cooling systems. In addition, the development of the physical design of a cooling plate as well as its channels has always been a focus of the liquid-cooled system. By focusing on characteristics such coolant pressure drop as well as cell core temperature, we may obtain the optimal design for a liquid cooling system [1].

Heat Pipe Battery Thermal Management System

Due to customer expectations, the vehicle's driving range must be expanded, which forces the battery's size to rise and, in turn, makes the battery's creation of heat a severe problem, making a great BTMS a fundamental need. An effective BTMS must be able to operate safely and heavily in the available area within the vehicle, and it has to be able to deliver the required heat transfer in addition to being able to be produced affordably. Due to its excellent temperature uniformity, portable size, and light weight, the heat pipe cooling system will show to be the ideal option for our issue under these conditions [2]. Along with having a history of use in the electrical sector, it also boasts exceptional cooling performance. Since there are no moving elements in this system, the heat transmission rate for just a heat pipe is greater than that of a solid metal rod with the same size. Because it is a passive system that does not draw any power from the battery, a well-designed heat pipe air conditioning system may guarantee great thermal performance regardless of the direction of the heat pipes. As a result, the battery's total efficiency is unaffected. The majority of the structural and operational requirements for a heat pipe cooling system may also be satisfied by developing the flow characteristics of the wick, including such pore size, porosity, penetrability, working fluid's type, as well as charging ratio, along with the assembly process, including such coating process, tying or locking technology, and integration principle [3].

The heat pipe BTMS is composed of three fundamental components:

Heat extraction unit

Its purpose is to offer thermal management at the level of the cell, and it is made up of heat pipe cooling plates that keep the temperature consistent inside the cells and transport heat from of the cells to an exterior plate.

Heat transmission unit

It is utilized to move heat away from the battery, and heat pipes are employed to transfer heat from of the exterior plate to a liquid cooling system that is placed far away.

Heat dissipation unit

In order to move heat away from the batteries and the system's electronics to the antifreeze of the heat pipes, which subsequently transmits heat to the radiator, it is utilized to offer thermal control throughout the whole set of cold plates.

Thermal Modelling of cooling system

Li-ion batteries undergo a chemical process that produces heat. This heat is transferred from the Li-ion batteries to the heat pipe cooling plate using coolant, which acts as a conduit for the heat transfer. Following the contact plate, where it is coupled with the heat from the cooling plate, this heat is conveyed to the distant heat transfer heat pipes using heat pipes. The heat is then remotely transferred by heat pipes towards the second contact plate, which is subsequently coupled with the liquid-cooled cold panels. By forcing cooling water via tiny channels, cold plates convey heat. Due to its great thermal qualities and high heat transfer efficiency, water is mostly employed as a coolant. The three forms of thermal resistance that make up the net thermal resistance of a heat pipe-based BTMS are contact resistance, heat pipe resistance, as well as the forced convection resistance of the cold plates.

Comparison of existing v/s proposed battery thermal management system

The current BTMS dissipates heat using a liquid cool plate that is mounted to the bottom of the cell. A mechanical pump to transfer liquid through the cooling loop, eight cold plates linked in series, and a remotely situated radiator to dissipate heat from the refrigerant make up the system's overall cooling system [4]. This active system draws energy from the batteries to remove heat from the coolant, which lowers the battery pack's overall efficiency and performance. The heat pipe cooling system that is being suggested would prove to be the greatest answer for our issue because of its high temperature uniformity, portability, light weight, and excellent cooling performance. It has also been used in the electronics sector in the past. Given that there are no moving elements in this system, the heat transmission rate for just a heat pipe is greater than that of a solid metal rod with the same size. The thermal performance may be guaranteed to be at a high level and irrespective of the orientation of a heat pipes in a well-designed heat pipe cooling system. By examining the design, structure, and kinds of materials utilized in the battery's construction, it is possible to improve the electrode's design and the battery's capability [5]. The electrode is the site of the chemical reaction, and by lowering the internal resistance of an electrodes, it is possible to reduce the amount of heat produced, hence extending the useful life and capacity of the cell.

According to their research, decreasing the size of the electrodes increases efficiency, but there is a limit to how much smaller the electrodes can be before the battery can no longer supply the required amount of energy. There are additionally additional tradeoffs with thinner material sizes, such as an increase in manufacturing costs. The overall design of a complete system might incorporate electrode size as a significant design aspect. It is feasible to optimize the transit distances or route of the ions' trip during the construction of the electrodes, which would increase their overall conductivity and thermal properties. The major objective of the BTMS is to control the battery's cell temperature in order to prolong the battery's life. Active systems and passive technologies are the two primary categories of BTMS. The active system primarily relies on the forced circulation of the particular coolant, such air or water [6]. A passive system enhances the vehicle's net efficiency by using techniques like heat pipes, hydrogels, and phase transition materials to always have zero power usage. In this essay, a thorough analysis of BTMS is reviewed from the literature that is currently accessible, and research for future advancement is emphasized.

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CHAPTER 13

COMPUTATIONAL FLUID DYNAMICS

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It is a branch of fluid mechanics that use numerical analysis and data structures to identify and address problems with fluid flows. Computers are used to do the calculations required to simulate the fluid's free-stream flow and interactions with surfaces restricted by boundary constraints (both for liquids and gases). Computer software, applied mathematics, and mathematics are utilized to illustrate how a liquid or gas travels and how it affects objects as it passes by. Computational fluid dynamics is based on the Navier-Stokes equations. A few of the research and development issues to which CFD is applied include aerodynamic efficiency and aerospace assessment, hypersonic, temperature simulation, basic sciences and environmental monitoring, manufacturing system evaluation and design, biochemical engineering, fluid flows in addition to heat exchange, engine and combustion assessment, as well as visual effects for video games and movies. The three fundamental phases of CFD analysis are shown in Figure 1: pre-processing, treatment, and post-processing [1].

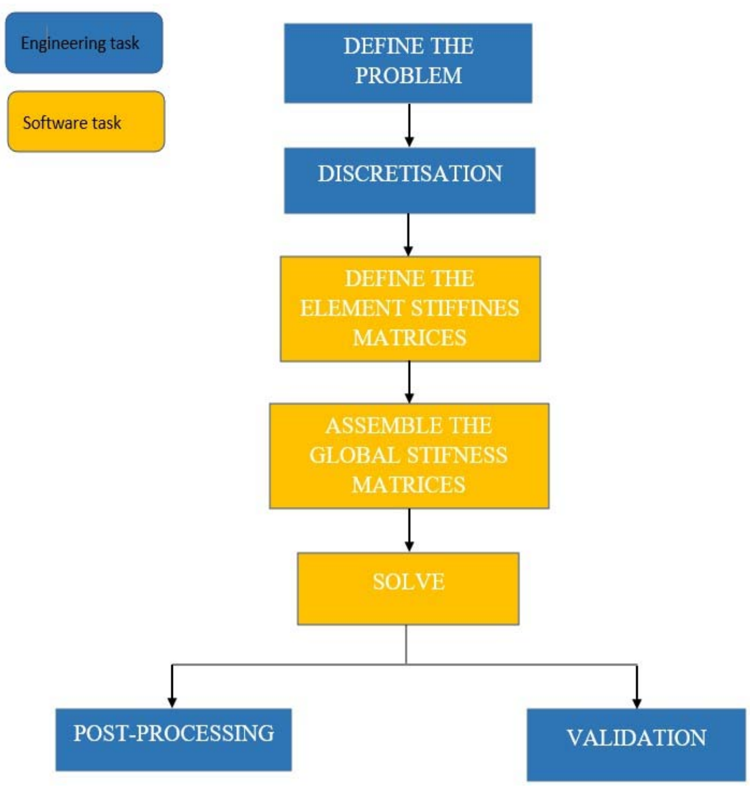

Figure 1: Illustrates the flow chart of Computational fluid dynamics.

Computational fluid dynamics (CFD) employs applied mathematics, physics, and computer software to simulate the motion and effects of a gas or liquid. Computational fluid dynamics is based on the Navier-Stokes equations. The connection between a flowing fluid's velocity, pressure, temperatures, and density is described by those equations. Many people are familiar with computational fluid dynamics, which has been used to assess air flow around cars and aircraft since the early 20th century. The complexity of the server room cooling design has led to the development of CFD as a useful tool for evaluating thermal properties and modeling air flow in the data center [2]. When utilizing CFD software, the size, make-up, and layout of the data center must be understood. It uses this information to create a grid-based 3D mathematical model that can be rotated and seen from different angles. Using CFD modeling to discover heated spots will allow an administrator to identify any locations where cool air is being wasted or mixed. By simply changing variables, the administrator can observe how cold air will flow through the data center under different scenarios. The administrator may use this data to forecast the effectiveness of a certain IT equipment configuration and maximize the effectiveness of the current conditioning infrastructure. For example, if the administrator wanted to split the hard drives from one storage rack into two racks, a CFD program might model the adjustment and help the administrator evaluate what modifications would be required to handle the greater heat load before another time or money was committed [3].

When an engineer is tasked with developing a new product, for instance a championship-winning racing vehicle for the next season, aerodynamics is a crucial part of the engineering process. At the concept stage, it might be challenging to quantify aerodynamic processes. The engineer can often only physically test product prototypes to fine-tune his ideas. Due to the advancement of computers and their ever-increasing computational power (thanks to Moore's law!), computational fluid dynamics has evolved into a commonly utilized technique for creating solutions for fluid flows with or without solid contact. The physical properties of fluid flow, such as velocity, pressure, temperature, density, and viscosity, are examined in a CFD software research. In order to actually design an accurate solution for a physical phenomenon associated to fluid flow, those characteristics must be taken into consideration simultaneously [4].

Ansys software

For the numerical study of a battery thermal management system, we used the Ansys Fluent 2022R1 student edition program. The corporate headquarters of the American company Ansys, Inc. It produces and markets CAE/Multiphysics engineering computer simulations, and it offers its products and services to customers all over the world. Ansys develops and markets software for engineering simulation that may be used across the whole product life cycle. Ansys Using mechanical finite element modeling software, the strength, durability, elasticity, temperature field, electromagnetic, fluid flow, and other properties of computer models of constructions, semiconductors, or machine components are studied [5]. Ansys is used to assess how a product might function under certain circumstances without developing test products or performing crash testing. For instance, Ansys software may simulate how a bridge will hold up over time, the most effective method to can fish to save waste, or how to build a slide that uses less material without sacrificing safety. The bulk of Ansys simulations utilize the Ansys Workbench system, one of the company's flagship products. Ansys users often break larger structures into smaller pieces, with each being modeled and tested individually. Prior to adding weight, pressure, temperature, or any other physical properties, an object's dimensions may well be determined. By modeling and examining these events, the Ansys software also assesses effects over time including movement, wear and tear, fracture, fluid flow, temperature distribution, electromagnetic efficiency, and others [6].

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