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SEPIC Converter Hybrid Energy Management

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ABSTRACT: This study focuses on validating an Intelligent Power Management System (IPMS) through simulations conducted in the HOMER environment, with particular emphasis on the integration of a SEPIC converter for enhanced performance. The IPMS is devised to efficiently handle fluctuations in power supply and demand, ensuring uninterrupted power delivery while maintaining high-quality power output. Renewable energy sources, including solar and wind, are harnessed by the IPMS, complemented by the utilization of battery storage and hydrogen fuel cells. This diversified energy portfolio enables the system to dynamically respond to varying load requirements, optimizing energy utilization and minimizing wastage. Through comprehensive simulations conducted under a spectrum of power supply and demand scenarios, the IPMS demonstrates its capability to consistently meet load demands without compromising power quality or supply stability. The incorporation of the SEPIC converter into the IPMS architecture plays a pivotal role in enhancing system performance and efficiency. By efficiently managing power flow and voltage regulation, the SEPIC converter facilitates seamless integration of diverse energy sources, mitigating the challenges associated with intermittency and variability inherent in renewable energy systems. The results of the simulations underscore the robustness and adaptability of the proposed IPMS, highlighting its efficacy in real-world applications within sustainable energy systems. The validation of the IPMS, coupled with the integration of the SEPIC converter, showcases a promising solution for addressing the complexities of modern power management, particularly in the context of renewable energy integration.

KEYWORDS: Intelligent Power Management System, Energy Management, Single-Ended Primary Inductor Converter

I. INTRODUCTION

1.1 HYBRID ENERGY SYSTEM (HES)

It will be good to start with hybrid energy system (HES). Hybrid energy system is the engineering design of hybridizing power supply components or pairing them, for example, arranging diverse energy resources to work in parallel (equivalent) is very common in power. So, hybridizing is defined as forming crossbreed of pairs of agent for working together to achieve a purpose. Thus, hybridizing is to manually or automatically synchronize two or more electric power generator resources or components to supply electric power to the grid, therefore forming hybrid energy system. Hybrid energy system is an infrastructural design that integrates diverse or multiple energy converters to energy storage, energy conditioners, energy management system. By and large hybrid renewable energy system (HRES) is an extension of HES that uses mix diverse resources as hybrid or all hybrid renewable energy resources to supply the electric power system.

1.2 WIND ENERGY AND PHOTOVOLTAIC SYSTEMS

A lot of studies are being done with divergent ideas and necessities on the possibility of integrating wind and PV system. The studies can be classified into, modeling, design, optimization, control and techno-economic strategies. On the other hand, some researchers proposed a stand-alone hybrid system, while others applied wind and PV system in grid connected mode.

1.2.1 MODELING AND DESIGN OF PV-WIND SYSTEM

A lot of modeling and design of the PV and Wind have been developed using different approaches. The design can be categorized into two, it can be a grid or stand-alone. A grid PV-Wind system uses Wind generator, wind side converter, DC-DC converter, and grid interface inverter. The MPPT is used to optimize the DC voltage coming from the solar panels.

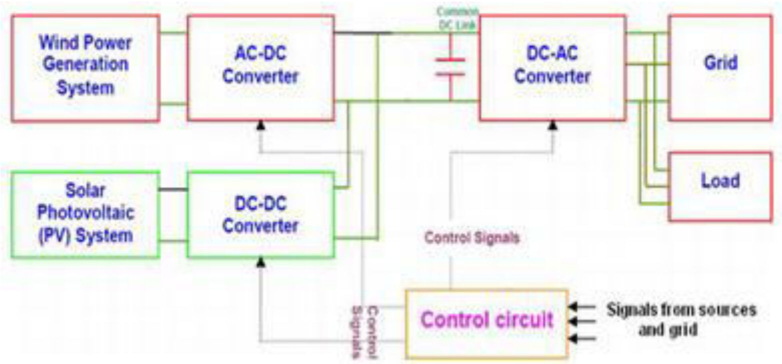

Figure 1.1. Schematic diagram of a grid PV-Wind system.

PV-Wind hybrid system was used to generate electricity in Iraq; the planned system was simulated using MATLAB solver, where the input variables for the solver were the meteorological data for the selected areas and the sizes of PV and wind turbines. Outcomes revealed that it is achievable in Iraq to implement the solar and wind energy to come up with enough power for some communities in the desert or rural area.

In our work a new converter technology to implement a hybrid PV-Wind System using Matlab. The topology utilizes a combination of Cuk and SEPIC converters. This setting enables the two resources to provide the load independently or at the same time dependent on the availableness of the energy sources. a control of a hybrid solar-wind system with acid battery for storage.

II. SOLAR AND WIND ENERGY CONVERTION SYSTEM

2.1 SOLAR ENERGY

Photovoltaic were initially solely used as a source of electricity for small and medium-sized applications, from the calculator powered by a single solar cell to remote homes powered by an off-grid rooftop PV system. As the cost of solar electricity has fallen, the number of grid-connected solar PV systems has grown into the millions and utility-scale solar power stations with hundreds of megawatts are being built. Solar PV is rapidly becoming an inexpensive, low-carbon technology to harness renewable energy from the Sun.

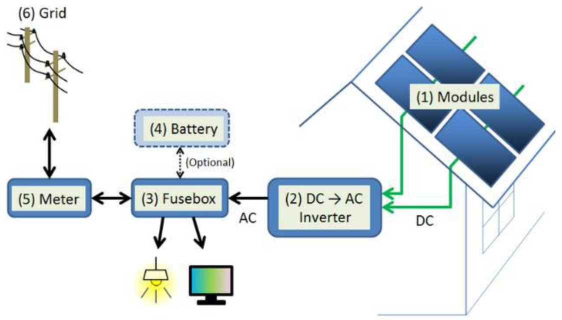

Figure 2.1Schematics of a grid-connected residential PV power system

A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line. The receiver is a tube positioned right above the middle of the parabolic mirror and is filled with a working fluid. The reflector is made to follow the sun during daylight hours by tracking along a single axis. Parabolic trough systems provide the best land-use factor of any solar technology. The SEGS plants in California and Acciona's Nevada Solar One near Boulder City, Nevada are representatives of this technology.

Compact Linear Fresnel Reflectors are CSP-plants which use many thin mirror strips instead of parabolic mirrors to concentrate sunlight onto two tubes with working fluid. This has the advantages that flat mirrors can be used which are much cheaper than parabolic mirrors, and that more reflectors can be placed in the same amount of space, allowing more of the available sunlight to be used. Concentrating linear Fresnel reflectors can be used in either large or more compact plants.

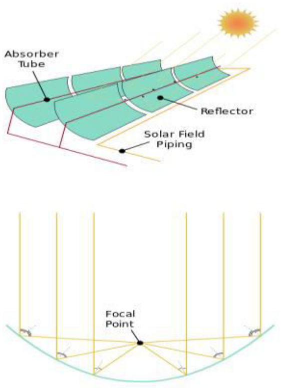

Figure 2.2 a parabolic collector concentrating sunlight onto a tube in its focal point.

2.2 WIND ENERGY

The three main technologies in wind energy conversion systems (WECSs) are power electronics, system control, and wind turbine technologies. There are two types of wind turbines: vertical and horizontal axis wind turbines, depending on how the wind turbine's rotating axis is oriented. The rotation axis of a wind turbine is perpendicular to the ground in vertical axis wind turbines, but parallel to the ground in horizontal axis wind turbines. Horizontal-axis wind turbines, which are commonly used in the wind energy business, have a higher wind energy conversion efficiency than vertical-axis wind turbines.

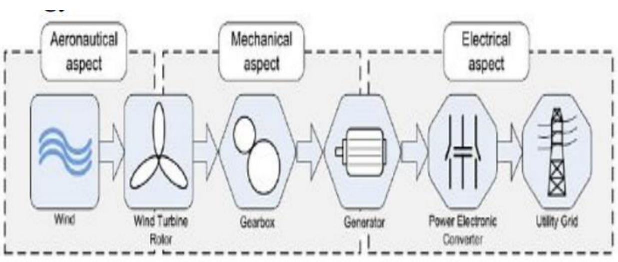

Figure 2.3. Wind Energy Conversion System (WECS).

III. PROPOSED SYSTEM DESCRIPTION

The block diagram of the proposed smart DC Micro-Grid is shown in figure 4.4. The sources include solar PV, wind and main ac grid. Apart from the sources, a battery storage system is also interfaced to the main DC bus. All sources are interfaced to the DC link via DC-DC converters. The battery storage system is connected through a bi directional buck-boost converter. As shown in the block diagram, the loads are driven by the load side converters. All loads are assumed to be priority loads that may include lighting, fans, and laboratory test benches for student's experimentation. The power management unit calculates the total generated and consumed power and based on it, the appropriate control modes are utilized. The specifications of the system are tabulated in the results and discussion section.

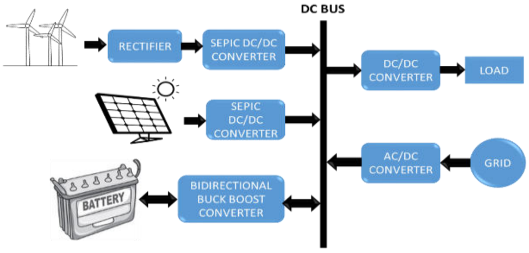

Figure 3.1 Proposed hybrid power management system

3.1 PV AND WIND ENERGY CONVERTER

SEPIC converter is used for both wind and solar energyextraction. A SEPIC is a cascaded boost/buck-boost converter, with its input stage similar to that of a basic boost converter, and its output stage is similar to that of a basic buck-boost converter.

The capacitive isolation prevents unwanted current from flowing from the input to output. Switch S's duty cycle controls the SEPIC's output voltage. Typically, the switch S is an electrically controlled switch, such as a power metal oxide semiconductor field effect transistor (MOSFET), power bipolar junction transistor (BJT) or insulated-gate bipolar transistor (IGBT). Its switching actions are controlled by a pulse-width modulation (PWM) or pulse-frequency modulation (PFM) controller. A PWM controller varies switch S's duty cycle while keeping its switching frequency constant; while a PFM controller varies S's switching frequency while keeping its duty cycle constant.

3.2 SEPIC OPERATION

The basic SEPIC performs DC-DC voltage conversion through energy exchange between its coupling capacitor and switching inductors (C_{in}, L_1 and L_2). The switch controls the energy exchange amount between the capacitor and inductors. Maximizing energy exchange efficiency and overall converter efficiency requires this SEPIC design operating in continuous conduction mode (CCM).

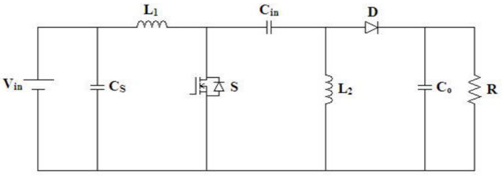

Figure 3.2 SEPIC converter

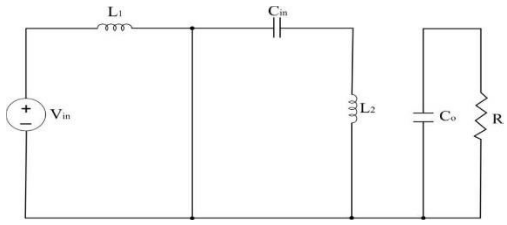

Figure 3.3 Switch on condition

3.3 Continuous Conduction Mode

In continuous conduction mode of operation, the inductor current will be continuous and never reaches to zero. That means operating the SEPIC in CCM means never letting the currents through L_1 and L_2 reduce to 0A – i.e. never letting L_1 and L_2 completely discharge. When the SEPI Reaches steady-state operation, the average voltage across C_{in} will be equal to that of V_{in}. Additionally, the average current through C_{in} is 0A in steady-state. When this steady-state phenomenon occurs, L_2 is the only source of current to the output load. Thus, L_2's average current equals that of the output load, and is independent of V_{in}.

In CCM, the sum of the average voltages across the SEPIC's energy storage elements (excluding input and output filter capacitors C_s and C_o) equal that of the SEPIC's input voltage described as follows,

$$V_{in} = V_{L1} + V_{Cin} + V_{L2} \qquad (4.1)$$

Since the average voltage across C_{in} equals that of V_{in}, V_{Cin} equals V_{in}, leading to

$$^{V}L1 \; ^{V}L2 \qquad (4.2)$$

Under CCM in steady-state, the SEPIC's operation further splits into two operation modes: when switch S conducts and when it does not conduct. Analyzing the SEPIC's entire operation in CCM requires analyzing it in switch S's conduction and non-conduction modes.

When switch is close

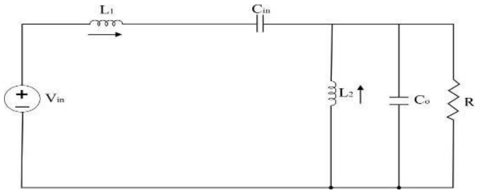

Figure 4.7 Switch off condition

Figure 4.6 shows the SEPIC's operation when switch S conducts. Filter capacitors C_s and C_o are assumed to be in steady-state, thus no current flows through these two components until they discharge. Furthermore, C_s and C_o are also assumed to be large enough in capacitance such that the SEPIC's input and output ripple voltages nearly comes to zero. When switch S conducts during the first half-switching cycle, the current through L_1 increases in the positive direction while the current through L_2 increases in the negative direction. Hence L_1 charges via V_{in}, while L_2 discharges (acting as a source) through C_{in}. S remains closed for a short time period and during this time period the instantaneous voltage across C_{in} equals V_{in}. Thus, V_{L1} and V_{L2} both equal approximately V_{in} in magnitude.

When switch is opened

Figure 3.6 shows the SEPIC operation when the switch is opened. At the end of one half-switching cycle, switch S turns off. The new path for the input current is through L_1 and C_{in}. Because current cannot change instantaneously through an inductor, Inductor Currents do not immediately change. Thus, capacitor current C_{in} equals L_1 current. L_2 continues to discharge, but during this half-switching cycle it discharges into C_o, thus turning on D i.e., forward biased and supplying current to the output load.

However, the direction of L_2 current causes it to add to the input current that already flows to the output load. Thus, when S does not conduct, both L_1 and L_2 supply current to the output load. V_{in} and L_1 charge C_{in} (which discharged during the half-switching cycle when switch S conducted), and L_2 continues discharging to the output load until switch S conducts again at the beginning of the next half-switching cycle (when C_{in} supplies current to charge L_2).

3.4Discontinuous Conduction Mode

In discontinuous conduction mode of operation, the inductor current reaches to zero. The discontinuous conduction mode occurs if the currents through L_1 and L_2 remain at 0A for any significant time period relative to switch switching period. Operating a SEPIC in DCM yields higher efficiency at lighter current loads, but requires operating at high current loads. Therefore, operating in CCM should yield better overall converter efficiency.

3.5 BATTERY STORAGE CONVERTER

Block diagram of battery storage system is shown in Figure 4. A buck boost converter is used for the integration of battery storage system to the main DC bus of the micro-grid. Depending on the state of charge (SOC), source side power availability and load side power demand, battery storage system can work either in charging or discharging mode. In charging mode, power from the main bus is transferred to the batteries and, therefore, the converter works in buck mode. When power is supplied back to the micro-grid, the battery converter operates in boost mode.

1. Boost mode: In boost mode, the reference battery current generated by the energy management system is positive. So the the boost mode is modeled as follows:

$$\begin{aligned}\frac{dI_b}{dt} &= \frac{V_b}{L_b} - (1 - U_{Q1})\frac{V_{dc}}{L_b} + D_7 \\ \frac{dV_{dc}}{dt} &= (1 - U_{Q1})\frac{I_b}{C_{dc}} - \frac{I_{o_b}}{C_{dc}} + D_8\end{aligned}$$

where Vb represents the battery voltage , Ib is the battery current, and UQ1 is the control signal. The terms D7 and D8 represent the uncertainty dynamics in the power stage parameters.

2. Buck mode: In buck mode, the reference battery current generated by the energy management system is negative.

$$\begin{aligned}\frac{dI_b}{dt} &= \frac{V_b}{L_b} - U_{Q2}\frac{V_{dc}}{L_b} + D_7 \\ \frac{dV_{dc}}{dt} &= U_{Q2}\frac{I_b}{C_{dc}} - \frac{I_{o_b}}{C_{dc}} + D_8\end{aligned}$$

Where UQ2 is the control signal in buck mode. The generalized model representing the buck and boost mode is expressed as follows:

$$\begin{aligned}\frac{dI_b}{dt} &= \frac{V_b}{L_b} - U_4\frac{V_{dc}}{L_b} + D_7 \\ \frac{dV_{dc}}{dt} &= U_4\frac{I_b}{C_{dc}} - \frac{I_{o_b}}{C_{dc}} + D_8\end{aligned}$$

When sw = 0 the buck mode controller UQ2 is activated and with sw = 1, the boost mode control UQ1 is active.

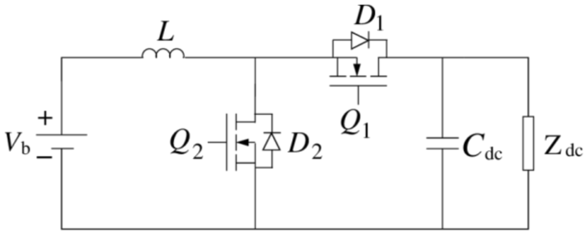

Figure 3.4. Battery Storage Converter Module

IV. SIMULATION AND RESULTS

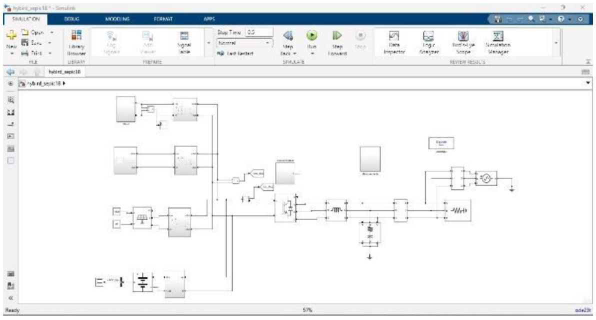

Fig 4.1 over all circuit battery charging bidirectional DC-DC converter

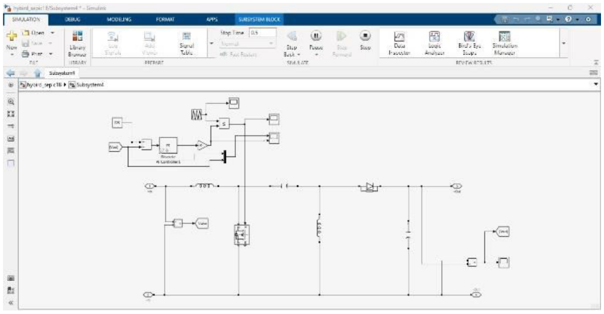

Fig 4.2 Sepic Converter

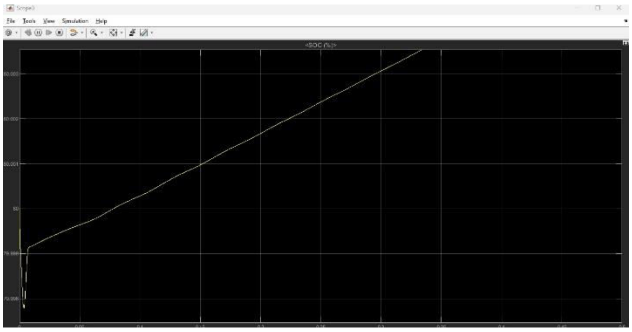

Fig 4.3 battery charging sc open dc microgrid wave from

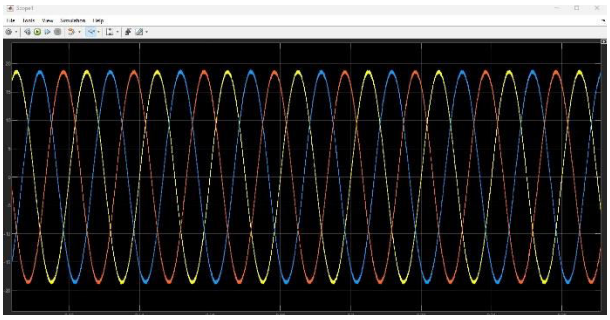

Fig 4.4 Inverter current

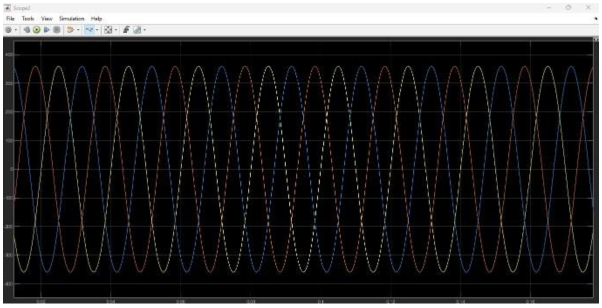

Fig 4.5 Inverter voltage

V. CONCLUSION

In this work a new method to optimize power generation use (wind and solar) on self-consumption infrastructures is proposed. An energy management unit is utilized to activate the appropriate mode of the controllers based on the measured source and load powers. The energy management unit prioritizes the renewable energy sources (PV and wind) in order to make the micro-grid as cost effective with essential loads and no load shedding scheme. The proposed controller is successfully implemented and the energy management algorithm is verified. Moreover the performance of the proposed fractional order controller is compared with the integer order controller (Appendix-II) under system parameters uncertainty.

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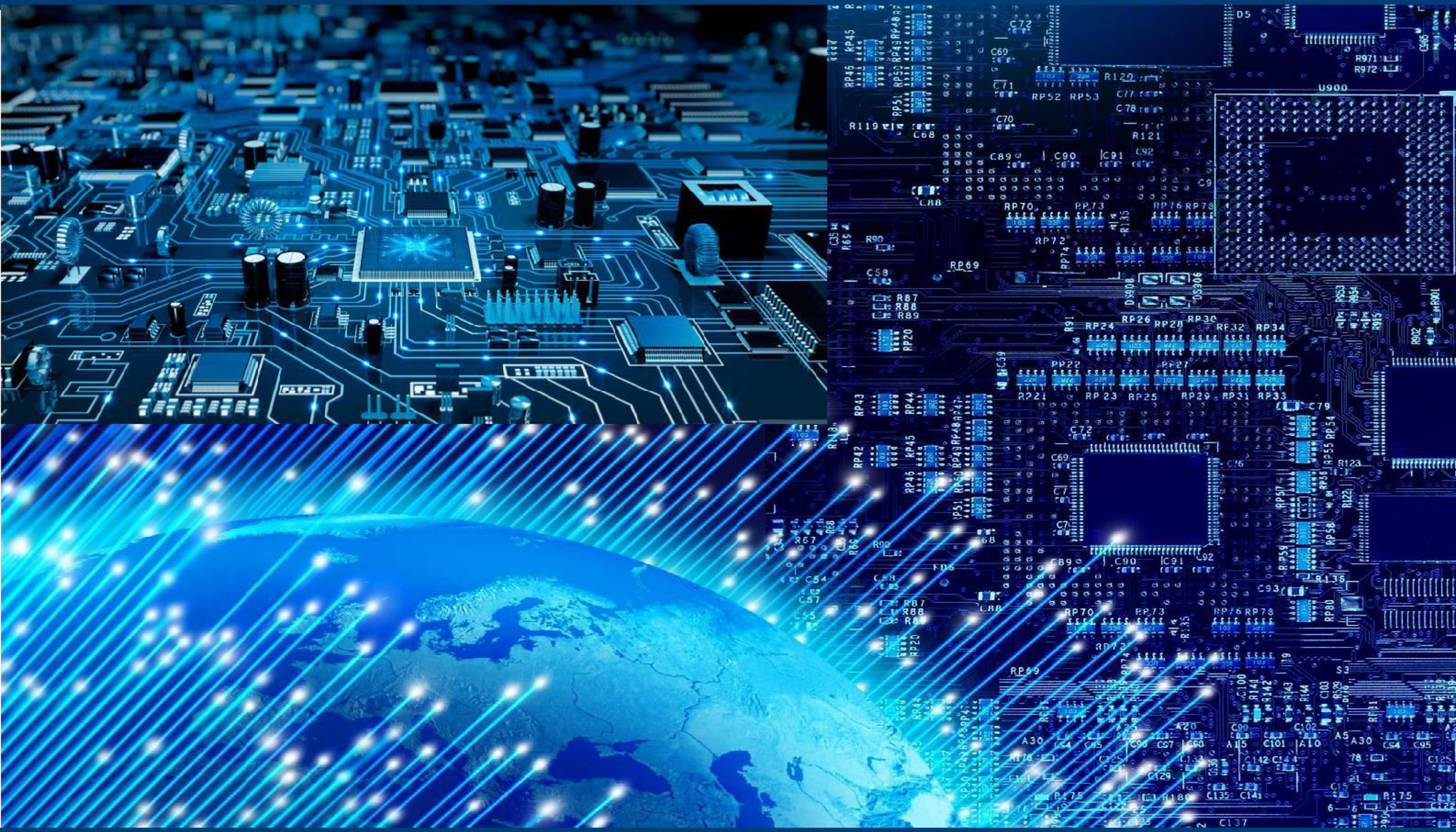

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