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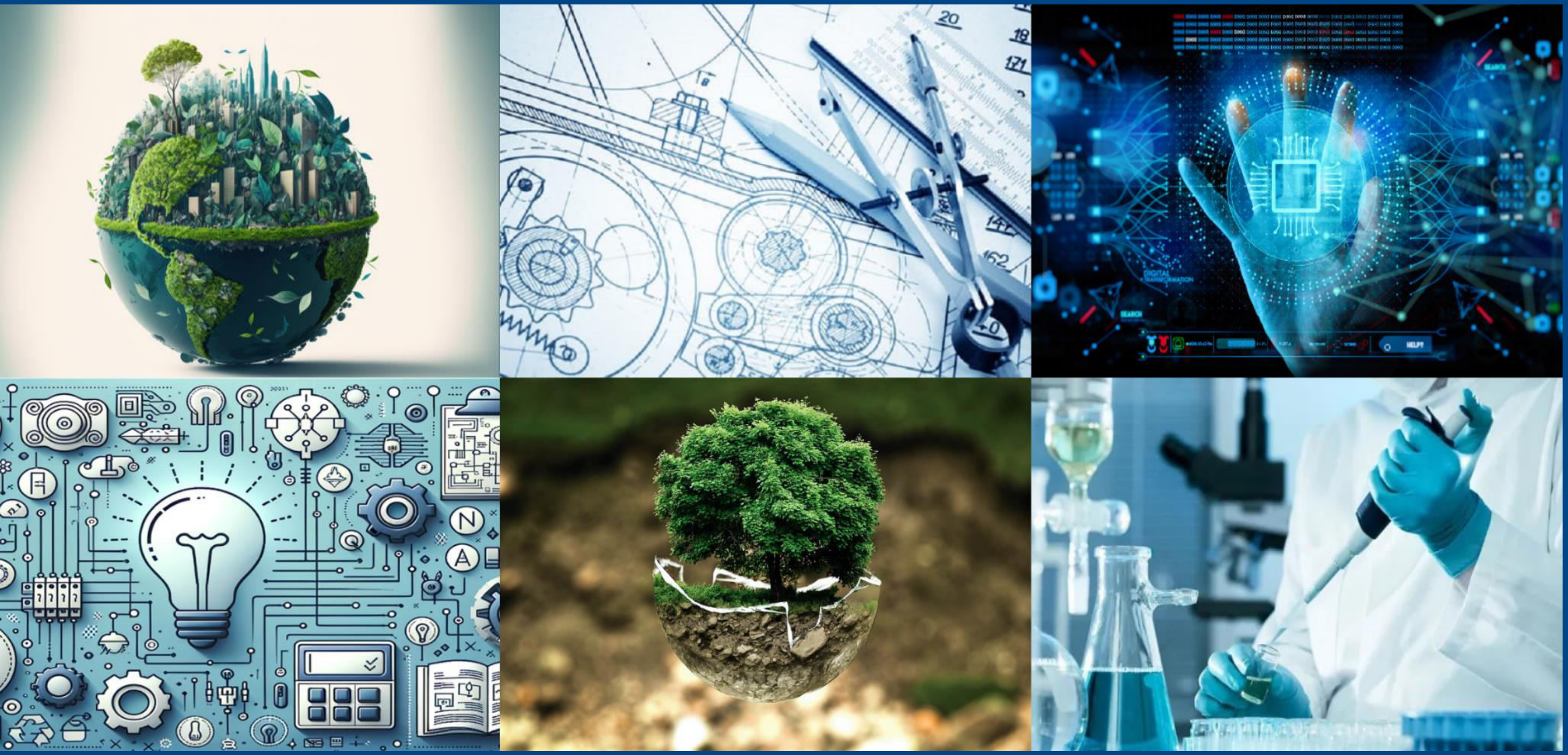

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A Review on Optimal Placement and Sizing of DG in Distribution System

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ABSTRACT: The integration of Distributed Generation (DG) into power distribution networks has gained significant attention due to its potential to enhance system efficiency, reduce power losses, and improve voltage profiles. Optimal placement and sizing of DG units play a crucial role in maximizing these benefits while ensuring network stability and reliability. This paper presents a comprehensive review of various optimization techniques employed for DG allocation, including heuristic, hybrid, and analytical approaches. Key methodologies such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Lion Optimization (ALO), and Water Cycle Algorithm (WCA) are discussed in detail, highlighting their advantages and limitations. Additionally, multi objective optimization frameworks that consider economic, technical, and environmental aspects of DG placement are examined. The review further explores the impact of factors such as load growth, voltage stability, and system reconfiguration on DG allocation. Recent advancements in computational intelligence and machine learning-based optimization techniques are also analyzed to provide insights into future research directions. The findings indicate that an integrated approach combining multiple optimization strategies can yield superior results in achieving efficient DG allocation. This study serves as a valuable reference for researchers and power system planners aiming to enhance the performance of modern distribution networks through optimal DG deployment.

KEYWORDS: Particle Swarm Optimization (PSO), Distribution Network (RDN), Distributed Generation (DG).

I. INTRODUCTION

Multi objective optimization techniques play a significant role in the effective planning and operation of power distribution systems, especially with the integration of distributed generation (DG). Several studies have explored various numerical and analytical optimization algorithms to enhance system performance.

Paper [1] proposed an innovative Jellyfish Search Algorithm to optimize distribution networks considering DG and static VAR compensators (SVCs). Their approach effectively enhances automation and reliability while maintaining system stability. Literature [2] introduced a heap-based algorithm, which exhibits superior exploitation capabilities for optimal DG placement and feeder reconfiguration. Reference [3] focused on a current control-based power management strategy to efficiently control distributed power generation systems, ensuring stable operation under varying load conditions. Similarly, conducted an economic analysis of grid-connected PV systems, providing insights into regulatory policies and their impact on DG integration given in [4]. Literature [5] provided a foundational definition and discussion of distributed generation, highlighting its benefits such as improved energy efficiency, reduced transmission losses, and enhanced system resilience. Paper [6,7] reviewed multiple planning techniques for integrating DG, discussing various optimization objectives and methodologies. Reference [8] developed a hybrid Genetic Algorithm-Particle Swarm Optimization (GA-PSO) approach to optimize DG allocation in power distribution networks, demonstrating improved convergence and solution quality. The Water Cycle Algorithm (WCA) for determining the optimal placement and sizing of DG and capacitor banks in distribution systems given in [9].

Literature [10] addressed the impact of load growth on DG placement, emphasizing optimal sizing and location to maintain voltage stability and minimize power losses [10]. Reference [11] utilized a nested multi-objective Particle Swarm Optimization (PSO) technique for the optimal allocation of renewable energy sources in DG systems [11]. The Elephant Herding Optimization algorithm for multi objective DG placement, ensuring an efficient trade-off between conflicting objectives given in [12]. Paper [13] proposed a comprehensive DG allocation technique, incorporating multiple constraints for radial distribution networks. The Ant Lion Optimization Algorithm, demonstrating its effectiveness in determining the best locations for renewable DG units while minimizing system losses given in [14]. Reference [15] integrated network reconfiguration with DG placement and shunt capacitors to achieve power loss minimization.

Literature [16] focused on the optimal sizing and placement of wind and solar-based DG units, utilizing a mixed-integer optimization approach [16]. Paper [17] adopted a stochastic method for PV placement, ensuring optimal distribution feeder performance.

The Shuffled Bat Algorithm (SBA) to optimize DG allocation, incorporating future load enhancement considerations in [18]. Reference [19] investigated reactive power optimization in distribution networks with DG integration, ensuring enhanced voltage stability.

Voltage stability and load variations in DG placement strategies, formulating a multiobjective framework for optimal resource utilization given in [20].
Paper [21] explored likelihood maximization in failure rate modelling, providing insights into reliability analysis for power systems. Literature [22] presented mathematical and statistical methods for actuarial sciences and finance, which have potential applications in energy optimization.

The integration of DG into power distribution networks requires robust optimization techniques to enhance efficiency, reliability, and sustainability. Various algorithms, including heuristic, hybrid, and analytical approaches, have been proposed to tackle the challenges associated with DG placement and system reconfiguration. Future research should focus on enhancing computational efficiency and developing adaptive optimization methods to address dynamic grid conditions.

II. DG TECHNOLOGY

Distributed Generation (DG) refers to the decentralized production of electricity near the point of consumption, reducing transmission losses and enhancing the efficiency and reliability of the power system. DG technologies are categorized based on energy sources and operational characteristics, contributing to the transition towards a more resilient and sustainable power grid. DG technology shown in Fig.1

A. Renewable Energy-Based DG

- Solar Photovoltaic (PV): Converts sunlight into electricity using semiconductor materials, commonly integrated into rooftops, solar farms, and microgrids.
- Wind Turbines: Utilize wind energy to generate power, suitable for both onshore and offshore applications.
- Small Hydropower (SHP): Generates electricity from flowing water with minimal environmental impact.
- Biomass and Biogas: Converts organic materials into electricity through combustion or anaerobic digestion, supporting waste-to-energy initiatives.
- Geothermal: Uses heat from the Earth's crust to produce steam for electricity generation.

B. Non-Renewable DG Technologies

- Microturbines: Compact gas turbines used for combined heat and power (CHP) applications, offering high efficiency.

- Reciprocating Engines: Internal combustion engines running on diesel, natural gas, or biofuels, widely used for backup power and peak shaving.
- Gas Turbines: Large-scale power generation units operating on natural gas, suitable for industrial and commercial applications.
- Fuel Cells: Electrochemical devices that convert hydrogen or natural gas into electricity with minimal emissions.

C. Benefits of DG Technology

- Improved Power Reliability: Reduces dependence on centralized power plants and mitigates grid failures.
- Energy Efficiency: Enhances energy utilization through CHP systems.
- Environmental Sustainability: Supports carbon emission reduction when integrated with renewable sources.
- Voltage Stability and Loss Reduction: Minimizes transmission losses and enhances voltage profiles in distribution networks.
- Economic Advantages: Reduces operational costs, peak demand charges, and enhances energy security.

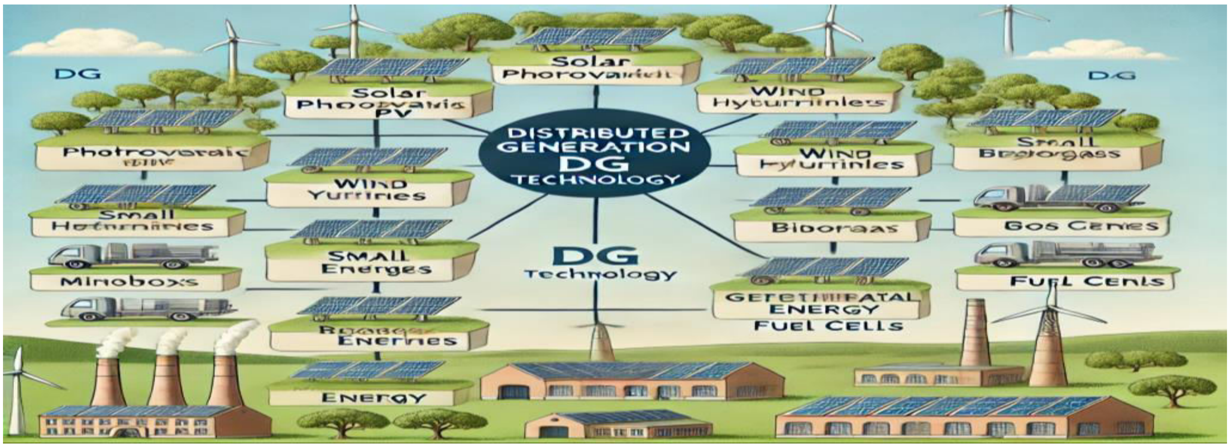

Fig. 1 DG in Distribution System

D. Challenges in DG Integration

- Intermittency: Renewable-based DGs like solar and wind are weather-dependent, requiring energy storage or hybrid solutions.
- Grid Compatibility: Proper synchronization and control mechanisms are essential for stable integration.
- Regulatory and Policy Constraints: Varying standards and regulations impact deployment and market participation.
- Investment Costs: Initial capital expenditure for installation and grid modernization can be high.

DG technology plays a crucial role in modernizing power distribution systems, promoting decentralized energy generation, and enhancing grid resilience. The integration of renewable and conventional DG sources, coupled with advanced control mechanisms, is essential for a sustainable and efficient energy future.

III. OPTIMIZATION TECHNIQUES

A hierarchical classification of multi objective optimization techniques given in fig [2], dividing them into two main categories: Numerical Algorithms and Analytical Algorithms.

A. Numerical Algorithms

These methods use iterative or heuristic approaches to find optimal solutions without explicitly deriving mathematical expressions. The techniques listed under this category include:

- Genetic Algorithm (GA): A nature-inspired optimization technique that mimics the process of natural selection to find optimal solutions.

- Differential Evolution (DE): A population-based optimization method that iterates through mutation and recombination to improve solutions.
- Particle Swarm Optimization (PSO): A swarm intelligence-based approach where particles adjust their positions based on personal and group experiences.
- Simulated Annealing (SA): A probabilistic method that explores the search space by simulating the cooling process of metals to escape local optima.
- Simple Genetic Algorithm (SGA): A basic form of the genetic algorithm that involves selection, crossover, and mutation to evolve solutions.
- Hybrid GA-PSO: A combination of genetic algorithm and particle swarm optimization, leveraging the strengths of both techniques.

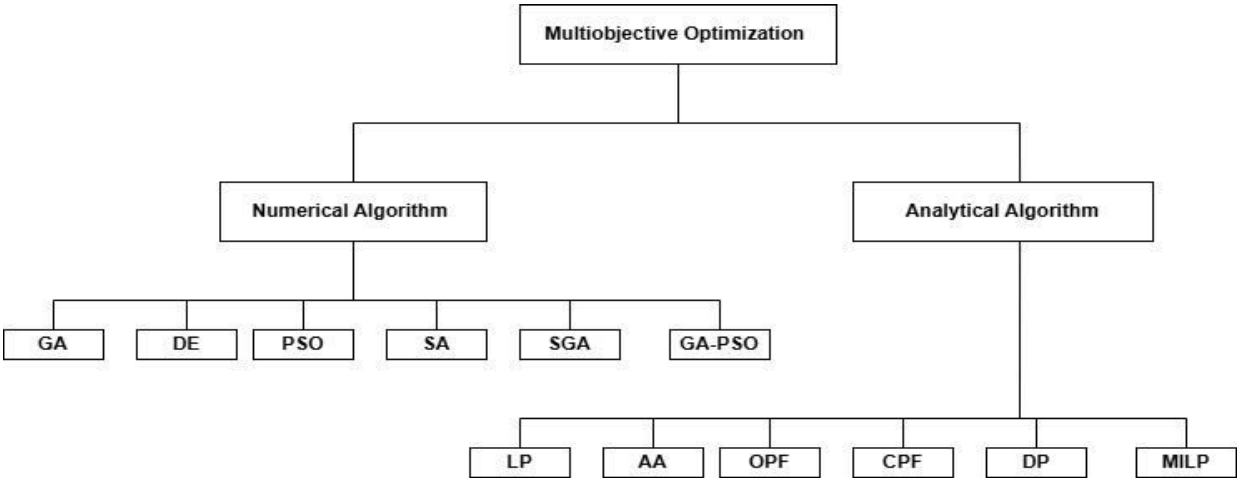

Fig. 2 Types of Optimization Technique

B. Analytical Algorithms

These methods rely on mathematical models and equations to derive exact or approximate solutions. The techniques under this category include:

- Linear Programming (LP): A mathematical approach for optimizing a linear objective function subject to linear constraints.
- Analytical Approach (AA): A general term for optimization techniques that use precise mathematical formulations.
- Optimal Power Flow (OPF): A specialized optimization method used in electrical power systems to determine the best power flow configuration.
- Continuation Power Flow (CPF): A technique used in power system analysis to study voltage stability and load flow.
- Dynamic Programming (DP): A method that solves complex problems by breaking them into simpler subproblems and solving them recursively.
- Mixed-Integer Linear Programming (MILP): A mathematical optimization technique that handles both integer and continuous variables in linear equations.

These Multi objective optimization techniques are widely applied in engineering, economics, and decision-making problems, depending on the complexity and requirements of the system being optimized.

IV. HARMONICS ANALYSIS

Harmonics in distribution systems are distortions in voltage and current waveforms caused by nonlinear loads and power electronic devices. These distortions can lead to inefficiencies, increased losses, equipment overheating, and potential power quality issues. Understanding the sources, effects, and mitigation techniques for harmonics is crucial for maintaining a stable and efficient power distribution network.

A. Sources of Harmonics

Harmonics are primarily generated by nonlinear loads, which draw current in a non-sinusoidal manner. Some common sources include:

- Power Electronic Devices – Inverters, rectifiers, and variable frequency drives (VFDs).
- Electric Arc Furnaces – Highly nonlinear loads causing significant harmonic distortion.
- Fluorescent Lighting and LED Drivers – Contribute to low-order harmonics.
- Transformers and Saturated Magnetic Devices – Generate odd harmonics due to magnetizing currents.

B. Effects of Harmonics

Harmonics can negatively impact power systems in several ways:

- Increased Losses – Higher resistance losses in transformers, cables, and conductors.
- Overheating – Excessive heat in motors and transformers due to harmonic currents.
- Equipment Malfunction – Sensitive electronic devices can experience malfunctions or failures.
- Resonance Conditions – Harmonics can interact with network impedances, leading to voltage amplification.

C. Harmonic Mitigation Techniques

To reduce harmonic distortion and improve power quality, several mitigation techniques are employed:

- Passive Filters – LC filters designed to absorb specific harmonic frequencies.
- Active Power Filters (APFs) – Use power electronics to dynamically cancel harmonic components.
- Isolation Transformers – Prevent harmonic propagation from nonlinear loads.
- Phase Shifting and Harmonic Cancellation – Using transformer connections to eliminate triple harmonics.
- Improved Power Electronics Design – Using multi-pulse rectifiers or soft-switching techniques to reduce harmonics.

D. Harmonic Standards and Regulations

Several international standards govern harmonic limits in distribution systems:

- IEEE 519 – Defines voltage and current harmonic limits for utility and industrial systems.
- IEC 61000-3 – Establishes electromagnetic compatibility (EMC) standards for harmonic emissions.
- EN 50160 – Specifies voltage characteristics in public distribution networks.

Harmonics in distribution systems pose significant challenges to power quality and system efficiency. Through proper harmonic analysis, mitigation strategies, and adherence to standards, utilities and industries can ensure reliable and efficient power distribution. Future advancements in smart grids and power electronics will play a crucial role in further minimizing harmonic distortions.

V. SHORT CIRCUIT ANALYSIS

Short circuit analysis is essential for assessing the reliability and safety of power distribution systems. It helps in determining fault currents, selecting protective devices, and ensuring proper system coordination. A short circuit occurs when an unintended low-impedance path allows excessive current to flow, potentially damaging equipment and disrupting power supply.

A. Types of Short Circuits

Short circuits in distribution systems can be classified into:

- Line-to-Ground (LG) Fault – A single phase comes into contact with the ground, common in overhead networks.
- Line-to-Line (LL) Fault – Two phases come into direct contact, causing a high-current fault.
- Double Line-to-Ground (LLG) Fault – Two phases are shorted to ground, leading to unbalanced fault currents.
- Three-Phase Fault (LLL or LLLG) – A symmetrical fault affecting all three phases, generating the highest fault current.

B. Importance of Short Circuit Analysis

- Protective Device Coordination – Ensures circuit breakers and fuses operate selectively to isolate faults.

- Equipment Rating Selection – Helps in designing components like transformers and cables to withstand fault currents.
- System Stability and Reliability – Prevents cascading failures and minimizes downtime.
- Safety Assurance – Protects personnel and infrastructure from hazardous fault conditions.

C. Methods of Short Circuit Analysis

- Per-Unit System Analysis – Simplifies calculations by normalizing electrical quantities.
- Symmetrical Component Method – Used for analysing unbalanced faults by decomposing them into symmetrical components.
- Impedance Matrix Method – Utilizes system impedances to determine fault currents and voltages.
- Digital Simulation Tools – Software like ETAP, MATLAB, and PSCAD are widely used for accurate fault analysis.

D. Mitigation and Protection Strategies

- Circuit Breakers and Fuses – Fast isolation of faulty sections to prevent damage.
- Protective Relays – Detect faults and trigger appropriate switching actions.
- Grounding Systems – Proper grounding helps in controlling fault currents and reducing over voltages.
- Fault Current Limiters – Reduce excessive fault currents to protect sensitive equipment.
- Short circuit analysis is a critical aspect of power system engineering, ensuring the safe and reliable operation of distribution networks. By employing advanced analytical techniques and protection strategies, utilities can minimize damage, improve system stability, and enhance power quality.

VI. CONCLUSION

The optimal placement and sizing of distributed generation (DG) in distribution systems play a crucial role in improving power quality, reducing losses, enhancing voltage stability, and ensuring efficient energy utilization. This comprehensive review has examined various methodologies, optimization techniques, and key considerations involved in DG allocation. Different optimization approaches, including heuristic, metaheuristic, analytical, and hybrid methods, have been extensively explored in the literature. These techniques aim to maximize the benefits of DG integration while addressing challenges such as power losses, voltage profile improvement, and network reliability. Moreover, various constraints, such as load demand, system constraints, and economic feasibility, must be carefully considered to ensure practical implementation.

Despite significant advancements, the integration of DG in distribution systems still faces challenges, including uncertainty in renewable energy generation, optimal coordination with existing grid infrastructure, and the need for real-time monitoring and control. The incorporation of advanced technologies such as artificial intelligence, machine learning, and smart grid solutions can further enhance the efficiency and reliability of DG deployment.

Future research should focus on developing more robust and adaptive optimization techniques that can handle dynamic load conditions, renewable energy intermittency, and evolving grid architectures. Additionally, hybrid optimization methods that combine multiple algorithms may provide more accurate and reliable solutions for DG placement and sizing. In conclusion, optimizing DG placement and sizing remains a vital area of research and practical implementation for modern power systems. By leveraging advanced computational techniques and emerging technologies, utilities can achieve a more resilient, cost-effective, and sustainable energy distribution network.

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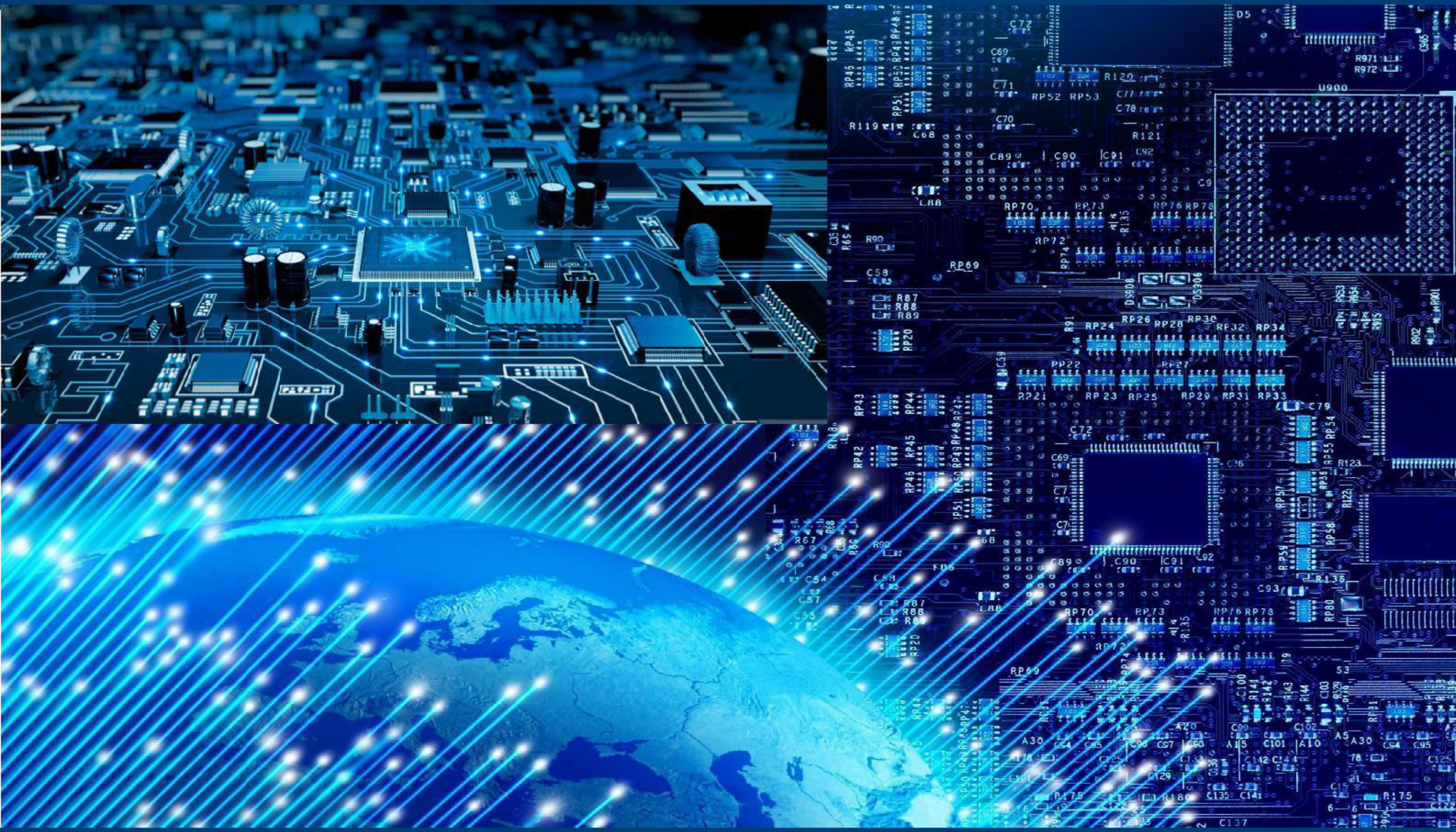

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