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Enhancement of MPPT of Grid Connected Solar System by using Model Predictive Controller (MPC)

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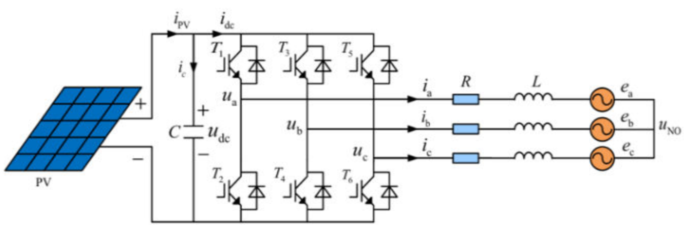
ABSTARCT*:* This paper takes a deep look at Maximum Power Point Tracking (MPPT) in solar photovoltaic (PV) systems using Model Predictive Control (MPC). As renewable energy sources like solar power grow, they need exact control methods to boost efficiency. MPPT techniques play a key role to get the most power from PV modules as conditions change. Our study examines how to use MPC as a control strategy for effective MPPT. This approach uses predictive algorithms to guess the system's response and choose the best control actions helping it find the maximum power point. We test the system's performance through simulations in MATLAB/Simulink showing how it's better at dynamic tracking and more reliable than older methods. We combine hardware parts like solar panels, buck converters, and microcontrollers to build the design. Our findings show that MPC can improve energy collection in solar PV systems, which could lead to better grid integration and long-term sustainability.

KEYWORDS: MPPT, Model Predictive Control, Photovoltaic System, Solar Energy, Buck Converter, MATLAB/Simulink.

I. INTRODUCTION

The world is shifting to sustainable energy, and solar photovoltaic (PV) systems are crucial in generating renewable power. These setups convert sunlight to electricity without emitting greenhouse gases providing a green solution to the expanding energy challenge [1]. Yet, the unpredictable nature of sunlight affected by things like temperature, shade, and weather changes, makes it hard to keep a steady power output. This unpredictability means we need smart control methods to make sure PV systems work well in all conditions [2].



Topological structure of grid-connected PV power generation system

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To tackle this issue, experts use Maximum Power Point Tracking (MPPT) algorithms. These algorithms keep tweaking how the PV array works helping it produce as much power as possible no matter what's happening outside [3]. People often use simple MPPT methods like Perturb and Observe (P&O) and Incremental Conductance (INC) because they're easy to set up and use [4]. But these methods have problems. They can be slow to react wobble around the best power point, and don't work as well when sunlight levels change or when parts of the system are in the shade [5].

Given these limitations, Model Predictive Control (MPC) has become a cutting-edge option for MPPT applications. MPC forecasts how a system will act in the future. It does this with a math model and fine-tunes control actions within a set time frame. This makes it a great fit for systems that aren't straight-line and change over time, like PV arrays [6]. This paper takes a deep dive into how to use MPC for MPPT in PV systems. We check if the proposed plan works through simulations in MATLAB/Simulink and then test it on real hardware. We also compare it to standard methods to show how MPC is better at tracking accuracy responding to changes, and overall system performance [7].

II. LITERATURE REVIEW

More and more people are looking at Model Predictive Control (MPC) for MPPT. They like it because it can predict what will happen, handle constraints, and work well in systems that change over time [8]. Unlike old-school MPPT techniques, MPC uses a dynamic model of the PV system to guess future outputs and make control actions as good as possible. This approach helps the system find the maximum power point faster and stand up better to changes in the environment [9].

Several researchers have demonstrated the superior tracking efficiency of MPC under rapidly fluctuating irradiance conditions. For instance, in [10], the authors applied MPC to a boost converter-based PV system and reported enhanced transient response and reduced power oscillation when compared to conventional P&O and INC algorithms. In another study [11], MPC was implemented with a constraint-aware optimization routine, enabling it to maintain stable operation even under partial shading. Furthermore, hardware-in-the-loop simulations confirmed the real-time feasibility of MPC for embedded MPPT applications.

Despite its advantages, MPC's adoption in practical PV systems remains relatively limited due to its computational complexity and the requirement of an accurate system model. Current research is focused on simplifying the control architecture and reducing processing overhead without compromising prediction accuracy [12]. Hybrid approaches, where MPC is combined with soft computing techniques such as fuzzy logic or reinforcement learning, have also been proposed to further enhance adaptability and reduce dependency on precise mathematical modeling [13][14]. These developments underscore the potential of MPC as a next-generation control strategy for efficient solar energy harvesting.

III. EXISTING SYSTEM

Engineers have used Traditional Maximum Power Point Tracking (MPPT) methods like Perturb and Observe (P&O) and Incremental Conductance (INC) to optimize how photovoltaic (PV) systems perform [15]. These methods work by tweaking the voltage or current to locate the maximum power point, but they often run into problems. They can be slow to adapt to changing weather and tend to wobble around the MPP when steady, which wastes energy [16]. Also when parts of the panels are in shade, these algorithms can get trapped at local high points missing out on the best overall power output [17].

To tackle these shortcomings, researchers have suggested several upgrades such as flexible step-size regulation and mixed approaches that blend fuzzy logic or neural networks. Although these improvements help a bit, they still react rather than predict, falling short of the foresight needed to and track maximum power under changing conditions [18]. This has pushed experts to look into Model Predictive Control (MPC). MPC offers better control by foreseeing future behavior and maximizing power extraction on the fly thus beating the drawbacks of standard methods [19].

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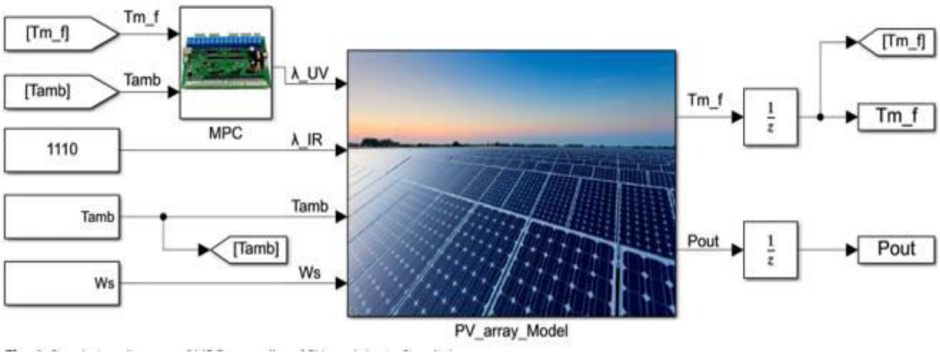
IV. PROPOSED SYSTEM

This paper suggests combining Model Predictive Control (MPC) with photovoltaic (PV) systems to boost energy collection and address the shortcomings of standard MPPT techniques. MPC stands out from usual methods by using a predictive model of the system to anticipate future behavior and optimize control actions making sure the PV system always runs at the maximum power point (MPP) [20]. The MPC approach we propose adjusts the duty cycle of a DC-DC converter on the fly, based on current irradiance and temperature data. This allows for quicker convergence and improved efficiency when conditions change. Figure 1 shows a diagram of the system's structure highlighting the main parts involved such as data input, processing, and output layers.



Simulation diagram of MPC controller of PV modules in Simulink

The system we're looking at uses a model of the PV array and converter that works in distinct time steps. This allows it to control things and handle limits, like those on voltage and current, to keep everything running and [21]. The controller at the heart of this system looks ahead to get the most power while staying within these limits. We've checked how well this works through computer simulations and by building it for real. It does a better job than older methods like P&O and INC. The system is better at following the best power point, keeps things more stable, and turns more of the sun's energy into electricity. This is true when parts of the panels are in shade or when the weather changes. If you look at Figure 1, you'll see how the whole system is set up, with a focus on how the controller connects to the PV system to adjust things as they happen [22].

V. HARDWARE IMPLEMENTATION

The hardware setup for the suggested Model Predictive Control (MPC) to track Maximum Power Point (MPP) in photovoltaic (PV) systems combines essential parts like the solar panel, DC-DC boost converter, and microcontroller to optimize power and control in real time. We designed the system to match the simulation model, which ensures it works and in real-life situations. We picked a microcontroller (such as Arduino or Raspberry Pi) because it can process data well and easily connects with the needed sensors. Figure 1 presents a detailed block diagram of the hardware setup showing the parts and how they connect.

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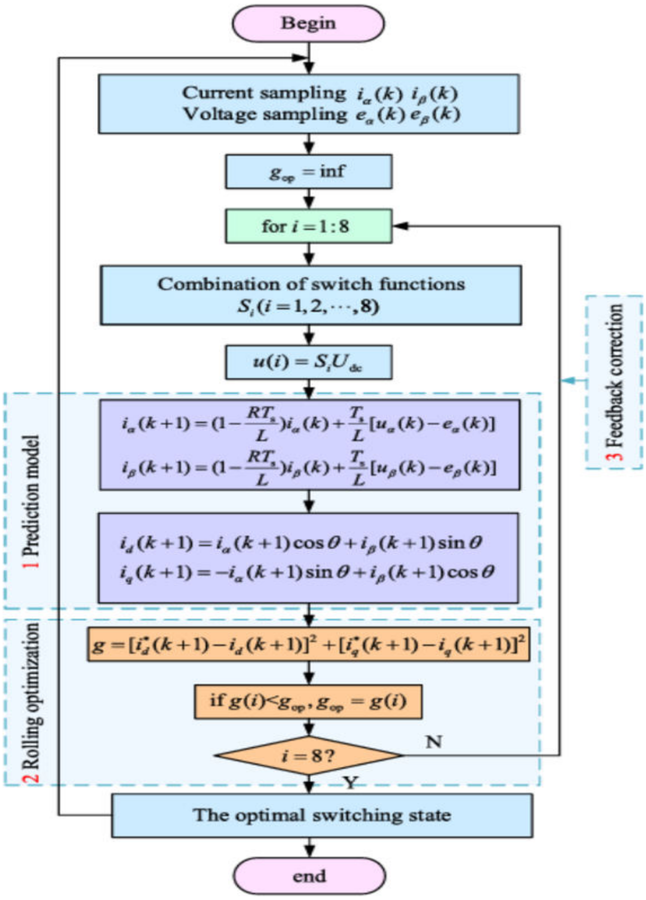


Algorithm flow of FCS-MPCC

5.1 PV Module

The PV module provides power to the system. It has sensors that measure key factors such as voltage, current, and irradiance. These factors are essential for the MPC algorithm to improve how well the PV system works. These measurements offer up-to-the-minute data to find the maximum power point.

5.2 DC-DC Boost Converter

The DC-DC boost converter controls the PV module's output voltage changing it to the level the load needs. The converter tweaks its duty cycle based on signals from the MPC controller. This ensures the system runs at peak power.

5.3 Current and Voltage Sensors

Current and voltage sensors have the job to measure the output voltage and current of the PV panel as it happens. These sensors give key information for the MPC algorithm to always change the duty cycle of the boost converter. This makes sure the system works at the best power point all the time.

5.4 Temperature and Irradiance Sensors

Temperature and irradiance sensors track environmental conditions such as air temperature and sunlight intensity, that influence the power output of the PV system. These sensors transmit current environmental data to the MPC controller. This enables it to adjust system operations based on external factors.

5.5 Microcontroller (e.g., Arduino or Raspberry Pi)

The microcontroller (like Arduino or Raspberry Pi) processes input data from various sensors and runs the MPC algorithm. It calculates the optimal duty cycle for the DC-DC boost converter ensuring the PV system operates at its maximum power point. The microcontroller also maintains system stability and safety by updating its control actions. The whole system fits in a small modular package, so it's easy to set up and use in real time. Adding MPC to the mix helps the system keep getting the most power possible from the PV setup showing how well it works in real-life situations.

VI.SOFTWARE IMPLEMENTATION

The software setup for the suggested Model Predictive Control (MPC) to track Maximum Power Point (MPP) in PV systems has an impact on creating the control algorithm connecting it to the hardware, and making sure data flows smoothly between system parts. Someone writes the MPC algorithm in Python (or another good programming language) and runs it on a microcontroller like Arduino or Raspberry Pi. This microcontroller handles real-time data from sensors and tweaks how the DC-DC boost converter works.

6.1 Sensor Data Acquisition

The software implementation kicks off by grabbing data from the current, voltage, and irradiance sensors. This data acts as the input for the MPC controller giving it the essential info to evaluate the PV system's real-time condition. On top of that, temperature sensors are added to factor in environmental elements that impact PV performance.

6.2 Data Processing and Prediction

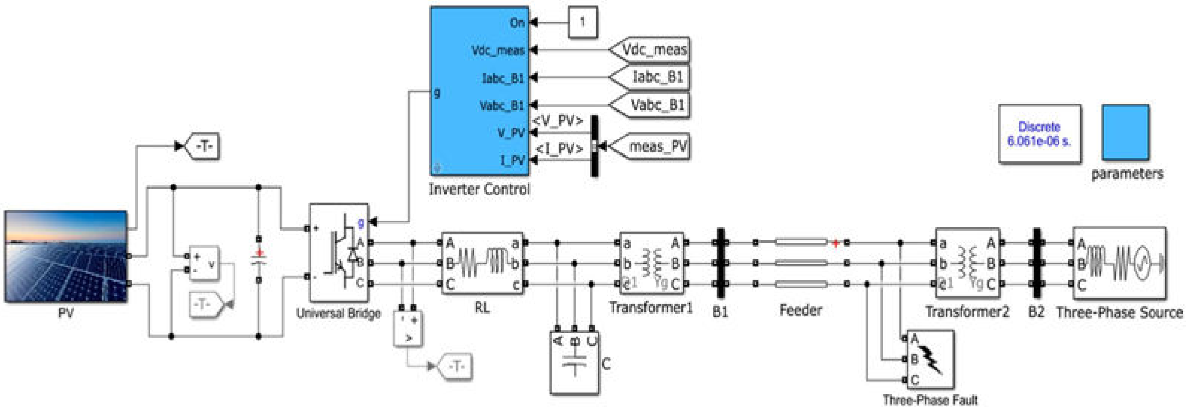
After the sensor data is collected, the MPC controller employs a state-space model to forecast how the PV system will behave in the future. The model processes the information to predict potential output changes and figure out the best control actions. This enables the system to expect shifts in environmental conditions and adjust how it works. The algorithm's ability to predict ensures that the system always runs at the maximum power point (MPP) even when irradiance and temperature vary.

6.3 Control Algorithm Execution

The software puts into action the MPC control algorithm, which figures out the best duty cycle for the DC-DC boost converter by looking at how the system might behave. The duty cycle gets updated as it happens making sure the system works at its peak efficiency. This feedback loop helps to keep energy loss low and keeps the PV system running at its best all the time.

6.4 System Efficiency and Performance The software has a modular and scalable design, which allows for future upgrades and tweaks. The system puts a high priority on productivity working with minimal delays in the control loop to ensure it performs in real-time. Using cutting-edge methods like recursive feature elimination and data normalization makes the system strong and reliable even when operating conditions change. By keeping high productivity and low delays, the system works at its best for MPPT in many different settings.

VII. SIMULATION RESULTS

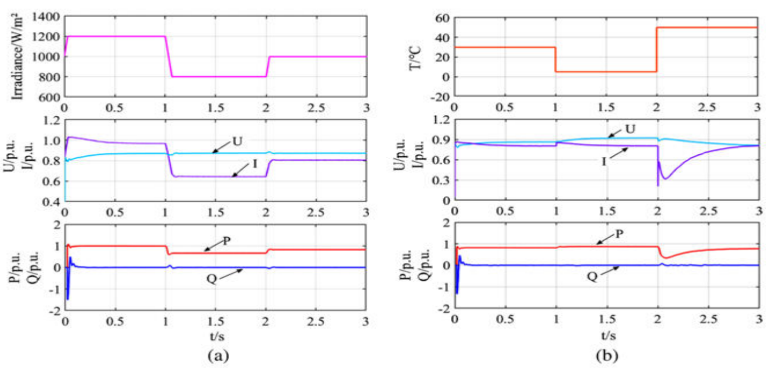


Simulation model of a grid-connected PV power generation system

We tested how well the model predictive control (mpc) method works for maximum power point tracking (mppt) in pv systems. Our team ran simulations in MATLAB/Simulink. We created a pv array model under normal light and heat conditions. Then, we checked the mpc controller's performance in various scenarios such as changes in sunlight and power use. We developed the mpc control algorithm and added it to the system using discrete-time prediction models. To put the control logic into action, we used Simulink's built-in MATLAB function block.

7.1 PV Array Modeling

The simulation kicked off by creating a model of the **PV array**. This model used key figures like **open-circuit voltage (Voc) short-circuit current (Isc),** and how temperature affects these values. These numbers helped simulate how much power the array would produce in different weather conditions. Getting the PV array model right is crucial. It makes sure the **MPC algorithm** works by mimicking how real-world PV systems behave.



Response Curves of PV arrays output during external conditions changes

(a) PV arrays output during sudden change of irradiance
(b) PV arrays output during sudden change of temperature

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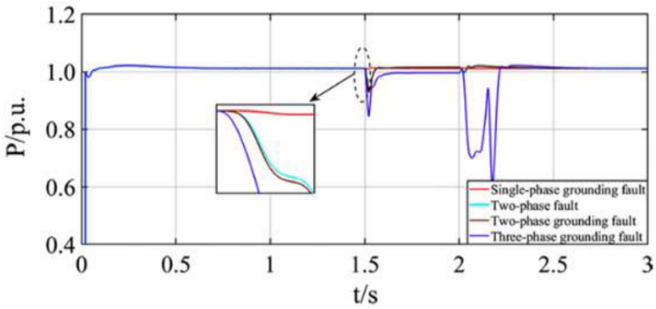
7.2 Converter Design

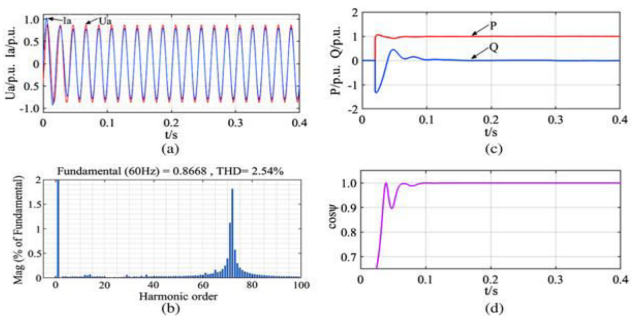
A team built a **DC-DC converter** in **Simulink**. They picked the right **inductors** and **capacitors** to keep output voltage ripples low. The design met system needs and aimed to boost efficiency while cutting down on voltage swings. The team tested how well the converter worked with different loads to see how it handled quick changes.

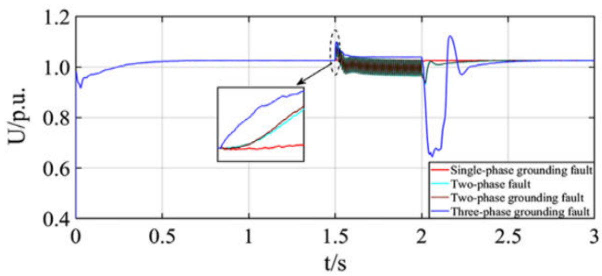


Comparison of active powers grid under different faults

7.3 MPC Control Implementation

The team incorporated the **MPC algorithm** into the setup, which improved the switching choices of the **DC-DC converter.** This algorithm forecasted how the PV system would act in the future and worked out the best control actions to boost efficiency and cut down on power waste. The control was set up to change with shifts in sunlight and heat making sure the system ran at its highest power point.





Comparison of voltages at PCC under different fault

A-phase waveforms of inverter with traditional feedforward decoupling PI control
under initial conditions

(a) PV arrays output during sudden change of irradiance

(b) PV arrays output during sudden change of temperature

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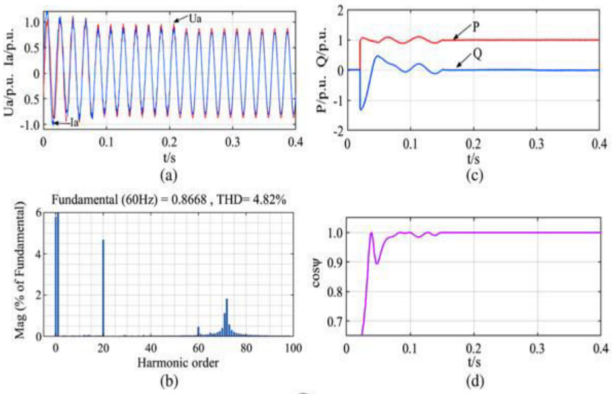
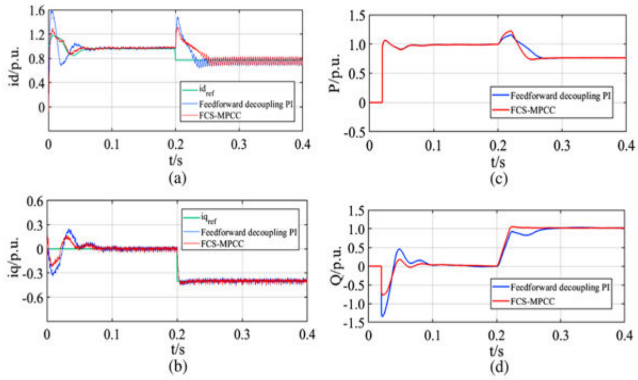
7.4 Performance Analysis

The simulation results revealed major improvements in how the system responded and how it worked. When compared to older MPPT techniques, the MPC-based setup tracked the maximum power point faster and more even when environmental conditions kept changing. The system showed better stability and took less time to track power proving the advantages of using MPC for MPPT in PV setups.





A-phase waveforms of inverter with FCS-MPCC under initial condition & Comparisons of waveforms with FCS-MPCC and traditional feedforward decoupling PI control after changing initial conditions

VIII. CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

This paper showed how to use Model Predictive Control (MPC) for Maximum Power Point Tracking (MPPT) in photovoltaic (PV) systems. The MPC method proved to work better to get the most power by always guessing and tweaking how the system runs. Tests showed that MPC can make things react faster, track quicker, and work better than the usual MPPT ways. Also when we built it for real, it worked well. The system could find the best power point and change when the weather did. These results prove that MPC is a good and useful way to control PV systems and make them work their best in real time.

8.2 Future Scope

Despite the successful implementation and validation of MPC for MPPT several areas still need exploration and improvement. Future research could aim to optimize the MPC algorithm to boost its computational efficiency allowing even quicker responses in real-time uses. Another area to develop could be to integrate MPC-based MPPT with energy storage systems like batteries, which would lead to more efficient energy management and ensure steady power supply when weather changes. Also, scaling up the system to handle bigger PV arrays or integrating it with multiple converters would give useful insights into how well the system scales and fits commercial uses. What's more hybrid control approaches that combine MPC with other methods like Fuzzy Logic or Artificial Neural Networks could offer more ways to handle complex non-linear behaviors in PV systems boosting overall energy conversion efficiency.

To wrap up, this study shows how MPC could be used for MPPT in photovoltaic systems. More research and fine-tuning will help the system handle real-world issues better and open doors for wider use of this tech in green energy.

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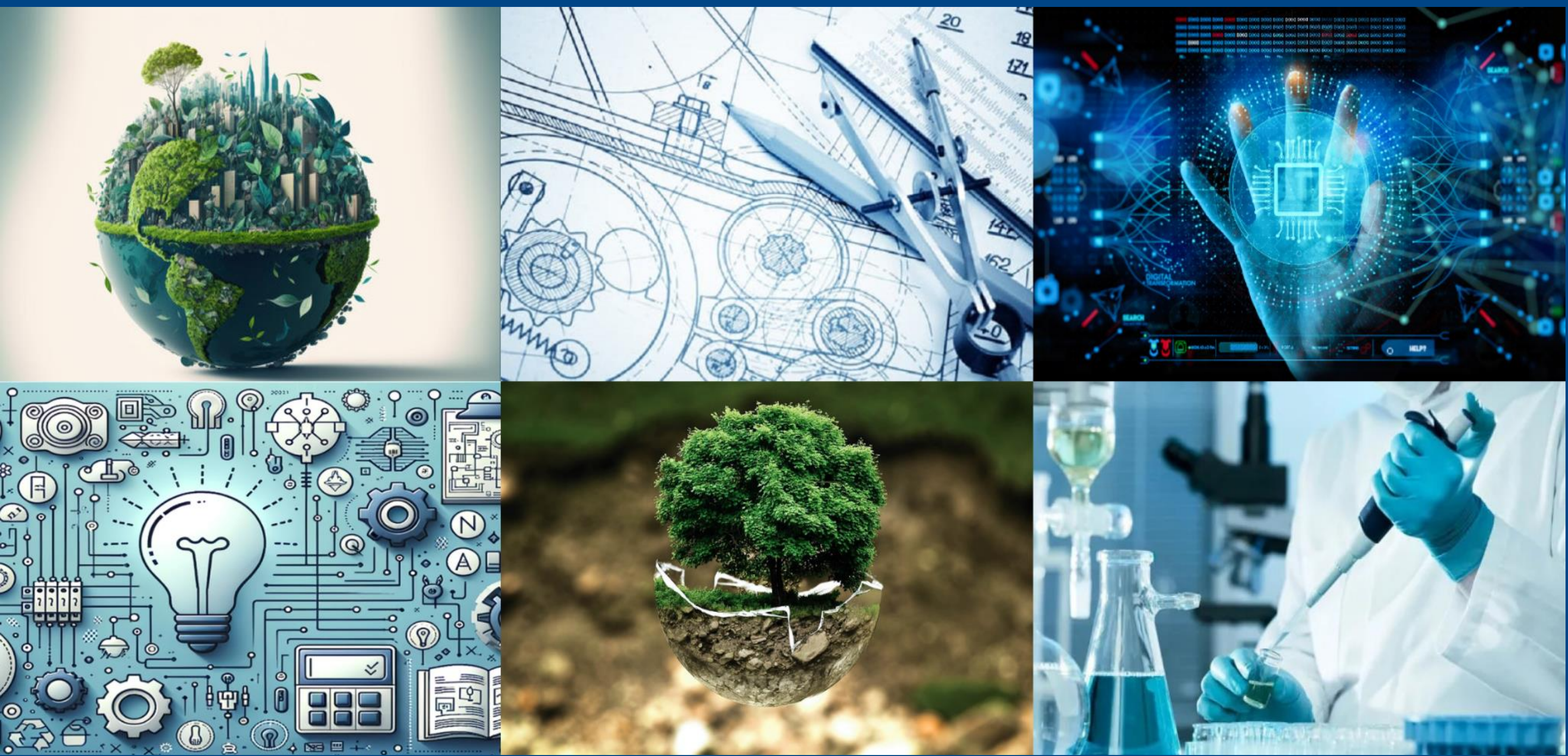

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