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Solar Heat Storage Technologies: Advancements and Integration in Renewable Energy Systems

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Abstract - *The project provides various data regarding solar heat storage technologies advancements and integration in sustainable energy systems. Based on the data researcher has been providing the various section which is containing the different parts of the project. Here researcher describes the methods, and in the method, the researcher has been describing their chosen methodology. Hence here also other data clearly describe which is helping efficiently describe the entire project. Effective interpretation of the result helps in understanding the basic concept along with detailed optimizing factors.*

Key Words: Storage tank, port, MATLAB, simulation, heat storage, temperature, node, ambient temperature, charging, discharging.

1.INTRODUCTION

1.1. Background

Implementation of solar heat storage technology entirely depends on the generation of energy whenever required without any fossil fuel integration. Such technology is responsible for generating the required energy without generating any harmful emissions aiming at the sustainability measurement in the environment. Sensible ***heat storage*** is responsible for storing ***thermal energy*** within a storage medium with temperature increment without integration of any phase transformation. Implementation of such a system involves providing a renewable source of energy for different purposes such as electricity. Most of the advanced technologies are used in different sectors where a huge amount of heat energy is required. Therefore, the study has aimed to obtain an extensive overview of the related factors and understanding of such technology.

1.2. Problem Statement

The most recent problem related to energy consumption is the utilization of fossil fuel in huge amounts that causes environmental pollution with the emission of several harmful gases. Thermal energy obtained from the sun can be stored as both ***latent heat***, ***thermo chemical heat,*** and ***sensible heat***. Such consideration is necessary for the exact utilization of the thermal energy and storage method. Hence, the paper is solely involved in implementing a method that stores solar energy as thermal energy in different weather conditions.

1.3. Aim and Objectives

Aim

The main aim of this report is the implementation of a thermal storage tank, ***Multiport store model*** which will provide an optimized outcome.

Objectives

Attainment of this determined aim different objectives have been constructed as followed:

- To evaluate the significance of a heat storage model.
- To simulate the model in both charging and discharging modes in MATLAB.
- To obtain the outcome based on the double port model.
- To optimize the temperatures in each node of the model.

1.4. Research Questions

The following structured questions are relevant to the entire research and model implementation process.

- What is the significance of solar heat storage technologies?
- How to simulate the model in both charging and discharging models using MATLAB?
- What are the procedures to implement a double port heat storage model?
- How to optimize the temperature from the nodes of the model?

1.5. Rationale

The implementation of the heat storage model is significant in its purpose as it involves optimizing the temperature in

different weather conditions and other relevant factors. Such a study is significant in providing an important means of heat energy transfer with renewable electricity production sectors.

1.6. Summary

The entire study has aimed to be structured based on the implementation of an effective thermal heat storage system for extensive renewable resources. Effective implementation of the objectives is significant for the study and simulation optimization of the ***MATLAB*** works. Evaluation and justification of the research will be performed based on the structured research questions. Each of the questions has been structured based on the basic concept optimization and final result optimization of the model that will be implemented to store solar energy as the form of heat energy. Therefore, it can be implicated that the optimization of the process of heat storage and energy transfer will be effectively performed based on the determined requirements.

2. LITERATURE REVIEW

2.1 Introduction

The researcher has been providing data about solar heat storage technologies and also describing the data about their advancement and integration in renewable energy storage. Hence in this literature chapter researcher have to describe the various data which is essential for the research process. Here researcher has discussed the advancement of ***"solar heat storage"*** and importance of the ***"solar heat storage technologies***". It describes the various parts that are essential for the data and it also provides a summary of the project, and the literature gap. According to the data, this thermal storage process has been using various applications which are essential for various features and power capacity and also help to increase the power capacity for short-duration energy storage. Hence short-time energy storage process has been included with the reserve and response services.

The studies from [56- 72] Anand Patel et al. [73] HD Chaudhary et al. [74] Patel Anand et. al for solar air and water heater [75] Patel, Anand for solar cooker evaluate different kind of with different geometry condition of solar thermal storage to enhance the renewability and heat transfer enhancement. This all literature review helps in the current study solar heat storage advancements efficacy increment using Matlab software as tool for analysis.

2.2 Solar Thermal Energy and Industrial Process Heating

"Solar thermal energy" can be used for industrial process heating, which involves using heat to carry out various industrial processes such as drying, melting, sterilizing, and chemical reactions. Solar thermal systems capture and concentrate sunlight to produce increased-temperature heat, which can exist utilized instantly or sorted for later use [1]. Additional kinds of ***"solar systems"*** can be utilized for industrial process heating, including flare plate collectors, evacuated tube collectors, and concentrating solar power systems. These devices absorb sunlight and transform it into heat using various technologies. The most popular solar thermal system for heating industrial processes uses flat plate collectors. They are made up of a heat transfer fluid, an absorber plate, and a flat, rectangular box with a transparent lid [2].

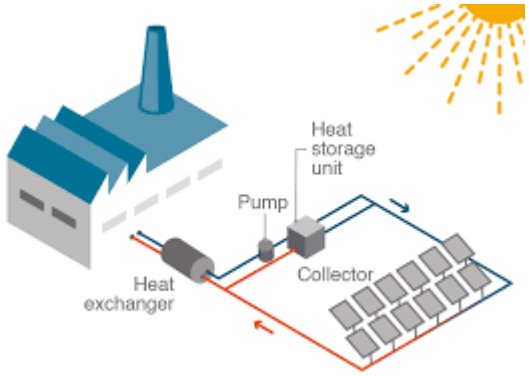

Figure 2.2.1: Solar Thermal Energy and Industrial Process Heating

Sunlight enters the transparent cover through the absorber plate, which heats up, transfers the heat to the fluid, and then exits through the transparent cover into the surrounding space. After that, the heated fluid can be utilized immediately to heat industrial processes or it can be stored for later use. Although they have a different construction, evacuate tube collectors are comparable to flat plate collectors [3]. They are created up of several ***glass tubes***, each with an absorber plate and a heat transmission device. The tubes' internal vacuum reduces heat loss and boosts effectiveness. Since evacuated tube collectors can reach higher temperatures and are more effective than flat plate collectors, they are appropriate for several industrial processes that call for high-temperature heat. ***"Concentrating solar power"*** systems are another type of solar thermal system that can be used for industrial process heating. These systems are usage mirrors or lenses to consolidate daylight onto a receiver, which soaks the concentrated sunlight and transforms it into warmth. CSP systems can achieve very high temperatures and are often used for large-scale industrial applications [4].

2.3 Future of *Solar Heat Storage Technologies*

The future of ***"solar heat storage"*** technologies exists promising, as the world continues to transition towards renewable energy sources. Here are some potential advancements and trends that could shape the future of solar heat storage:

1. Advanced material:

An investigator has been researching contemporary fabrics with increased warmth warehouse capabilities like ***"Phase change materials"*** and refined ceramics. These fabrics could hold and discharge warmth additional efficiently, enhancing the general routine of solar warmth repository [5].

2. Thermal energy storage:

"***TES***" methods are achieving vogue as they qualify for the repository of surplus heat caused by ***"solar thermal collectors"***. ***TES*** methods can utilize that for a comprehensive course, permitting it to exist operated during overcast days or in darkness when solar exuberance production is descending. Progress in ***TES*** technology, like the usage of ***"molten salts"*** or elevated-temperature liquids, could greatly improve the efficiency and degree of ***"solar heat storage"*** [6].

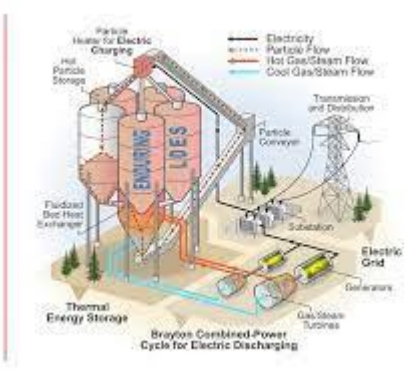

Figure 2.3.1: Thermal energy storage technology

3. Integration of other renewable energy technologies:

"Solar heat storage" can be combined with different renewable vitality technologies like robust ***"solar power or geothermal energy"***. This integration authorizes a more varied and dependable renewable exuberance mix as extra warmth from ***"solar collectors"*** can exist operated to develop electricity or supply heating in a mixture with different renewable embryones [7].

4. Grid integration and demand response:

Solar heat storage systems can be connected to the electrical grid, enabling the stored heat to be used for space heating, water heating, or other applications when the demand is high. This grid integration can help balance e energy supply and demand, marking sook, ar heat storage a valuable asset for grid operators [8].

5. Decentralization ad off-grid applications:

Solar heat technologies can be particularly useful in off-grid remote areas where access to electricity is limited. Using the storing excess heat during sunny times, these systems can provide a reliable and sustainable source of heat for cooking, heating, or other thermal applications [9].

2.4 The cost-effectiveness of Solar heat Storage Technologies

The cost-effectiveness of ***"solar heat storage technologies"*** can differ relying on several elements, including the initial investment cost, the efficiency of the technology, and the local energy prices [10].

1. Initial investment cost:

The upfront cost of installing solar heat storage technologies can be relatively high. This includes the cost of solar panels, heat storage systems, and any additional equipment required. However, the cost has been decreasing over the years due to technological advancements and economies of scale [11].

Figure 2.4.1: Storage features

2. Efficiency:

The efficiency of solar heat storage technologies determines how much energy can be stored and utilized. A higher efficiency system can store and release more heat resulting in better cost-effectiveness. efficiency improvements can make the technology more economically viable by reducing the amount of solar panels and storage capacity required [12].

2.5 Advantages and Disadvantages of Solar Heat Storage Technologies

Advantages of the "Solar Heat Storage Technologies"

1. Renewable energy source:

Solar heat storage technologies utilize the sun's energy, which is a renewable resource, this reduces dependence on fossil fuels and contributes to a cleaner and greener environment [13].

2. Cost-effective:

Once installed, solar heat systems have low operating costs as they rely on free solar energy, which can lead to significant savings on energy bills in the long run [14].

Figure 2.5.1: Advantage of Solar energy storage

3. Energy independence:

Solar heat storage systems allow individuals and business to generate their energy, reducing dependence on the grid ad providing energy security [15].

4. Reduce carbon emissions:

Solar heat storage systems deliver uncluttered energy and accomplish not radiate conservatory gases, assisting to relieve ***"carbon emissions"*** and ***"combat climate change"*** [16].

Disadvantages of Solar Heat Storage Technologies

1. Initial cost:

The upfront cost of installing a solar heat storage system can be relatively high, including the cost of solar panels, storage tanks, and installation, this can be a barrier for some businesses [18].

2. Weather dependents:

Solar heat storage systems rely upon sunlight to generate energy, therefore, their performance is affected by weather conditions, like cloudy days or reduced sunlight during winter months [22].

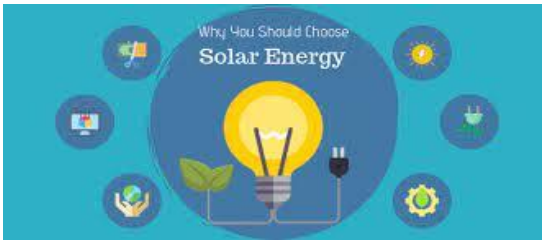

Figure 2.5.2: Disadvantages of solar energy

3. Space requirements:

"Solar panels" require a noteworthy amount of margin for building specifically as a large amount of energy needs to be generated [19]. This might limit their feasibility in urban areas or places with limited available space.

2.6 Classification Of *Solar Energy Storage Technologies*

Solar energy storage technologies can be classified into multiple categories based on the type of storage medium or technology used. Here are some common classifications:

1. Battery storage:

This includes various types of batteries like ***"Lithium-ion", "Lead-acid", "flow batteries", and "sodium-ion batteries"***. These batteries accumulate extra solar power during the day for service during times of low or no daylight [23].

2. Thermal storage:

This category includes technologies that store ***"solar energy"*** in the form of heat, some instances are ***"molten salt storage"***, which stores heat in salts, and phase change materials, which absorb and release heat during phase transitions [20].

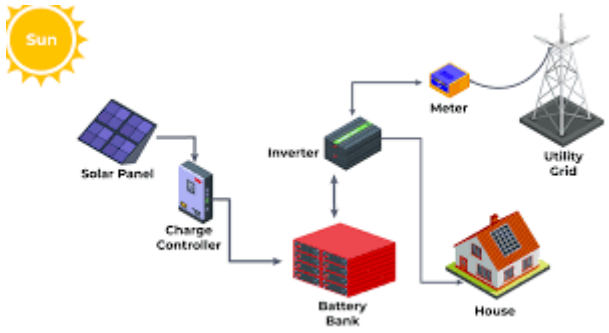

Figure 2.6.1: Different types of Solar energy technologies

3. Pumped Hydro Storage:

This method has been involving using excess solar energy can then pump water from a lower waterhole to a more elevated waterhole. The accumulated energy can then exist removed by allowing the water to flow back down through turbines to make electricity [21].

2.7 Linkage to Objective

The researcher has collected various data which is essential for the research purpose, term ***"solar thermal energy"*** refers to the use of heat for industrial process heating, which includes carrying out processes like drying, melting, sterilizing, and chemical reactions. Sunlight is captured and

concentrated by solar thermal systems to provide high-temperature heat that can be used right away or stored for later use. Solar systems of many kinds, such as concentrating solar power systems, evacuated tube collectors, and flare plate collectors, can be used to heat industrial processes. These gadgets use a variety of technologies to absorb sunlight and convert it to heat. Flat plate collectors are the most widely used solar thermal technology for heating industrial processes. They consist of an absorber plate, a heat transfer fluid, and a flat, rectangular box with a clear cover.

2.8 Literature Gap

The researcher has been providing various data which is essential for understanding the topic of the project. Thus, lack of time, resources, the team works, there are some research gaps are provided. Hence researchers are also not providing the various crucial information which is essential and those help future research [24].

2.9 Summary

According to the data, the researcher has been providing the proper data regarding the ***"Solar heat storage technologies*** "and their advancement and integration for sustainable energies. Based on that, the researcher has been describing the various crucial data which is essential for implantations. Hence, here researcher has been using ***"MATLAB"*** to design a solar energy storage system. After that researcher has also described the objective of their project and the gap in the research process.

3. METHODOLOGY

3.1. Research Philosophy

"Research philosophy" is a group of actual thoughts that handle the layout and implementation of various research analyses, and perspectives suggest various forms of comprehending technical research. This is a very important part of the success of a project. A proper form of research philosophy can enhance the quality of a project to a great extent. The success of a project work depends on the various aspects and these aspects are greatly influenced by the exact form of ***research philosophy*** [26]. ***Positivism***, ***interpretive***, ***pragmatic***, and ***realism*** are four kinds of research philosophies that are observed in recent projects. ***Positivism*** is embedded in the assumption that learning can be acquired via factual observations and proportions. This type of research philosophy shows that the responses are found by analyzing and measuring the numerical data.

Figure 3.1.1: Research Philosophy

Interpretive is mainly a ***sociological*** process of study in which an activity generally is examined and established on the views, values, and standards of the society in which the process is done. ***Pragmatic research philosophy*** is all about the conceptions that are relevant only if it supports the activity. This procedure helps to generalize the information and also in validating and designing the data [27]. The ***realism*** technique depends on the view of the independence of the actuality from the human mind. This philosophy is mainly based on the belief in a scientific technique for the expansion of knowledge.

3.2. Research Design

"Research design" is the main structure of study procedures and approaches selected by a user to perform a project. The layout permits researchers to deepen the various study strategies appropriate for the subject and built analyses for accuracy. It is a very crucial part of ***Solar Heat Storage Technologies*** to get successful [28]. ***Descriptive***, ***experimental***, ***correlational***, ***diagnostic***, and ***explanatory*** research are the main types of design methods utilized in recent projects. A well-planned design of research assures that the methodologies match the relevant aims and objectives of the project. It also confirms the high-quality collection of data and the suitable kind of research analysis to respond to the queries with the help of authentic and trusted sources [29]. Proper design ensures the accuracy of the result and it also helps to draw appropriate decisions for the project.

3.3. Research Approach

The ***research approach*** is the method preferred by the student to gather, analyze, or solve information. It is generally a plan and technique that is made of the steps of widening assumptions to a thorough procedure of ***data collection*** and analysis [30]. Research problems are also being discussed here in this part for the betterment of the project. ***Inductive*** and ***deductive*** are the two kinds of research approaches there in recent studies. The ***inductive research approach*** is mainly a flexible procedure that enables the researcher to adjust the topics and approaches of the research based on the collected data [31]. Researchers have the freedom to learn new phenomena and concepts that

they do not think before. The deductive research approach is the kind of research approach in which researchers begins with a thesis and then tests it via ***data collection*** and observations [49]. The main benefit of this approach is the option to explain the way how the variables and concepts are connected to each other's cause and effect. It also enables the researcher to take data from two or more remarks and pull a logically rational decision. This is the reason why the ***deductive*** research approach is used here in this project of "***Solar Heat Storage Technologies Advancements and Integration in Renewable Energy Systems***".

3.4. Research Strategy

Research strategy brings the main and primary elements of the research project like research subject area and priority, research objectives, and research design and approaches. A proper form of research strategy helps to comprehend the project in a better way and in that way the result can be drawn with better numbers [32]. ***Solar Heat Storage Technologies*** are an important thing in reticent days and the proper research strategy need to be implemented to accomplish this job in an efficient manner. Everything requires to be planned properly for getting a better outcome. In a way, it is said that the proper form of strategy helps to save time to a great extent, and helps to rectify the errors and mistakes [33]. This is the reason behind choosing proper strategies for the research of this project.

3.5. Data Collection

"Data collection" signifies the accumulation of data or information related to the subject for better understanding and analysis of the project. It needs to be done in a systematic and ordered way that helps the researcher to respond to the different questions of the research and evaluate theories and results [48]. It is one of the most important parts of the project and a proper form of collection of data can enhance the quality of the project to a great extent. ***"Quantitative"***, ***"qualitative***, and ***"mixed"*** processes are the main types of ***data collection*** used in recent studies [34]. ***"Quantitative"*** collection of data or information defines the accumulation of numerical information that may be analyzed by operating ***statistical*** techniques. This kind of ***data collection*** is usually utilized in ***surveys***, experimentations, and various other methods of research [35]. ***"Qualitative"*** collection of data is the explanatory and conceptual discoveries gathered via discussions, questionnaires, or observation. Analyzing qualitative data enables users to analyze views and further demonstrate ***quantitative*** outcomes. ***Mixed*** methods of ***data collection*** are the combination of both processes "***quantitative***" and ***"qualitative"*** [36].

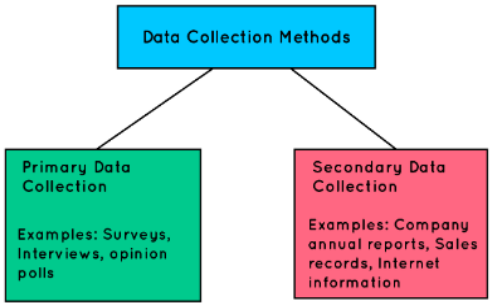

Figure 3.5.1: Data Collection Method

"Primary" and ***"secondary"*** are also two important parts of the data collection process. The ***primary*** method is the collection of data from actual sources [37]. The ***secondary*** collection method is the method in which data is collected from previously done journals, projects, books, interviews, and focus groups. Sources of ***secondary*** data are extremely easy to approach, low in cost, and time-saving to a great extent. This is the reason behind the selection of ***"secondary"*** and ***"qualitative"*** techniques for the betterment of the ***Solar Heat Storage Technologies*** project [38].

3.6. Tools and technologies

Various advanced tools and the latest technologies are used here in this project for better analysis of the data and output efficiency. "***Unglazed solar collectors***", "***Transpired solar air collectors***", "***Flat-plate solar collectors***", and "***Concentrating solar systems***" are the main types of technologies used in ***"solar thermal technologies"*** [39]. Elements like gravel, rubber, quartzite, and pebbles are even utilized to keep solar energy. "***Two-Tank Direct System***" is the process of how ***solar energy*** is stored in the storage [47]. ***MATLAB*** software is used here in the project for the analysis of the designs of ***solar energy storage technology***.

3.6 Feasibility

Matlab is used here in this project for the design and analysis of the system and it is very useful in the success of the project. It executes and experiments the algorithms in a very easy and effective way, creates the codes of the computation also very smoothly, and debug effortlessly [40]. ***MATLAB*** operates utilizing a bigger database of structured algorithms and processes images and develops ***simulation*** videos effectively. It also can call external libraries for the betterment of the design process. It can generate results with less error and better accuracy. This is the reason why ***MATLAB*** is chosen here in this project to guide this in a better direction.

4. RESULTS AND DISCUSSION

Three different methods of thermal energy storage are used to implement for different purposes [51]. In this paper sensible type of thermal energy storage has been implemented to obtain the optimized result of the temperature differences based on different measurements of the parameters. Sensible heat is involved in the measurement of the heat capacity of a particular material. This added ***thermal energy*** stored in that material results in an increased temperature [52]. The major configuration of this model is based on two-tank integration where the heat is measured. A similar storage material is used for the heat transfer process.

The simulation has been constructed by implementing a double port discharging and charging model of heat storage [53]. A constant power gas has been maintained to optimize the measurement of different factors that evaluates the significant outcomes. Several fixed inputs have been maintained adequately including the capacity of the tank in a litre, the height of the storage tank, and heat loss rates in the top, bottom, and zones. While the exchangers are not in use, the variables(HX) have been set to nan value [54]. The changes in the parameters of the ports have been optimized from the relative positions. The ambient temperature has been initiated at 15 C in the entire storage tank.

The heating temperature has been measured based on the different measurements of standby temperatures and durations. The first measurement of these variables has been structured as 30 KW per hour with a downtime of 1 hour. The first measurement of these variables has been structured as 20 KW in 4 hours with a downtime of 1 hour. The discharging process has been performed with 20 KW and 15 KW in 3.5 hours respectively for the different conditions. Effective implementation of the loops helps in optimizing the adequate measurement of the determined values of the temperature readings to optimize the system function [55]. The entire simulation has been effectively performed to justify the implementation of the model. It is the process of transferring heat from one system to another.

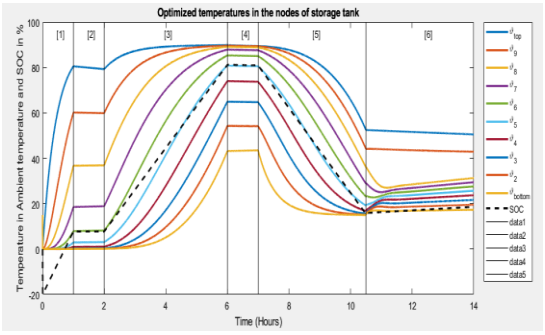

Figure 4.1: Optimized temperatures in the nodes of the storage tank

The figure is responsible for providing an overview of the charging and discharging states of the nodes (6 nodes) with proper differentiating the temperature in all the nodes. The dotted line resembles the SOC line of the model. All the heating measurements in both ports have been adequately evaluated through the graph. The time has been structured along the x-axis whereas the optimized temperatures of the ports have been structured along the y-axis. It has been effectively measured that the heat storage system is significant in its purpose and justified the simulation outcomes. Potential heat transfer records can be effectively observed through the graph that has been obtained from the simulation result of the implemented model.

5. FUTURE WORK

The initial expense of buying a ***solar system*** is comparatively high which is the reason why cost optimization needs to be done for better use in the upcoming days. Solar energy is mainly weather-dependent technology [41]. Solar can be still gathered at the time of rainy and cloudy days but it rewires some modifications. These modifications need to be done in an effective manner for the betterment of the entire system in the days to come [42]. There is also an issue regarding the limitations of the capacity. This is the reason why this capacity limitation needs to be addressed properly and assessed for upgradation. Maintenance of the system is also mandatory for efficient results and it needs to be done repeatedly for the discovery of errors and mistakes [43]. There are some risk factors associated with the process of implementation and also the entire process. These risk factors need to be assessed properly and require to be resolved in order to run the entire process in a smooth way for a longer time.

Future works are very important for the upgradation and betterment of the system. The system can be enhanced greatly if some things are changed or modified. Incentives require to be built by setting new influential policies, rules, and market tools that identify the importance of energy storage. Technical issues or challenges may be handled by improving the interoperability, integration, safety, standardization, and interpretation of energy storage procedures. Research and evolution can enhance the durability, efficiency, and recyclability of technologies of energy storage [44]. Implementation of these procedures can greatly improve the overall system in the days to come. Mandates and subsidies can also be set for the storage of energy integration or deployment. General norms and protocols must be embraced to promote the exchange of data or information between various devices. Testing, credentialing, and repeated monitoring processes must be implemented to provide the reliability and quality of the storage of solar energy [50]. These are the steps to be followed to make the system very much efficient in the future days.

6. CONCLUSION AND RECOMMENDATIONS

A project is done on the "***Solar Heat Storage Technologies Advancements and Integration in Renewable Energy Systems***" with the help of the ***MATLAB*** software platform. ***Solar energy*** has been used widely in recent times as a source of ***renewable*** energy. This is the reason why proper research is needed to analyze the data regarding the advancement and integration procedure. It has been observed in the research that ***solar energy*** has a crucial role in decreasing ***greenhouse gas*** discharge and mitigating weather change. The project has been done in an effective manner with the proper form of research approach, strategy, and philosophy. Data has been collected from ***secondary*** sources that are authentic and trusted for better analysis.

6.1 linkage to the objective

The main objective of this project is to evaluate the importance of the ***heat storage model***. This work has been achieved with high accuracy in this project. Another objective is to simulate the design model in charging and discharging models with the help of MATLAB software. This objective is also fulfilled properly with effective results. It is also required to obtain the result based on the ***double port model***. Optimization is also needed to be done with the temperatures in every node of the model. These two work is also done in a proper way to accomplish maximum success. There are some research questions that are also addressed properly and responded to with accurate results. The procedures are properly followed and explained for the betterment of the project.

6.2 Recommendations

Certain recommendations are done in the project for the betterment of the system in the current scenario. Cost optimization is a great factor that is required to be done in order to draw the customer's interest [45]. The importance of solar energy in the case of renewable energy sources is very high and to maintain this position some modifications are to be done. It has been suggested to monitor the entire system repeatedly to increase the efficiency and durability of the system. This can greatly improve the system and it will make the system more adaptable to the society. The roles and responsibilities of the experienced employees are high in this case. New and fresher employees need to be trained properly for the better implementation of ***solar energy storage technology*** [46]. The latest trends and patterns need to be observed properly in this scenario for a better understanding of the market. It is recommended to use the latest tools and technologies for better accuracy of the system output. Storage capacity is limited in the recent scenario and it is suggested to be assessed properly for the betterment of the system.

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